

Unit - 01/04

Basic concept of thermodynamics

Thermodynamic :- उष्मागतिकी इंजीनियरिंग की वह शाखा है जिसने अन्तर्गत उष्मा, Work, Heat एवं कार्य के पारस्परिक परिवर्तनों का अध्ययन किया जाता है।

वर्तमान युग में इंजन की कमी को देखते हुए यह आवश्यक हो गया है कि कार्य प्रारंभ हेतु नये उपकरणों की खोज की जाये। जैसे - सौर ऊष्मा के विद्युत के लिए अधिक क्षमता वाले उपकरणों का निर्माण इनकी क्षमता में वृद्धि के साथ आदि। यह उष्मागतिकी के अध्ययन से ही संभव हो सकता है।

Thermodynamic System :

System is a kind of the quantity of matter and region of space where our attention is focused.

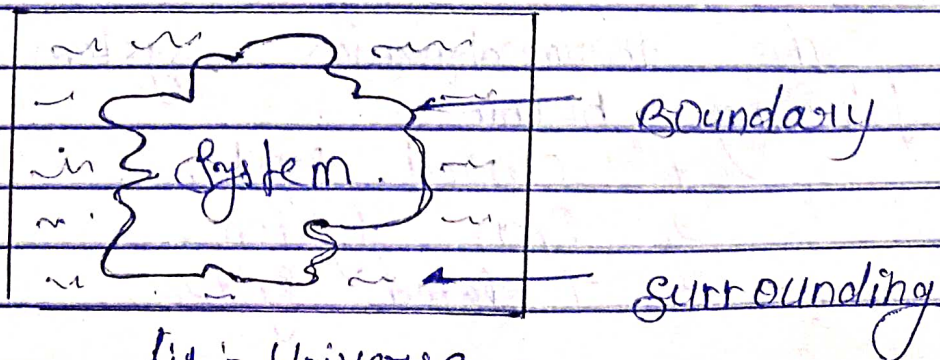
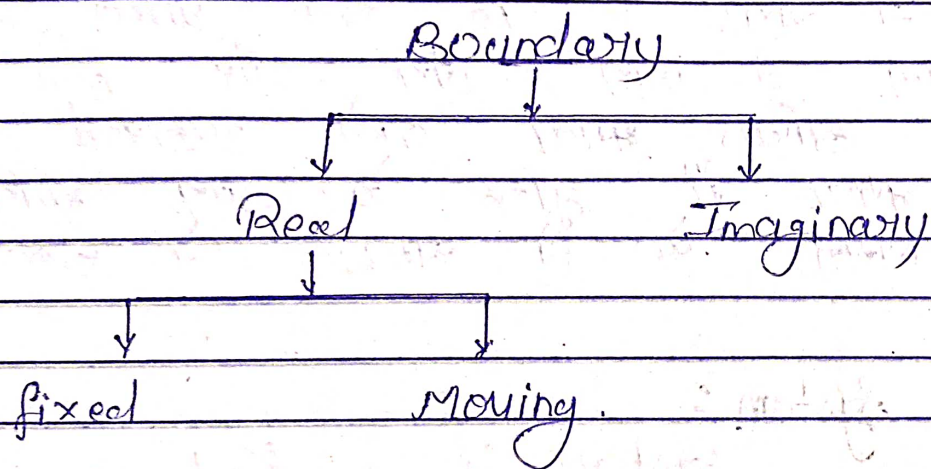


Fig - Universe

Surrounding :- वह क्षेत्र एवं अन्य पदार्थ Boundary के बाहर की ओर स्थित होता है, परिवेश (Surroundings) कहलाता है।

Boundary :- वह सीमा रेखा (Real or Imaginary) जिसके द्वारा System को Surrounding से प्रयुक्त किया जाता है, परिधीय (Boundary) कहलाती है।



Classification of thermodynamic system

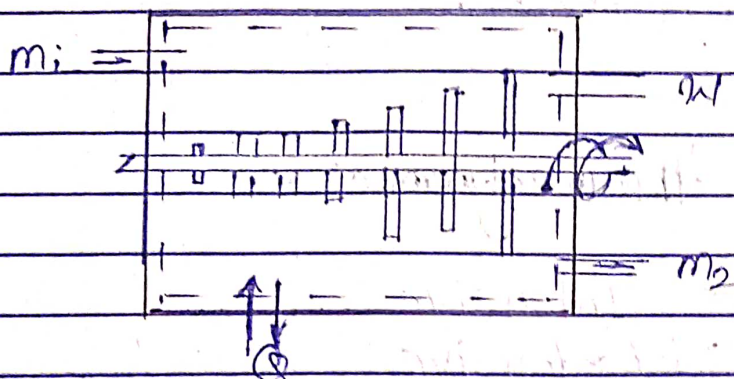
The thermodynamic system is divided into the following below -

1. closed system.
2. Open system.
3. Isolated system.

1. Open System :-

यदि किसी तंत्र (System) में mass तथा Energy का दोनो का स्थानान्तरण होता है उसे open system कहते हैं।

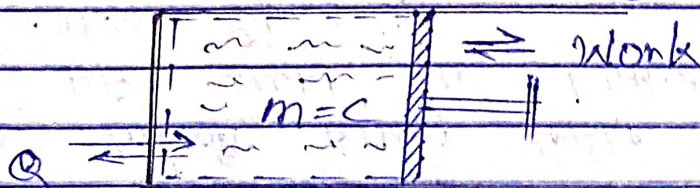
Exa :- Boiler, Turbine, etc.



2. Close System :-

जिसमें न तो कोई पदार्थ प्रवेश कर सकता है और न ही निकल सकता है। Boundary के अंदर-बाहर किसी भी प्रकार का स्थानान्तरण नहीं हो सकता, केवल उष्मान्तरण व कार्यान्तरण संभव है।

Exa :- Cylinder - Piston - Arrangement



3. Isolated System:- यदि किसी system में न तो ऊष्मा न स्थानान्तरण होता है और न ही द्रव्यमान का परिवर्तन, तो इस प्रकार के system को विभाजित (Isolated System) कहते हैं।

Ex:- Thermos flask.

Properties of thermodynamics:-

→ Intensive
→ Extensive

जिसमें पदार्थ को पूर्णतः परिभाषित (define) किया जा सके, उसे द्रव के गुणधर्म कहते हैं। जिन गुणों से किसी विभाजित system को इस तरह स्पष्ट किया जा सके उसे विभाजित गुणधर्म (Thermodynamic properties) कहते हैं।

Ex:- Pressure, temperature, Volume, density, Internal energy, enthalpy, Entropy etc.

1. निर्णय-गुणधर्म (Intensive) :-

यदि किसी तंत्र का गुणधर्म उसके द्रव्यमान पर निर्भर नहीं होता है तो इस गुणधर्म को मात्र निर्णय गुणधर्म कहते हैं।

Example:- Pressure, Velocity, temperature etc.

७ Extensive (Extensive) :- यदि किसी पदार्थ का गुणधर्म उसके स्थानान्तरण पर निर्भर करता है तो उसे मापन व्यापक गुणधर्म कहते हैं।

Example :- Entropy, Enthalpy, Energy, Volume etc.

Temperature :- It is an intensive thermodynamic property which the degree of hotness or the level of heat intensity of a body said to be at a high temperature or heat it at shows high level of heat intensity in heat. Similarly a body said to be have low temperature air held it should a low level of heat intensity.

$$\frac{C}{100} = \frac{F - 32}{180}$$

$$\Rightarrow \frac{C}{5} = \frac{F - 32}{9}$$

The temperature measure from a cold absolute temperature the absolute temperature in is called Kelvin (K)

$$| K = C + 273 |$$

Thermodynamic Equilibrium :-

Mechanical chemical Thermal

1. Mechanical Equilibrium :- जब किसी System पर किसी प्रकार का कोई बाहरी असंतुलित बल कार्य न कर रहा हो अर्थात् System पर कार्य करने वाले सभी बाहरी बल संतुलित हो स्थिति में हो तब उस संतुलन को यांत्रिक सम्य कहा जाता है।

2. Chemical Equilibrium :- यदि किसी तन्त्र (System) की आणविक संरचना (molecular structure) में कोई परिवर्तन हो तो System को chemical Equilibrium में कहा जाता है।

3. Thermal Equilibrium :- यदि कोई System उष्मीय सम्य के साथ-साथ chemical और mechanical Equilibrium की स्थिति में हो, तब उस System को उष्मागतिक सम्य (Thermodynamic Equilibrium) में कहा जाता है।

Energy :- किसी वस्तु के कार्य करने की क्षमता को Energy कहते हैं।

The energy possessed by system is of the following two types.

1. संचयी ऊर्जा (Stored Energy) :- संचयी ऊर्जा वस्तु में संग्रहीत होती है। यह वस्तु में कई रूपों में पाई जाती है। जैसे :- Internal energy, kinetic, potential energy, chemical energy, magnetic energy etc.

Types of stored energy :-

i. Potential Energy :- किसी वस्तु की प्रवेष्ट सतह से ऊपर के कारण वस्तु में जो ऊर्जा संचित होती है, स्थितिज ऊर्जा कहलाती है।

$$P.E. = mgh = wh$$

where w = weight of the body (N)

m = mass of the body (kg)

g = acceleration due to gravity

h = distance through

(Unit - N-m)

ii) Heat rejected by the system is taken as negative (ve)

Heat : It is defined as the transfer of energy without mass transfer across the boundary of a system because of temperature diff. between system and surrounding. It is usually measured in J and is expressed in joule or kJoule.

Specific Heat :

Heat required = $mc(T_2 - T_1)$

Unit - $\frac{kJ}{kg(Kelvin)}$

Specific heat depending on a process and also having a gas.

1. Specific heat at constant pressure (C_p)
2. Specific heat at constant volume (C_v)

Note : Constant = 4.18 $\frac{kJ}{kg Kelvin}$

$C_{p, air} = 2.011 \frac{kJ}{kg Kelvin}$

for Air

$C_p = 1.005 \frac{kJ}{kg Kelvin}$

$C_v = 0.718 \frac{kJ}{kg Kelvin}$

[$C_p > C_v$]

Q.1. Calculate the quantity heat required to raise the temperature of steel for 200 kg of balls 100 kg from 200 Kelvin to 225 Kelvin the specific heat of steel = $0.49 \frac{kJ}{kg Kelvin}$

Sol. Given - $m = 100 \text{ kg}$

$T_1 = 200 \text{ Kelvin}$

$T_2 = 225 \text{ Kelvin}$

Specific heat of steel = $0.49 \frac{kJ}{kg Kelvin}$

Formula :

Heat Required = $mc(T_2 - T_1)$

$$Q = 100 \times 0.49 (225 - 200)$$

$$Q = 85.493 \text{ kJ Ans}$$

Work: किसी पिष्ट पर लागने वाले बल की दिशा में पिष्ट द्वारा की गई कुल एवं पिष्ट पर लागने वाले बल के गुणनफल को कार्य या यांत्रिक कार्य कहते हैं।

$$W = F \cdot d$$

$$\text{where } W = \text{work}$$

$$F = \text{force}$$

$$d = \text{distance}$$

$$\text{while } = \text{tule (N-m)}$$

In thermodynamic work is defined as follows:

यदि किसी द्रव्य के कणों में परस्पर के प्रभावों के कारण गति की दिशा में कोई प्रवणनत्व बल के कारण द्रव्य पर कार्य हो तो प्रवणनत्व बल का व्यपन्न किया गया माना जाता है।

Power: किसी कण के कार्य करने की दर को शक्ति कहते हैं। - गुणांक इकाई सामान्य (Unitless) है।
किताब का दिया माना है इस शक्ति कहते हैं।

$$\text{Power} = \text{work done} / \text{Time Taken}$$

G.T. Unit - watt

Note:- If T is torque transmitted in N-m or tula and

ω = angular velocity in radian/sec

then

$$P = T \cdot \omega = T \cdot 2\pi N$$

60

$$\Rightarrow P = \frac{2\pi T N}{60}$$

where

N = Speed in rpm

Efficiency:

The ratio of power output to power input is known as efficiency. It is always less than unity and is presented as percentage mathematically

$$\text{Efficiency (}\eta\text{)} = \frac{\text{Power output}}{\text{Power input}}$$

Quasi-static process:

यदि किसी द्रव्य में परिवर्तन होता है एक नियत रूप से तो द्रव्य में परिवर्तन होता है एक नियत रूप से।

के ठीक अनुक्रम के लिए, निम्न दिए अवस्थाओं से दोनो अवस्था है, इन सभी बिन्दुओं (अवस्थाओं) पर निम्न अनुक्रम की अवस्था में है। उससे लिए यह अवस्था है कि निम्न की अवस्था परिवर्तन के दोनो इन सभी बिन्दुओं पर एक एक एक एक एक में बहुत कम अंतर होना चाहिए।

कारण जब एक एक दो दोनो गति से परिवर्तन किया जाना चाहिए इस प्रकार की किया जावे।

प्रक्रम के दोनो सभी अवस्था है।

दोनों - स्थिति प्रोसेस कहलाता है।

Zeroth Law of Thermodynamic

Zeroth Law :- "जब दो पिंड A और B एक-दूसरे के द्रव्यीय अवस्था की दृष्टि से हैं और यदि पिंड B दूसरे कण से पिंड C से द्रव्यीय सम्पर्क में है तो पिंड A और पिंड C भी एक-दूसरे से द्रव्यीय सम्पर्क में होगा।"



Thermal Equilibrium Thermal Equilibrium



Thermal Equilibrium

Trial and Error :-

1. Boyle's Law :-

गैस के अणुओं - प्रारंभिक अवस्था पर, किसी अवस्था में गैस की निम्न भाग का आयतन इसके निरपेक्ष दबाव के व्युत्क्रमानुपाती होता है।

$$PV = P$$

Boyle

$$P = \text{गैस का निरपेक्ष दबाव}$$

$$V = \text{गैस का आयतन}$$

2. Charles Law :-

गैस के अणुओं - प्रारंभिक अवस्था पर, किसी अवस्था में गैस के आयतन - दबाव के एक समान होता है।

$$V \propto T$$

$$P \propto T$$

So by Combination equation (I) and (II)

$$PV \propto T$$

$$PV = nRT \quad (11)$$

absolute pressure (0 paad)

$$V = \text{volume (cm}^3\text{)}$$

$$m = \text{mass (kg)}$$

$$T = \text{absolute temperature}$$

$$R = \text{characteristic gas}$$

constant

$$= 0.287 \text{ (kg} \cdot \text{K}^{-1} \cdot \text{m}^3\text{)} \text{ (kg} \cdot \text{K}^{-1} \cdot \text{m}^3\text{)}$$

Note :-

$$\text{No. of moles (n)} = \frac{\text{mass (m)}}{\text{molecular weight (M)}}$$

$$n = \frac{m}{M}$$

from equation (10)

$$PV = nRT$$

$$\Rightarrow PV = nRT$$

absolute pressure = universal gas constant

$$R = 8.314 \text{ J} \cdot \text{K}^{-1} \cdot \text{mol}^{-1}$$

$$\text{Note: } R = \frac{R}{M}$$

close system / non flow / P-dy work: (work done)

Thermodynamic process:

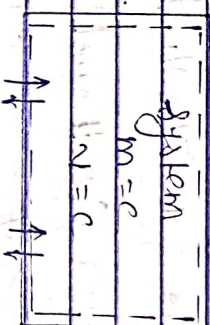


(V=c) (P=c) (T=c) (PV^γ=c) (P^{1/γ}=c)

work transfer for various close system process:

1. Constant volume process (Isochoric):

System is constant volume or



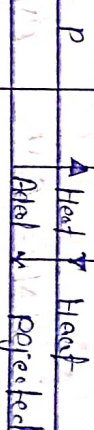
$$P = \frac{mRT}{V}$$

$$P \propto T$$

$$\frac{P_2}{P_1} = \frac{T_2}{T_1}$$

$$dV=0$$

$$W_{1-2} = \int_1^2 P dV$$

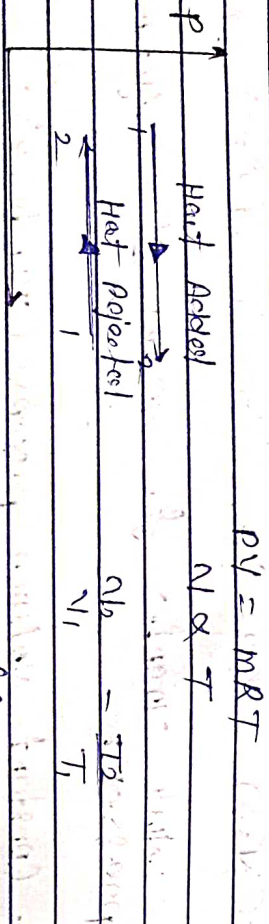


$$= P(V_2 - V_1)$$

$$W_{1-2} = 0$$

2. Constant Pressure process (Isobaric):

रिक्टर दबाव प्रणाली में - system (फिजिक) का दबाव स्थिर रहता है।



$$PV = nRT$$

$$n \propto T$$

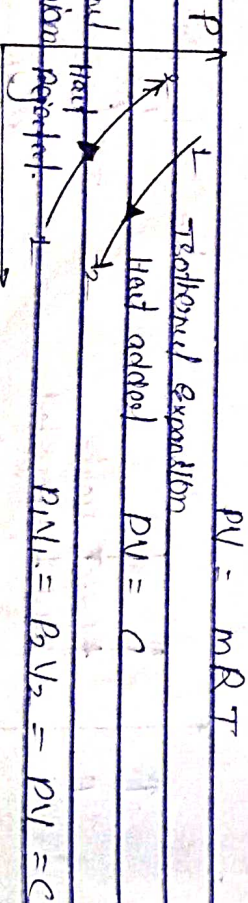
$$W_{1-2} = \int_1^2 P dV$$

$$= P \int_1^2 dV$$

$$W_{1-2} = P (V_2 - V_1)$$

3. Constant Temperature process (Isothermal):

रिक्टर ताप प्रणाली में - system का ताप स्थिर रहता है।



$$PV = nRT$$

$$PV = C$$

$$P_1 V_1 = P_2 V_2 = PV = C$$

$$W_{1-2} = \int_1^2 P dV$$

$$= \int_1^2 \frac{C}{V} dV$$

$$= C \int_1^2 \frac{1}{V} dV$$

$$= P_1 V_1 \ln \frac{V_2}{V_1}$$

$$W_{1-2} = C \ln \frac{V_2}{V_1}$$

1) Isothermal expansion possible when heat is added to the system and where as isothermal compression possible when heat is rejected from system.

2) Isothermal is very slow process.

3) A real gas under goes isothermal process follows isobaric hyperbola in P-V diagram.

4. Adiabatic process (PVR = e):

इस प्रणाली में कोई भी ऊष्मा - surroundings से विचार में प्रणाली के 1 और 2 के बिना ही सम्बन्धित है। अतः प्रणाली में सम्बन्धित है। अतः प्रणाली में सम्बन्धित है।

ଉତ୍ତର ଓଃ ସମାପ୍ତାବଳୀର ଉତ୍ତର ଦେଖା ଶୁଦ୍ଧ

$$PV^{\gamma} = C$$

$$\text{ଉତ୍ତର } \gamma = \frac{C_p}{C_v} = \left(\frac{1.005}{0.718} \right) \text{ air}$$

$$\gamma \approx 0$$

$$PV^{\gamma} = C \Rightarrow P = \frac{C}{V^{\gamma}}$$

$$\Rightarrow P_1 V_1^{\gamma} = P_2 V_2^{\gamma} = C$$

$$Q_{1 \rightarrow 2} = \int_1^2 \frac{2}{\gamma} C \frac{dV}{V^{\frac{\gamma}{\gamma}+1}}$$

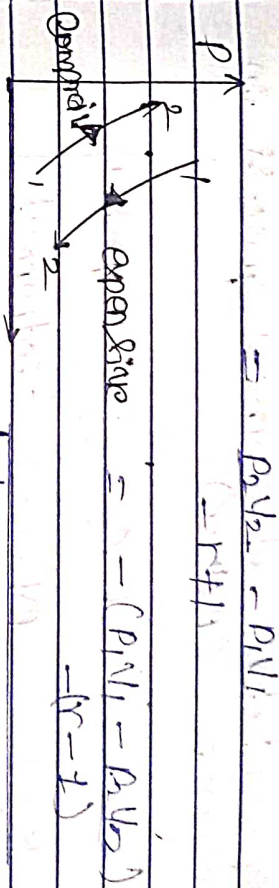
$$= C \int_1^2 V^{-\gamma} dV$$

$$= C \left[\frac{V^{-\gamma+1}}{-\gamma+1} \right]_1^2$$

$$= C \left[\frac{V_2^{-\gamma+1} - V_1^{-\gamma+1}}{-\gamma+1} \right]$$

$$= \frac{C V_2^{-\gamma+1} - C V_1^{-\gamma+1}}{-\gamma+1}$$

$$= \frac{P_2 V_2^{\gamma} V_2^{-\gamma+1} - P_1 V_1^{\gamma} V_1^{-\gamma+1}}{-\gamma+1}$$



5. Polytropic process ($PV^n = C$):

$$Q_{1 \rightarrow 2} = \frac{P_1 V_1 - P_2 V_2}{n-1}$$

ଉତ୍ତର $n = \text{polytropic index}$

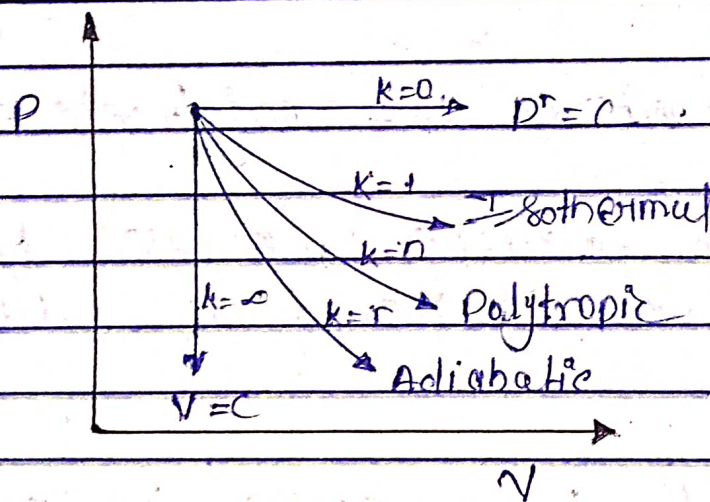
Note: ① In polytropic process heat transfer also taken place along with work transfer.

② all the process in p-v diagram can be other process by equation: $PV^n = C$

ଉତ୍ତର $\gamma = 1$ is depend on process

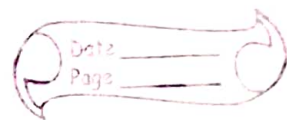
Representation of various process on p-v diagram ($pV^k = C$)

1.	$k = 0$	$p = C$	Constant pressure
2.	$k = 1$	$pV = C$	Isothermal
3.	$k = n$	$pV^n = C$	Polytropic
4.	$k = \gamma$	$pV^\gamma = C$	Adiabatic
5.	$k = \infty$	$V = C$	Constant volume



Note: Area of the cycle in p-v diagram gives net work transfer. All cycles are power producing cycle. All cycles are power consuming cycle (Refrigeration cycle).

1st law



first law of thermodynamic

(I) This law may be state follows a cyclical process is law when a close system goes a thermodynamic cycle the net heat transfer is equate to the

$$\sum Q = \sum W$$

In other words the cycling internal law of heat transfer the cycling internal of work transfer

$$Q_{net} = W_{net}$$

(II) ऊष्मागतिकी के प्रथम नियम की उत्पत्ति ऊष्मीय अवस्था परिवर्तन के नियम से हुई है। इसलिए इस नियम को समझने के लिए ऊष्मीय अवस्था परिवर्तन के नियम को जान लेना जरूरी है। इसके अलावा,

ऊष्मीय न तो उत्पन्न की जा सकती है और न ही नष्ट हो सकती है, केवल इसका रूप परिवर्तित किया जा सकता है।

इस नियम का एक रूप प्रेरक द्वारा प्रतिपादित यान्त्रिक कार्य तथा उष्मा की तुल्यता (Equivalence) का नियम है। यह नियम नि. वि. प्रकार है -

जैसे ही जो निकाश होता है उसका वे सा उष्मा को ना निकालेगा वे उष्मा को वापस लेगा और ना निकालेगा वे ही उष्मा को ना निकालेगा वे ही उष्मा को ना निकालेगा

$$dE = dQ - dW$$

According to first law

$$dQ = dU$$

$$dQ = dU$$

$$dQ = dU - dW$$

$$dQ = dU + dW \quad [E = R.T + P.V + U]$$

$$dQ = dU + R.T + P.V + dU$$

$$dQ = dU + dU$$

first law of thermodynamic for closed system which going the process kinetic energy and potential energy nothing.

Note: Energy of an isolated system is always constant for isolated system.

उष्मा, उष्मा, उष्मा

$$Q_1 = Q_2 = 0$$

$$dQ = 0$$

$$dU = 0$$

Enthalpy (H) :-

In thermodynamic the term $U + PV$ is called Enthalpy. So for a system Enthalpy is given as enthalpy

$$H = U + PV$$

where U = Internal Energy

PV = flow work

It is an extensive property and the specific enthalpy

$$h = \frac{U}{m} + \frac{PV}{m}$$

$$\Rightarrow h = U + PV \text{ specific}$$

Note: for ideal gas

$$du = m \cdot c_v \cdot dT$$

$$dH = m \cdot c_p \cdot dT$$

valid for all the processes

Heat transfer for various close system process.

1.) Constant volume process ($V=c$)

$$dQ = du + dW$$

$$\Rightarrow dQ = du +$$

$$\Rightarrow dQ = m \cdot c_v \cdot dT$$

2.) Constant pressure process ($P=c$)

$$dQ = du + dW$$

$$dQ = du + P \cdot dV$$

$$\Rightarrow dQ = du + d(PV)$$

$$\Rightarrow dQ = d(u + PV)$$

$$\Rightarrow dQ = dH$$

$$\Rightarrow dQ = m \cdot c_p \cdot dT$$

3.) Isothermal process ($T=c$)

$$dQ = du + dW$$

$$\Rightarrow dQ = P \cdot V \cdot \ln \frac{V_2}{V_1}$$

4.) Adiabatic process:

$$dQ = 0$$

Note:

Ques: to find for ideal gas $C_p - C_v = R$ proved that.

Soll: we know that

$$H = u + PV$$

$$dH = du + d(PV)$$

$$m \cdot c_p \cdot dT = m \cdot c_v \cdot dT + m \cdot R \cdot dT$$

$$\text{and } PV = mRT$$

$$d(PV) = dT \cdot mR$$

$$d(PV) = mR \cdot dT$$

$\therefore$ mcpdt = mcv dt + mRdt

$$C_p = C_v + R$$

$$C_p - C_v = R \quad \text{Proved}$$

also know that

$$C_p = \gamma \Rightarrow C_p = \gamma C_v$$

$$C_p = \gamma C_v = R$$

$$\Rightarrow \gamma C_v = R$$

$$\Rightarrow C_v (\gamma - 1) = R$$

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

$$\bar{R} = RM \Rightarrow R = \frac{\bar{R}}{M}$$

$$C_v = \frac{\bar{R}}{m(\gamma - 1)} \quad \& \quad C_p = \frac{\gamma \bar{R}}{m(\gamma - 1)}$$

q10 :- So that ideal gas equation for
reversible isobaric process $PV = c$.

Sol

$$PV = \text{constant}$$

[$\because$ Adiabatic process
dq = 0]

$$dy^0 = du + dW$$

$$\Rightarrow 0 = du + dW$$

$$\Rightarrow PdV = -mvdT \quad (1)$$

also know that

$$H = U + PV$$

$$dH = du + PdV + VdP$$

$$\Rightarrow dH = vdp$$

$$\Rightarrow vdp = mvdT \quad (2)$$

By eqn (1) & eqn (2)

$$\frac{vdp}{PdV} = \frac{mvdT}{mvdT}$$

$$\Rightarrow \frac{vdp}{PdV} = \frac{C_p - \gamma}{\gamma - 1}$$

$$\Rightarrow \frac{dp}{p} = -\gamma \frac{dv}{v}$$

$$\Rightarrow \frac{dp}{p} + \gamma \frac{dv}{v} = 0$$

Integration by

$$\int \frac{dp}{p} + \gamma \int \frac{dv}{v}$$

$$\Rightarrow \ln p + \gamma \ln v = \ln c$$

$$\Rightarrow \ln p + \ln v^\gamma = \ln c$$

$$\Rightarrow \ln p v^\gamma = \ln c$$

$$\Rightarrow p v^\gamma = c$$

Different form of ideal gas equation for reversible isobaric process.

Ideal equation

$$p v^\gamma = c$$

$$p_1 v_1^\gamma = p_2 v_2^\gamma$$

~~Find~~ $\Rightarrow$

$$\frac{p_1}{p_2} = \left(\frac{v_1}{v_2} \right)^\gamma$$

and $p v^\gamma = c$

$$p_1 v_1^{\gamma-1} = c$$

$$m R T \cdot v^{\gamma-1} = c$$

$$T_1 v_1^{\gamma-1} = T_2 v_2^{\gamma-1}$$

$$\frac{T_2}{T_1} = \left(\frac{v_1}{v_2} \right)^{\gamma-1}$$

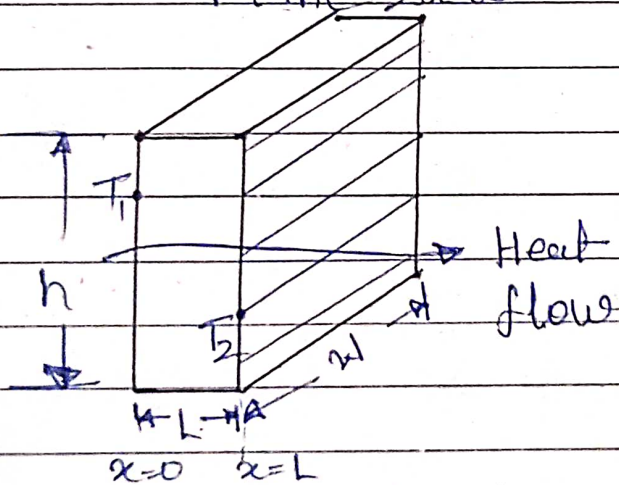
$$\frac{T_2}{T_1} = \left(\frac{p_2}{p_1} \right)^{\frac{\gamma-1}{\gamma}}$$

Temp Distribution & Heat Conduction equation.

Assumption :-

- 1.) 1-Dimension heat flow
- 2.) Steady state
- 3.) No internal heat generation.
- 4.) $k = \text{constant}$
- 5.) Surface maintain at constant temp.

Case I Plane wall
Plane slab



$$\frac{\Delta T}{\Delta x} = C_1$$

Again Integrate

$$[T = C_1 x + C_2] \quad \text{--- eq (1)}$$

from $x=0$, $T = T_1$

$$[C_2 = T_1]$$

$x=L$, $T = T_2$

$$T_2 = C_1 L + T_1$$

$$[C_1 = \frac{T_2 - T_1}{L}]$$

$$\frac{\Delta^2 T}{\Delta x^2} + \frac{\rho g}{k} = \frac{1}{\alpha} \frac{\Delta T}{\Delta t}$$

$$\frac{\Delta^2 T}{\Delta x^2} = 0$$

Integrate from equation.

Putting the value of C_1 & C_2 in equation (1)

$$T = (T_2 - T_1) \frac{x}{L} + T_1$$

$$\left[\frac{T_2 - T_1}{T_2 - T_1} = \frac{x}{L} \right]$$

$$\Rightarrow Q = -kA \frac{\Delta T}{\Delta x}$$

$$Q = -kA C_1$$

$$Q = -kA (T_2 - T_1) \frac{1}{L}$$

$$Q = \frac{T_1 - T_2}{\frac{L}{kA}} \quad \text{Formula}$$

Concept of thermal Resistance :-

any ϕ / T_2

$$Q = \frac{\Delta T}{R} \Rightarrow R = \frac{\Delta T}{Q} \left(\frac{k}{\text{unit}} \text{ or } \frac{\text{unit}}{\text{unit}} \right)$$

$$Q = \frac{T_1 - T_2}{\frac{L}{kA}} = \frac{\Delta T}{R}$$

$$R_{\text{thermal}} = \frac{L}{kA}$$

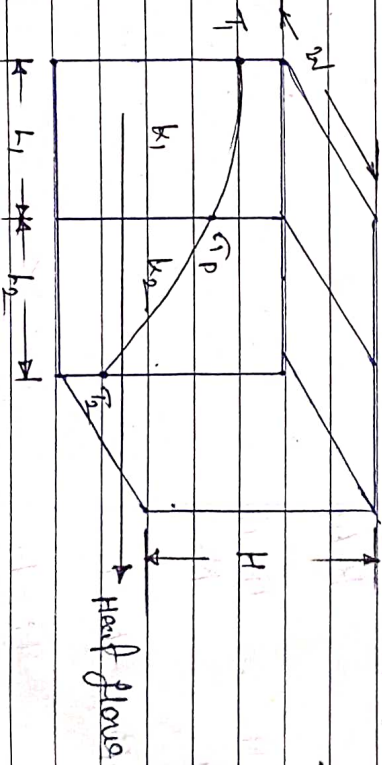
From Newton's law of cooling -

$$Q = hA \Delta T$$

$$Q = \frac{\Delta T}{\frac{1}{hA}} = \frac{\Delta T}{R}$$

$$R_{\text{convective}} = \frac{1}{hA}$$

Plane wall connected in series :- Composite wall



2 - wall

$$A_1 = A_2 = HW$$

$$Q = AT$$

$R_{thermal}$

$$AT = Q \cdot R_{thermal}$$

$$T_1 - T_2 = Q \cdot R_1 \quad \text{--- (I)}$$

$$T_2 - T_3 = Q \cdot R_2 \quad \text{--- (II)}$$

$$Q_{wall} \text{--- (I)} + Q_{equl} \text{--- (II)}$$

$$T_1 - T_2 = Q(R_1 + R_2)$$

$$\Rightarrow Q = \frac{T_1 - T_2}{R_1 + R_2} \quad \text{--- boundary}$$

$$R_1 = \frac{l_1}{k_1 A_1}, \quad R_2 = \frac{l_2}{k_2 A_2}$$

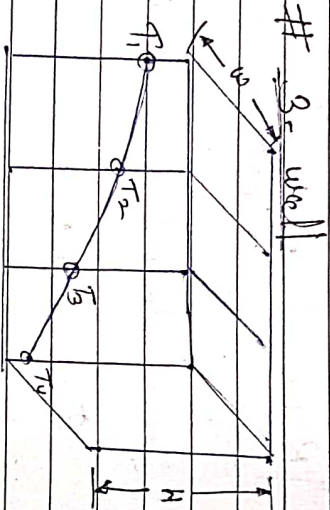
$$Q = \frac{T_1 - T_2}{R_1} = \frac{T_1 - T_2}{R_2}$$

$$\textcircled{4} \quad AT = [R_1 + R_2]$$

$$T_1 - T_2 = T_2 - T_3$$

$$2T_2 = T_1 + T_3$$

$$T_2 = \frac{T_1 + T_3}{2} \quad \text{--- boundary}$$



Q.1- A glass window of a room have a total area of 10 m^2 a glass

Given that

$$A_{\text{area}} = 10 \text{ m}^2$$

$$l_{\text{thickness}} = 4 \text{ mm} = 0.004 \text{ meter}$$

$$T_1 = 25^\circ\text{C} + 273 = 298 \text{ Kelvin}$$

$$T_2 = 10^\circ\text{C} + 273 = 283 \text{ Kelvin}$$

$$k = 0.84 \text{ watt/m.kelvin}$$

$$Q = \frac{T_1 - T_2}{\frac{l}{kA}}$$

$$Q = 298 - 283$$

$$0.004$$

$$0.84 \times 10$$

$$Q = 31500 \text{ Jule} \quad \text{Ans}$$

Q.2 A boiler is made of iron plate 10 mm thickness if the temperature of outside surface be 100°C and that of inner 100°C calculate

The quantity of heat assume that area of heating surface is 5 m^2 and $k = 84 \text{ wett/m.kel}$

Sol: Given that-

$$\text{Area} = 5 \text{ m}^2$$

$$l = 12 \text{ mm} = 0.012 \text{ meter}$$

$$T_1 = 120^\circ\text{C} + 273 = 393 \text{ kel.}$$

$$T_2 = 180^\circ\text{C} + 273 = 453 \text{ kel.}$$

$$k = 84 \text{ wett/m.kel.}$$

$$Q = \frac{T_1 - T_2}{\frac{l}{kA}}$$

$$\frac{0.012}{84 \times 5}$$

$$84 \times 5$$

$$Q = \frac{393 - 453}{\frac{0.012}{84 \times 5}}$$

$$0.012$$

$$84 \times 5$$

$$Q = 700000 \text{ wett/hr}$$

Ans

Q. (2) :- The wall of a room consists of parallel plates

Sol: Given that-

$$A = 1 \text{ m}^2$$

$$T_1 = 30^\circ\text{C} + 273 = 303 \text{ kel}$$

$$T_2 = 5^\circ\text{C} + 273 = 278 \text{ kel}$$

$$k_1 = 0.294$$

$$l_1 = 20 \text{ mm} = 0.02 \text{ meter}$$

$$k_2 = 0.252$$

$$l_2 = 300 \text{ mm} = 0.3 \text{ meter}$$

$$k_3 = 0.168$$

$$l_3 = 10 \text{ mm} = 0.01 \text{ meter}$$

$$Q = \frac{T_1 - T_2}{\frac{l_1}{k_1 A} + \frac{l_2}{k_2 A} + \frac{l_3}{k_3 A}}$$

$$\frac{l_1}{k_1 A} + \frac{l_2}{k_2 A} + \frac{l_3}{k_3 A}$$

$$Q = \frac{303 - 278}{\frac{0.02}{0.294} + \frac{0.3}{0.252} + \frac{0.01}{0.168}}$$

$$0.02$$

$$0.294$$

$$0.3$$

$$0.252$$

$$0.01$$

$$0.168$$

$$Q = 18.96 \text{ wett/hr}$$

Q. (3) :-

Q. (4) :- Heat is conducted through a composite plate of two parallel plates of different material A and B of conductivity 134 wett/m.kel and 42 wett/m.kel and each of thickness 80 mm and 40 mm respectively. If the temperature at the outer surface of the slab A and B are found to be steady at 96°C and 8°C respectively, find the temperature at the interface A/B.

the interface A/B.

Sol Given that -

$$A = 1 \text{ m}^2$$

$$T_A = 96^\circ\text{C} + 273 = 369 \text{ kelvin}$$

$$T_B = 82^\circ\text{C} + 273 = 355 \text{ kelvin}$$

$$k_A = 134 \text{ w/m.k}$$

$$k_B = 60 \text{ w/m.k}$$

$$L_A = 86 \text{ mm} = 0.086 \text{ meter}$$

$$L_B = 42 \text{ mm} = 0.042 \text{ meter}$$

$$Q = \frac{T_A - T_B}{\frac{L_A}{k_A A} + \frac{L_B}{k_B A}} = \frac{T_A - T_B}{\frac{L_A}{k_A} + \frac{L_B}{k_B}}$$

$$\frac{L_A}{k_A A} + \frac{L_B}{k_B A}$$

$$T_i = 344.59 \text{ kelvin}$$

$$T_i = 71.59^\circ\text{C} \quad \text{Ans}$$

Given: A composite wall is made up of brick work, fiber glass and insulating board with thickness and thermal conductivity is given below.

Brick work	$L_1 = 110 \text{ mm}$	$k_1 = 1.15 \text{ W/m.k}$
Fiber glass	$L_2 = 75 \text{ mm}$	$k_2 = 0.04 \text{ W/m.k}$
Insulating board	$L_3 = 95 \text{ mm}$	$k_3 = 0.06 \text{ W/m.k}$

Find the overall coefficient of heat transfer if the coefficient of heat transfer for the surface

and inside wall are three point one w/m².k and 9.51 w/m².k respectively also find the heat loss per hour through each of wall at 90°C when the temperature difference is 27 kelvin

Sol Given that

$$L_1 = 110 \text{ mm} = 0.11 \text{ meter}$$

$$L_2 = 75 \text{ mm} = 0.075 \text{ meter}$$

$$L_3 = 95 \text{ mm} = 0.095 \text{ meter}$$

$$k_1 = 1.15 \text{ w/m.k}$$

$$k_2 = 0.04 \text{ w/m.k}$$

$$k_3 = 0.06 \text{ w/m.k}$$

$$A = 20 \text{ m}^2$$

$$Q = A(T_A - T_B)$$

$$\frac{1}{h_A} + \frac{L_1}{k_1} + \frac{L_2}{k_2} + \frac{L_3}{k_3} + \frac{1}{h_B}$$

$$Q = 420(3.1 - 2.51)$$

$$Q = 0.322 \times 20(3.1 - 2.51)$$

$$Q = 173.9 \text{ J/sec}$$

At overall heat coefficient (U)

$$\frac{1}{U} = \frac{1}{h_A} + \frac{L_1}{k_1} + \frac{L_2}{k_2} + \frac{L_3}{k_3} + \frac{1}{h_B}$$



$$V = \frac{1}{\frac{1}{3.1} + \frac{1}{0.110} + \frac{1}{0.045} + \frac{1}{0.02} + \frac{1}{0.09} + \frac{1}{0.06} + \frac{1}{2.51}}$$

$$V = 0.322 \text{ m/s}$$

Radiation :-

Radiation is the transfer of heat through space for matter by means other than conduction or convection. Radiation of heat takes place through electromagnetic waves and radio waves. All body radiate heat so a transfer of heat by radiation occurs likewise a heated body emit more heat that eat emit in normal condition radiant energy required no medium for propagation but eat can pass through a vacuum radiation is independent of medium.

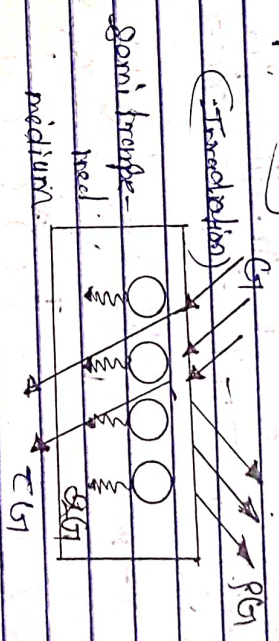
em wave can travel with a speed of light under vacuum condition there for radiation is a fastest mode of heat transmission.

Radiation is airectional depended phenomenon because radiation itself are more in direction to the surface.

Irradiation (G) :-

Heat is a total rate of energy incident on the surface from all direction G for all longer wave length per unit surface area. i.e. G unit is $\frac{\text{W}}{\text{m}^2}$

Irradiation is out a property of surface it is quantity of total energy incident on the surface unit of which some energy get absorbed, reflect, transmit even as absorptivity (α), reflectivity (ρ), transmissivity (τ)



$$G_i = G_r + G_a + G_t$$

$T_1 = \rho + \alpha + \tau$	for Solid $\tau = 0$
$T_1 = \rho + \alpha$	

where ρ = reflectivity (ρ)
 α = absorptivity (α)
 τ = transmissivity (τ)

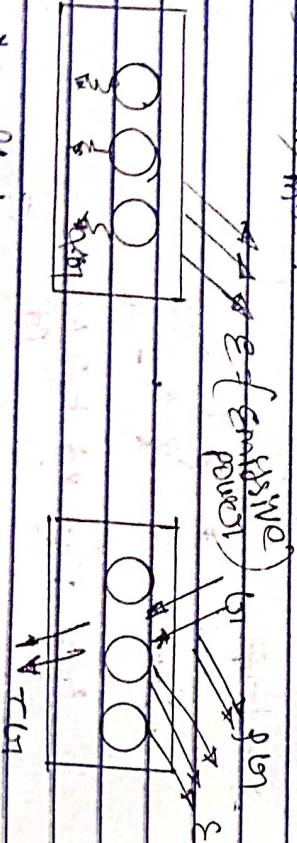


Emissive power :-

Emissive power is rate of energy emitted by the material present at surface of do all direction for all longer wave length per unit surface area. The unit is W/m^2 emissive power does not take care of reflection and transmission.

Radiosity (J)

Radiosity is define as total rate of energy (coming from the surface & due to reflection & transmission (emission)) to all direction for all longer wave length per unit surface area. It will is W/m^2 .



$$J = \rho G + \epsilon + \tau G$$

$$\tau = 0, \tau = 0$$

$$[J = E]$$

$$\text{Solid } \tau = 0$$

$$J = \rho G + E$$

Concept of Black Body :-

Black Body is ideally solid body which can absorb all the radiation incident on it irrespective of wave length and direction. It means radiation of any wave length in any direction following an black body when black body completely absorb.

$$\tau = 0$$

$$\alpha = 1$$

Emissivity (ϵ) :-

The ratio of emissive power of any body at a given temperature to the emissive power of black body at same temperature is known as emissive.

$$\epsilon = \frac{E_{\text{any body}}}{E_{\text{black body}}}$$

Gray Body :-

A Gray body is non ideal body that can absorb some of the incident radiation and emits only a portion of the radiation.

Stefan Boltzman law :-

Stefan Boltzman law state that total emissive power of black body is directly proportional to fourth power of absolute temperature.

$$E_b \propto T^4$$

$$\Rightarrow [E_b = \sigma T^4] \text{ watt/m}^2$$

$$\Rightarrow [E_b = \sigma A T^4] \text{ watt}$$

Emissivity (ϵ)

$$\epsilon = \frac{E_{\text{anybody}}}{E_{\text{black body}}}$$

$$\therefore E_{\text{anybody}} = \epsilon \cdot E_{\text{black body}}$$

$$\Rightarrow E_{\text{anybody}} = \sigma T^4 A \epsilon$$

$$\Rightarrow [E_{\text{anybody}} = \sigma A \epsilon T^4] \text{ (watt)}$$

Where

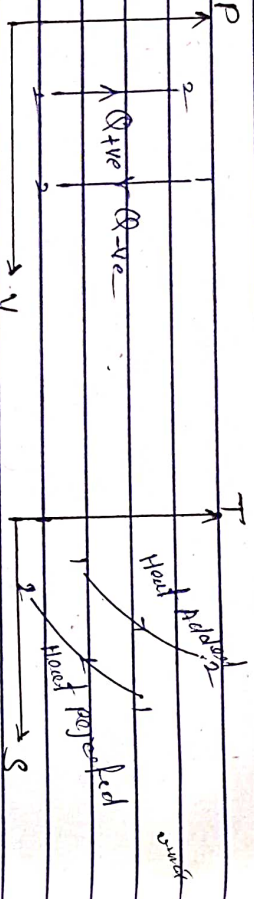
$$\sigma = \text{Stefan Boltzman Constant}$$

$$\sigma = 5.67 \times 10^{-8}$$

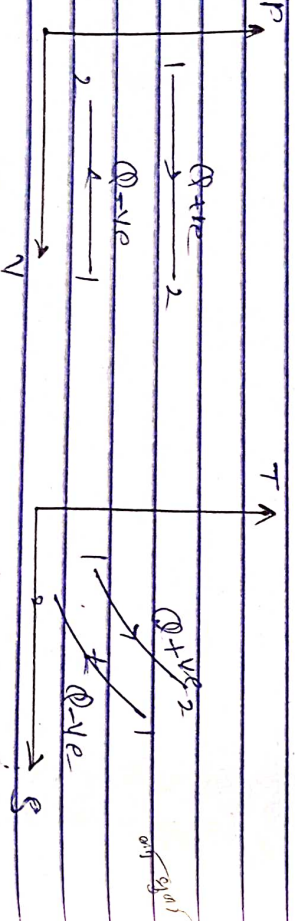
TOP

Representation of thermodynamic process on P-V and T-S diagram.

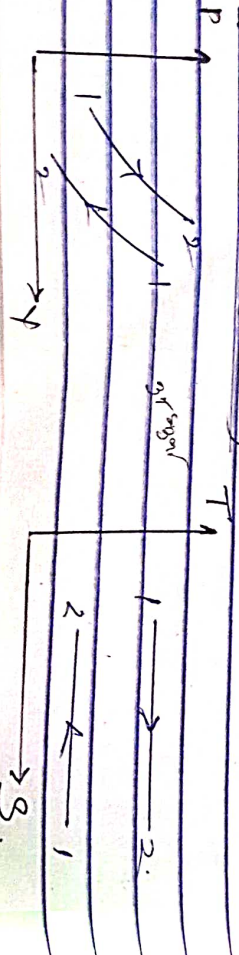
1.) Constant Volume (Isochoric)



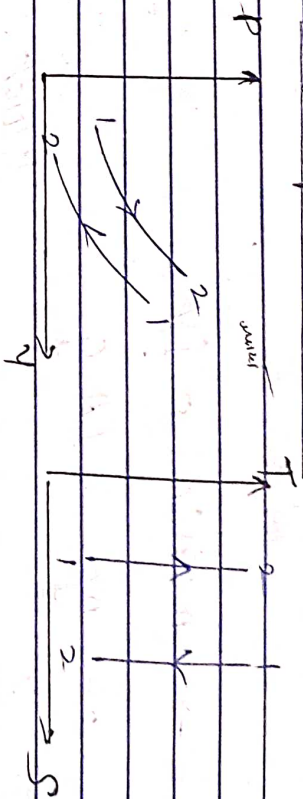
2.) Constant Pressure (Isobaric)



3.) Isothermal ($T=c$)



4.) Adiabatic ($Q=c$)



Open system:-

In open system mass transfer also takes place along with energy transfer.

Open system steady flow:

Mass balance: It is based on law of conservation of mass.

By law of conservation of mass the rate of mass of accumulated within the control volume is equal to the rate of mass crosses the control volume.

for state flow there should no accumulation of mass exist in the control volume at no. so state of mass entering must equal to rate of mass leaving.

$f = \text{mass}$
 volume

$\Rightarrow \text{mass (m)} = \rho V$

$\Rightarrow m = \rho A L$
 $f =$

$[m = \rho A L]$

$C = \text{velocity}$

$m_1 = m_2$

$\rho_1 A_1 C_1 = \rho_2 A_2 C_2$

$m_1 A_1 C_1 = m_2 A_2 C_2$
 $\frac{m}{V_1} = \frac{m}{V_2}$

$\frac{A_1 C_1}{V_1} = \frac{A_2 C_2}{V_2}$

for open system work:

External work flow work

External work:

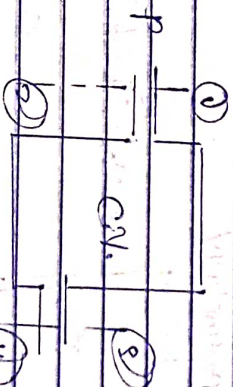
The work which crosses the boundary of system other than due to pressure (fluid force / fluid pressure)

flow work:

(Internal) The work which is responsible for flow to flow fluid if it occurs at fluid forces

flow work:

The work which involve increasing the fluid element either entering to the system exiting from the system



$P = \frac{f}{A}$

$f = P \times A$

$\text{Net flow} = P V$

$\text{entry work flow} = P_1 V_1$

$\text{exit work flow} = P_2 V_2$

12

$$E = K.E. + P.E. + I.E. + \text{energy}$$
$$E_1 = \frac{1}{2} m v_1^2 + m g z_1 + m \psi_1 + Q_1$$
$$E_2 = \frac{1}{2} m v_2^2 + m g z_2 + m a d_2 + m a$$
$$F_1 = F_2$$
$$\frac{1}{2} m_1 v_1^2 + m_1 y_{21} + m_1 u_{11} + 18 =$$
$$\Rightarrow m \sqrt{2u_1 + c^2 + g_{21} + u_1 + g}$$
$$\frac{1}{2} \frac{d}{dt} \left[h^2 \right] = m^2 h^2 + c^2 + g_{20} + u_{20} + \dots$$
$$\Rightarrow m[h_1 + \frac{c_1^2}{2} + g_{21}] + q = m[h_2 + \frac{c_2^2}{2} + g_{22}]$$


Journal $h_1 + \frac{C_1^2}{2000} + g_{21} + g = h_2 + \frac{C_2^2}{2000} + g_{22}$

Friday

$$I = \epsilon \pi m \omega$$
$$v = 2$$

first law of thermodynamic for open system
steady flow (each second has in kg/s)

It is valid for reversible as well as irreversible.

Note: GEEF by neglecting kinetic energy and potential energy.

$$m/h_1 + Q = m/h_2 + mcv$$

$$[h_1 + q = h_2 + mcv]$$

It is valid for reversible as well as irreversible.

Example:- Nozzle, Compressor, Turbine, Throttling valve, etc.

Imp:-

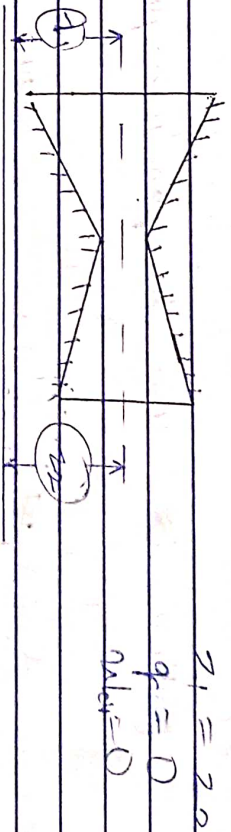
Example for open system steady flow

1.) Nozzle:

अस के लिए Nozzle का उपयोग किया जाता है जो गैस को उच्च दबाव से निम्न दबाव में परिवर्तित करता है।

जो प्रवाह में आए वो उसका दबाव भी कम हो जाएगा।
जो प्रवाह में आए वो उसका दबाव भी कम हो जाएगा।
जो प्रवाह में आए वो उसका दबाव भी कम हो जाएगा।

$$Q_{loss} = 0$$



first law

$$h_1 + C_1^2/2000 + q = h_2 + C_2^2/2000 + q_{loss}$$

$$h_1 + C_1^2/2000 = h_2 + C_2^2/2000$$

$$C_1 \ll C_2 \quad C_1 = \text{neglect}$$

$$h_1 = h_2 + C_2^2/2000$$

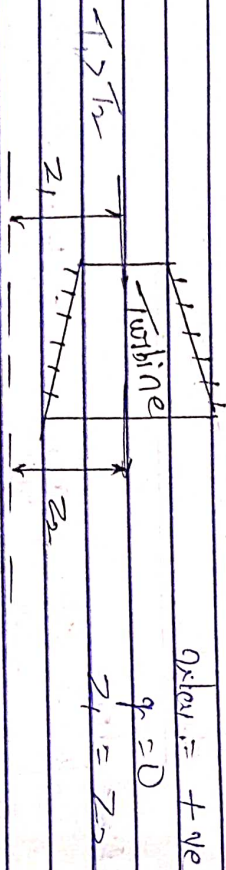
$$C_2 = \sqrt{2000(h_1 - h_2)}$$

2.) Turbine:

अस के लिए Turbine का उपयोग किया जाता है जो गैस को उच्च दबाव से निम्न दबाव में परिवर्तित करता है।

है। इसमें फ्लोइड्स प्रवाह को रोकने में कार्य करने वाले डिवाइस को, गतिमान फ्लो में परिवर्तन करने वाला है। ठोस: Turbine में Turbine आगे प्रवाह को रोक, फ्लोइड्स में परिवर्तन के द्वारा फ्लो को रोकने वाले पर प्रवाह को रोकने वाले को रोकने वाले।

Turbine is use to produce power.



First Law: (SEEF) Neglecting kinetic energy and potential energy changes

$$m(h_1 + q) = m(h_2) + q_{out}$$

$$m h_1 = m h_2 + q_{out}$$

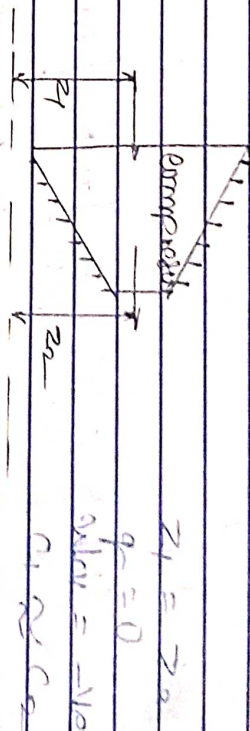
$$q_{out} = m h_1 - m h_2$$

$$[q_{out} = m(h_1 - h_2)] \text{ kJ/s}$$

$$[q_{out} = h_1 - h_2] \text{ kJ/kg}$$

2) Compressor:

Compressor is a power consuming device which is used to increase the pressure of the gas



First Law: (Neglecting kinetic energy and potential energy changes.)

$$m h_1 + q = m(h_2) + q_{out}$$

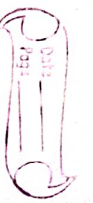
$$m(h_1) = m(h_2) - q_{in}$$

$$[q_{in} = m(h_2 - h_1)] \text{ kJ/s}$$

$$[q_{in} = h_2 - h_1] \text{ kJ/kg}$$

4) Throttling valve:-

example: 1. throttle partial open but 2. throttle very and opening



$$z_1 = z_2 \quad C_1 = C_2$$

$$q = 0 \quad m_1 C_1 = 0$$

1st law

$$h_1 + \frac{C_1^2}{2000} + \frac{q_1}{1000} = h_2 + \frac{C_2^2}{2000} + \frac{q_2}{1000}$$

$$+ \frac{q_2}{1000} + m_1 C_1$$

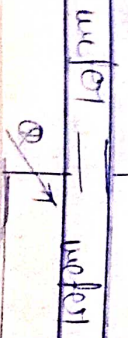
$$h_1 = h_2$$

Throttling is isenthalpic expansion process

5.) Boiler:

A boiler is a device which supply heat to the water and generate steam in this system there is known any change in p.e. and p.e. also that it is work done by the system.

if steam output



$C = \text{velocity}$

$AK.E = 0, \quad AK.E = 0, \quad u = 0$

$$h_1 + \frac{C_1^2}{2000} + \frac{q_1}{1000} = h_2 + \frac{C_2^2}{2000} + \frac{q_2}{1000}$$

$$q = h_2 - h_1$$

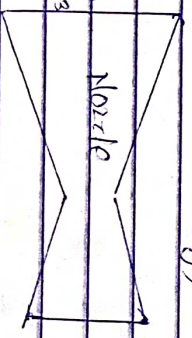
Q.11) A gas expand through and ideally incompressible following a reversible polytropic law

$PV^n = c$ there is no change in potential energy heat the pressure drops from 2 bar to 0.5 bar and specific volume increases from 0.05 m³ to 0.3 m³ of the initial velocity is 80 m/s determine the exit velocity

Q.11 Given

$$u_1 = C_1 = 80 \text{ m/s}$$

$$u_1 = 0.05 \text{ m}^3$$



$$u_2 = 0.3 \text{ m}^3$$

$$h_1 + \frac{C_1^2}{2000} + \frac{q_1}{1000} = h_2 + \frac{C_2^2}{2000} + \frac{q_2}{1000}$$

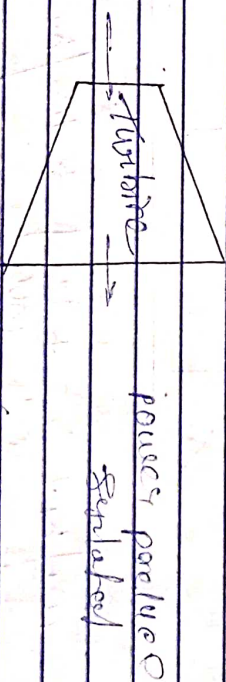
$$h_1 + \frac{C_1^2}{2000} = h_2 + \frac{C_2^2}{2000}$$

$$\Rightarrow (h_1 + h_{v1}) + \frac{C_1^2}{2000} - (h_2 + h_{v2}) + \frac{C_2^2}{2000}$$

2000

Ques: In a gas turbine the gases flow at the rate of 5 kg/sec the gas inlet the turbine at the pressure 1 bar without velocity 100 m/s and inlet of pressure 1 bar with velocity 200 m/s the turbine is insulated at the entropy of gases at the inlet is 900 kJ/kg and at outlet 1000 kJ/kg determine the capacity of turbine.

Sol:



$$m_{1-2} = (h_1 - h_2) + \left(\frac{C_1^2}{2000} - \frac{C_2^2}{2000} \right)$$

$$m_{1-2} = (900 - 1000) + \left(\frac{100^2 - 200^2}{2000} \right)$$

$$m_{1-2} = 0.75.95 \text{ kg/kg}$$

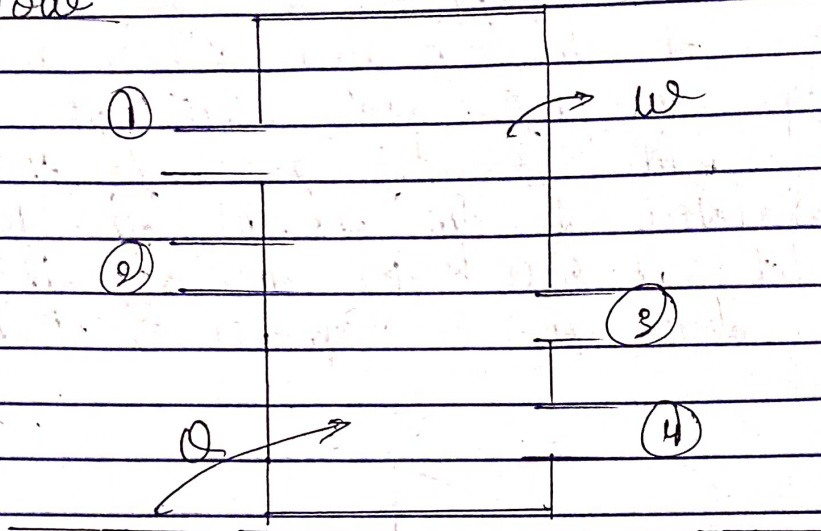
$$\text{Power (capacity)} = m \times m_{1-2}$$

$$= 5 \times 275.95$$

$$= 1379.75 \text{ kW}$$

Ans

Steady flow :- energy equation for multistream flow



$$m_1 \left[h_1 + \frac{C_1^2}{2000} + \frac{gz_1}{1000} \right] + m_2 \left[h_2 + \frac{C_2^2}{2000} + \frac{gz_2}{1000} \right]$$

$$= m_3 \left[h_3 + \frac{C_3^2}{2000} + \frac{gz_3}{1000} \right] + m_4 \left[h_4 + \frac{C_4^2}{2000} + \frac{gz_4}{1000} \right]$$

(a) if $m_1 = 0.01$

(1) $h_1 = 2952$
 $C_1 = 20$

(2) $m_2 = 0.1$
 $h_2 = 2569$
 $C_2 = 120$

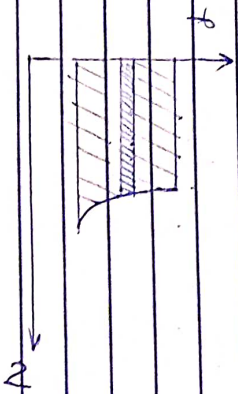
$Q = 0$

$w = 25 \text{ kg}$

(3) $m_3 = 0.001$
 $h_3 = 420$
 $C_3 = 0$

(4) $m_4 = 2$
 $h_4 = 3$
 $C_4 = 0$

Open system Reversible work:



$$Q_{1-2} = \int V dp$$

Area under the curve when projected on pressure axis in $P-V$ diagram gives open system reversible work.

Open system work for various process:

1.) Constant volume process:

$$Q_{1-2} = - \int_1^2 V dp$$

$$= -V \int_1^2 dp$$

$$= -V(P_2 - P_1)$$

$$Q_{1-2} = V(P_1 - P_2) \quad /$$

Example: Pump

2.) Pressure constant process: (Isobaric)

$$Q_{1-2} = - \int_1^2 V dp$$

$$= -V(P_2 - P_1) \quad [V = \text{const}]$$

$$Q_{1-2} = 0 \quad /$$

Example: Heat exchanger, Boiler, Condensation

3.) Temperature constant (Isothermal)

$$P_1 V_1 = P_2 V_2 = PV = C \Rightarrow PV = C$$

$$V = \frac{C}{P}$$

$$Q_{1-2} = - \int_1^2 V dp$$

$$= - \int_1^2 \frac{C}{P} dp$$

$$= -C \ln \frac{P_2}{P_1}$$

$$= C \ln \frac{P_1}{P_2}$$

$$Q_{1-2} = P_1 V_1 \ln \frac{P_1}{P_2}$$

or

$$Q_{1-2} = P_1 V_1 \ln \frac{V_2}{V_1} \quad / \quad - \text{reversed}$$



4) Adiabatic ($PV^\gamma = c$)

$$P_1 V_1^\gamma = P_2 V_2^\gamma$$

$$\text{order} = \gamma \text{ mol closed}$$

example:- Turbine, compressor etc

5) Polytropic ($PV^n = c$)

$$P_1 V_1^n = P_2 V_2^n \quad (n = \gamma)$$

$$\text{order} = n \text{ mol closed}$$

2nd Law

≠ Second Law of thermodynamic:

Heat cannot flow from a colder body to a hotter body without the aid of external work.

or Heat cannot flow from a colder body to a hotter body without the aid of external work.

or Heat cannot flow from a colder body to a hotter body without the aid of external work.

2nd Kelvin Plank Statement:

It is impossible to construct a heat engine that operates in a cycle and produces no other effect than the extraction of heat from a single reservoir and the performance of an equivalent amount of work.

Heat cannot flow from a colder body to a hotter body without the aid of external work.

एक ही गीत में दो में एक सबेरे।

High Temp Reservoir

(I) T_1

(II) Heat engine

Low Temp Reservoir $\rightarrow$ (III) T_2

$\Sigma Q = \Sigma W$ efficiency = $\frac{W}{Q_{input}}$
 $Q = W$

$h = \frac{W}{Q}$

$h = 100\%$

The efficiency of π is 100% which is not possible

(I) Clausius Statement:

Clausius ने कहा कि, "उष्मा के लिए यह सम्भव नहीं है कि वह एक ही ताप के एक ही स्थान से दूसरे स्थान पर जा सके।"

T_1 Heat source

(I) $Q_1 = Q_2 = Q_3$

T_2 (Sink)

(I) Concept of Heat engine:

Heat engine is a device which takes heat from high temperature source convert a part of heat into work and reject remaining to sink.

T_1 Source $\rightarrow$ Q_{in} $\rightarrow$ Q_{out} $\rightarrow$ T_2

$Q_{in} - Q_{rej} = W$

$Q_{in} - Q_{rej} = W$

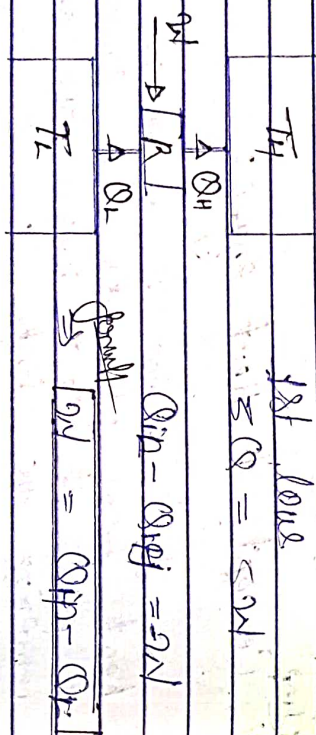
T_2 Sink $h = \frac{W}{Q_{in}}$

$h = \frac{Q_{in} - Q_{rej}}{Q_{in}}$

$h = 1 - \frac{Q_{rej}}{Q_{in}}$

Concept of Refrigerator:

एक ठंडा करने वाला यंत्र (refrigerator) है, जिसका कार्य है, गर्म ठंडा करने के लिए गर्म स्थान T_1 से ठंडा स्थान T_2 पर गर्मी को हटाना।

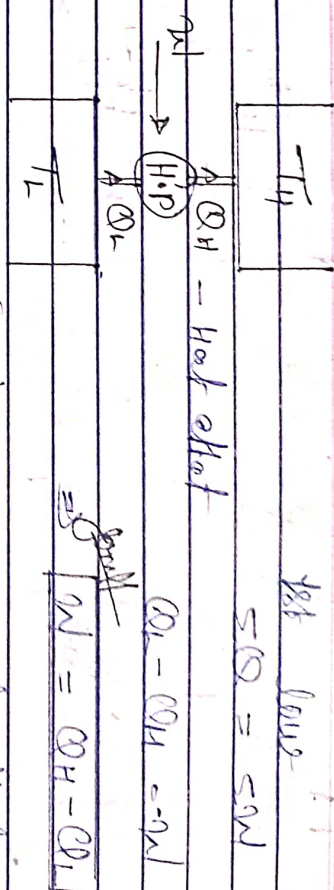


(COP) Coefficient of Performance

$$\text{COP}_R = \frac{Q_L}{Q_H - Q_L}$$

Concept of Heat Pump:

Heat pump is a device which maintain higher temperature than surrounding.



(COP)_{HP} = Heat added

$$\text{COP}_{HP} = \frac{Q_H}{Q_H - Q_L}$$

Note: (COP)_{HP} - (COP)_R = 1

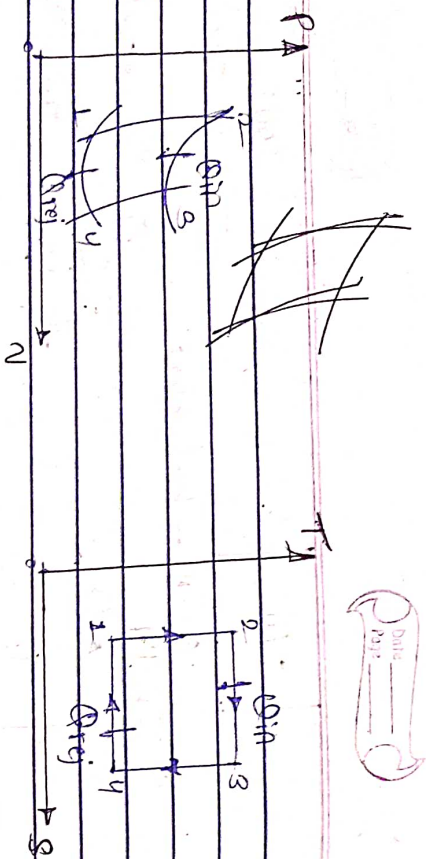
$$(COP)_{HP} = (COP)_R + 1$$

(COP)

CARNOT Cycle:

In Carnot cycle two processes are isothermal and two processes are adiabatic.

Isothermal is very-very slow process where as adiabatic is very-very fast process. So that the combination of this two processes in cycle is not possible.



Process:

- 1-2 = Reversible adiabatic compression
- 2-3 = Isothermal expansion (Heat added)
- 3-4 = Reversible adiabatic expansion
- 4-1 = Isothermal compression (Heat rejected)

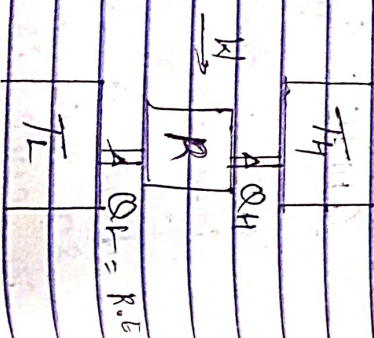
Efficiency = $\frac{W_{out}}{Q_{in}}$

Reversible Refrigerator:

$\pi = \frac{W}{Q_C} = \frac{Q_H}{Q_C} - 1$

$Q_C - Q_H = W$

$\Rightarrow W = Q_H - Q_C$



(ii) Now $\int \frac{dQ}{T} = 0$

$\Rightarrow \frac{Q_C}{T_C} = \frac{Q_H}{T_H} \Rightarrow \frac{Q_C}{Q_H} = \frac{T_C}{T_H}$

$(COP)_R = \frac{R.E.}{W_{in}}$

$(COP)_R = \frac{Q_C}{Q_H - Q_C}$ [Reversible as well as Irreversible]

$(COP)_R = \frac{Q_C}{1 - \frac{Q_C}{Q_H}}$

$(COP)_R = \frac{T_C/T_H}{1 - T_C/T_H}$

$(COP)_R = \frac{T_C}{T_H - T_C}$ Valid for reversible only

Similar for heat pump:

$(COP)_{HP} = \frac{H.E.}{W_{in}} = \frac{Q_H}{Q_H - Q_C}$



$$\left[\frac{(COP)_{H.P.} - T_H}{T_H - T_L} \right] \text{ valid for reversible only}$$

Note: $\left[\frac{(COP)_{H.P.}}{R+1} \right]$ only valid for some temperature limit

Option

1200K	$Q_{in} = 40 \text{ kJ/s}$
-------	----------------------------

Sol: Given that $\left[\frac{H.P.}{Q_{in}} \right]_{\text{rev}} = 2$
 $T_H = 1200 \text{ K}$
 $T_L = 300 \text{ K}$
 $Q_{in} = 40 \text{ kJ/s}$

$Q_{in} = 40 \text{ kJ/s}$

(i) $\eta = \frac{T_H - T_L}{T_H}$

$\eta = \frac{1200 - 300}{1200}$

$\eta = 0.75$

$\eta = 75\%$



(ii) $\eta = \frac{Q_{in} - Q_{rej}}{Q_{in}}$

$0.75 = \frac{40 - Q_{rej}}{40}$

$0.75 \times 40 = 40 - Q_{rej}$

$30 - 40 = -Q_{rej}$

$Q_{rej} = 40 \text{ kJ/s}$

(iii) $Q_L = Q_{in} + Q_{rej}$

$Q_L = 40 - 10$

$Q_L = 30 \text{ kJ/s}$

Ques: An engine works between the temperature limit of 1775 K and 375 K what can be maximum efficiency of this engine

Sol: $T_H = 1775 \text{ K}$ and $T_L = 375 \text{ K}$

$\eta = \frac{1 - Q_{rej}}{Q_{in}}$



$$\Rightarrow \frac{1-375}{1775}$$

$$= 0.7887$$

$$= 78.87\% \quad \underline{\text{Ans}}$$

Solution: as cold storage is to be maintain at -5° to 80° and one use the heat degree from the surrounding into the cold storage is stored to be 99 kwh the actual (COP) at the refrigerator this is at an ideal plant working between the same temperature find the power required to drive the plant

Sol Given $Q_1 = 99 \text{ kwh}$

20°K	20°K
28°K	28°K

 $Q_2 + Q_1 = 129 \text{ kwh}$

$T_1 = -5^\circ = 268 \text{ K}$
 $T_2 = 80^\circ = 308 \text{ K}$

$\Rightarrow (P)$

(COP)_R = $\frac{Q_1}{Q_2 - Q_1}$

-5°	20°K
28°K	28°K

 $Q_1 = 99 \text{ kwh}$

(COP)_R = $\frac{T_1}{T_2 - T_1}$

(COP)_R = $\frac{268}{308 - 268}$

(COP)_R = 0.7

(COP)_{total} = $\frac{1}{2} \times 0.7 = 0.283$

(COP) = $\frac{Q_1}{Q_2 - Q_1}$

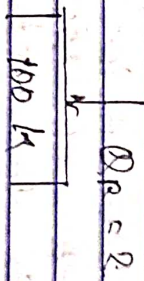
$= 0.283 = \frac{29}{101}$

$\Rightarrow Q_2 = 10.987 \text{ kwh}$

Solution:

800 K	600 K
-----------------	-----------------

$Q = ?$



$\oint dQ = 0$

$Q_1 + Q_2 = Q_R = 0$
 $800 + 600 = Q_R = 0$



$$\Rightarrow \frac{1}{48} \times 100 = Q_R$$

$$\Rightarrow Q_R = 2.08$$

$$\eta = 1 - \frac{Q_{rej}}{Q_{in}}$$

$$\eta = 1 - 2.08$$

$$\eta = 1 - 2.08$$

$$14$$

$$\eta = 10.851$$

$$\eta = 85.1\% \quad \text{Ans}$$

Q.10

A cycling heat engine operates between a source temperature of 600°C and sink temp. at 30°C what is the net work output of the engine.

Sol

$$\eta = 1 - \frac{Q_{out}}{Q_{in}}$$

$$\frac{W}{Q_{in}} = 1 - \frac{300}{600} = 0.5$$

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

$$300K$$

$$\eta = 1 - \frac{300}{600}$$

$$100\%$$

$$\eta = 0.5$$

$$\eta = 50\%$$

$$Q_{in} = (Q_{out} + W)$$

$$1 - 1.408 = (Q_{out} + W)$$

$$Q_{out} = 0.408 \text{ kJ/s}$$

Entropy

Entropy is a measure of the disorder or randomness in a system. The concept arises out of thermodynamics which deals with the transfer of heat energy with in the system.

$$\frac{dQ}{T} \geq 0$$

$$\text{for reversible } \oint \frac{dQ}{T} = 0$$

Case I: Reversible cycle

for cycle (1000 h)



net work

$$\left(\frac{dQ}{T} \right)_{1000} + \left(\frac{dQ}{T} \right)_{2000} = 0$$

for cycle (1aoc1)

$$\left(\frac{dq}{T}\right)_{1aoc1} + \left(\frac{dq}{T}\right)_{oc1} = 0 \quad (11)$$

Equation (1) - Equation (11)

$$\left(\frac{dq}{T}\right)_{1aoc1} + \left(\frac{dq}{T}\right)_{oc1} = 0$$

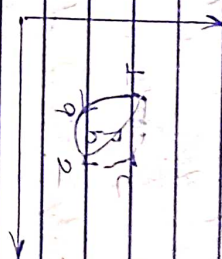
$$\left(\frac{dq}{T}\right)_{1aoc1} + \left(\frac{dq}{T}\right)_{oc1} = 0$$

$$\left(\frac{dq}{T}\right)_{1aoc1} - \left(\frac{dq}{T}\right)_{oc1} = 0$$

$$\left(\frac{dq}{T}\right)_{1aoc1} = \left(\frac{dq}{T}\right)_{oc1} = \left(\frac{dq}{T}\right)_{oc1}$$

The quantity $\left(\frac{dq}{T}\right)_{oc1}$ here is same for path Band c of means it only depend on end point of does not depend on path allowed by the system so it must be a property and this property is known as entropy.

Case II: Irreversible cycle:



for cycle (1aoc1)

$$\left(\frac{dq}{T}\right)_{1aoc1} + \left(\frac{dq}{T}\right)_{oc1} = 0$$

$$\left(\frac{dq}{T}\right)_{1aoc1} = -\left(\frac{dq}{T}\right)_{oc1}$$

for cycle (1aoc1)

$$\left(\frac{dq}{T}\right)_{1aoc1} + \left(\frac{dq}{T}\right)_{oc1} = 0$$

$$-\left(\frac{dq}{T}\right)_{oc1} + \left(\frac{dq}{T}\right)_{oc1} = 0$$

$$\left(\frac{dq}{T}\right)_{1aoc1} = \left(\frac{dq}{T}\right)_{oc1}$$

$$\Rightarrow \left(\frac{dq}{T}\right)_{1aoc1} = \left(\frac{dq}{T}\right)_{oc1}$$

$$dq = \left(\frac{dq}{T}\right)_{irre}$$

1. between two states of no. of reversible paths are three than for each path the quantity $(ds)_T$ is a constant quantity $(ds)_T$ as entropy $(T)_{rev}$

2. $(ds)_T$ is not a property it is just a quantity which is always less than entropy

3. as the entropy is property & does not depend on path follow by system it only depend on end point and only at the end point we can entropy change. this also can

Entropy principle :

Entropy of isolated system for any system.

$$ds > 0$$

$$ds = 0, \text{ due to } 0$$

$$(ds)_{isolated} \geq 0$$

Entropy of an isolated system is never

becomes. the best example of isolated system is universe $(ds) \geq 0$.

$$(ds)_{system} + (ds)_{surrounding} \geq 0$$

Second law of T. dynamic process.

1. Entropy of system may be increase or decrease or become constant.

2. Similarly entropy of surrounding may increase or decrease or be constant.

3. But only all entropy it is known as entropy principle.

Entropy principle gives the key for the possibility of a process.

if $(ds)_{system} + (ds)_{surrounding} = 0$ - Reversible

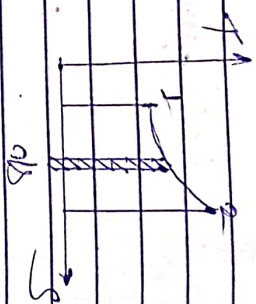
$(ds)_{system} + (ds)_{surrounding} > 0$ - Irreversible

$(ds)_{system} + (ds)_{surrounding} < 0$ - Not possible

Temperature - entropy diagram. (T-S)

$$(ds) = \left(\frac{dq}{T} \right)_{\text{rev}}$$

$$dq = T \cdot ds$$



Integration:-

$$\int_1^2 dq = \int_1^2 T \cdot ds$$

$$Q_{\text{rev}} = \int_1^2 T \cdot ds$$

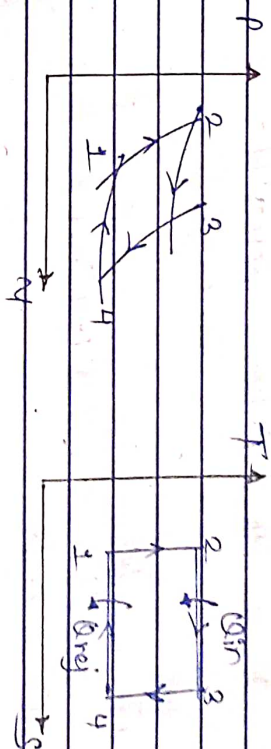
Area under the curve when projected on entropy axis T-S diagram if reversible heat transfer

Area of the cycle in T-S diagram. If not work transfer and area of the cycle in T-S diagram if not heat transfer and according to 1st law both are same.

Representation of CARNOT cycle T-S diagram.

1-2 Reversible adiabatic compression

2-3 Reversible isothermal expansion



3-3. Isothermal expansion (Heat Added)

3-4 Reversible Adiabatic expansion

4-1 Isothermal compression (Heat rejected)

(Entropy, expansion)

$$Q_{\text{in}} = T_h \cdot ds$$

$$Q_{\text{rev}} = T_c \cdot ds$$

$$Q_{\text{net}} = Q_{\text{in}} - Q_{\text{rev}}$$

$$Q_{\text{net}} = (T_h - T_c) \cdot ds = \text{Area under the curve}$$

$$h = Q_{\text{net}} = 1 - Q_{\text{rev}}$$

$$Q_{\text{net}}$$

$$Q_{\text{in}}$$

$$h = 1 - T_c \cdot ds$$

$$T_h \cdot ds$$

$$h = 1 - \frac{T_c}{T_h}$$

Such as hardness, strength, ductility.

Combine 1st law and second law of thermodynamics.

1st law

$$dU = dq + dw \quad \text{--- valid reversible/irreversible}$$

$$dU = dq + P \cdot dv \quad \text{--- Reversible}$$

Second law

$$ds = \frac{dq}{T}$$

$$dU = T \cdot ds \quad \text{--- reversible}$$

$$[dq + P \cdot dv = T \cdot ds]$$

1st law and 2nd

$$H = U + PV$$

$$dH = dU + P \cdot dv + v \cdot dp$$

$$dH = dU + v \cdot dp$$

$$dU = dH - v \cdot dp$$

2nd law

$$T \cdot ds = dU$$

$$[T \cdot ds = dH - v \cdot dp]$$

Entropy change for ideal gas:

Case I:

To find change of temperature and volume

$$T \cdot ds = dq + P \cdot dv$$

$$\int_1^2 ds = \int_1^2 \frac{dq}{T} + \int_1^2 \frac{P \cdot dv}{T}$$

$$ds = dq + P \cdot dv$$

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

$$\int_1^2 ds = \int_1^2 \frac{C_v \cdot dT}{T} + \int_1^2 \frac{R \cdot dv}{v}$$

$$\Delta S = C_v \ln \frac{T_2}{T_1} + R \ln \frac{V_2}{V_1} \quad \text{--- kg} \cdot \text{K}$$

$$(\Delta S - \Delta S_1) = m \left[C_v \ln \frac{T_2}{T_1} + R \ln \frac{V_2}{V_1} \right] \cdot \text{kg}$$

Case II:

To find change of temperature and pressure

1st law and 2nd

$$T \cdot ds = dU - v \cdot dp$$

$$\int_1^2 ds = \int_1^2 \frac{dH}{T} = \int_1^2 \frac{dU + PdV}{T} \quad dH = mc_p dT$$

$$\int_1^2 ds = \int_1^2 \frac{C_p dT}{T} - \int_1^2 \frac{R dp}{p} \quad \frac{p}{T} = \frac{R}{T}$$

$$(s_2 - s_1) = C_p \ln \frac{T_2}{T_1} - R \ln \frac{p_2}{p_1}$$

$$\text{Similarly } (s_2 - s_1) = m \left[C_p \ln \frac{T_2}{T_1} + R \ln \frac{p_2}{p_1} \right]$$

Case III:

T is constant and pressure and volume

$$(s_2 - s_1) = C_v \ln \frac{T_2}{T_1} + R \ln \frac{v_2}{v_1} \quad \therefore R = C_p - C_v$$

$$(s_2 - s_1) = C_v \ln \frac{T_2}{T_1} + (C_p - C_v) \ln \frac{v_2}{v_1}$$

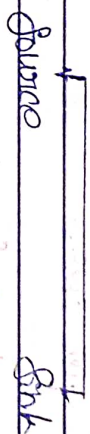
$$(s_2 - s_1) = C_v \ln \frac{T_2}{T_1} + C_p \ln \frac{v_2}{v_1} - C_v \ln \frac{v_2}{v_1}$$

$$(s_2 - s_1) = C_v \left[\ln \frac{T_2}{T_1} - \ln \frac{v_2}{v_1} \right] + C_p \ln \frac{v_2}{v_1}$$

$$(s_2 - s_1) = C_v \left[\ln \left(\frac{T_2}{T_1} \times \frac{v_1}{v_2} \right) \right] + C_p \ln \frac{v_2}{v_1}$$

$$(s_2 - s_1) = C_v \ln \frac{p_2}{p_1} + C_p \ln \frac{v_2}{v_1}$$

Entropy change for reservoir Reservoir



$$\left[\frac{T_1}{T_2} \right] \rightarrow \text{Source} \xrightarrow{\text{Heat}} \left[\frac{T_2}{T_1} \right] \rightarrow \text{Sink}$$

$$ds = \frac{dq}{T_1} = ds = \frac{dq}{T_2}$$

Entropy change for finite temp. body.

$$ds = \frac{dq}{T}$$

$$\int_1^2 ds = \int_1^2 \frac{dq}{T}$$

$$= \int_1^2 \frac{mc_p dT}{T}$$

$$\text{Similarly } (s_2 - s_1) = mc_p \ln \frac{T_2}{T_1}$$

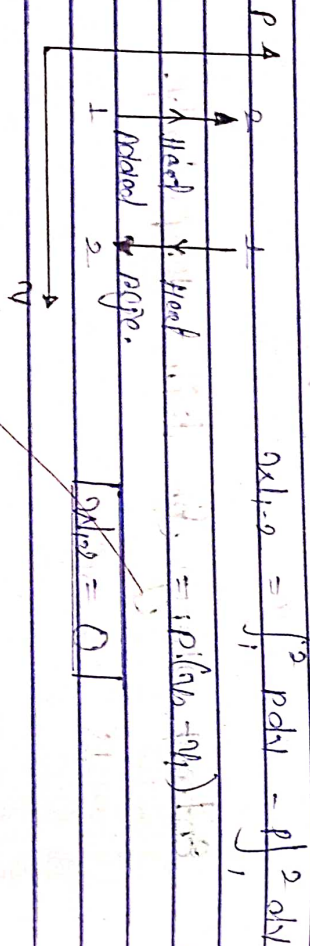
Note: Entropy change due to free change can be given as.

Assignment-2

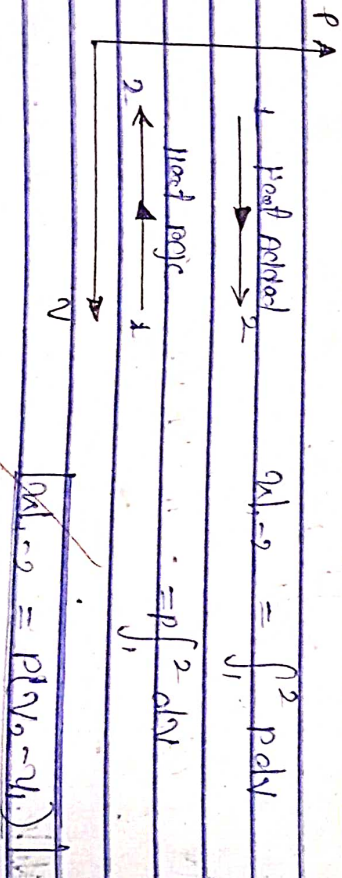
Q.1 Given an expression for work done in the following process.

Ans: Work done in the following process.

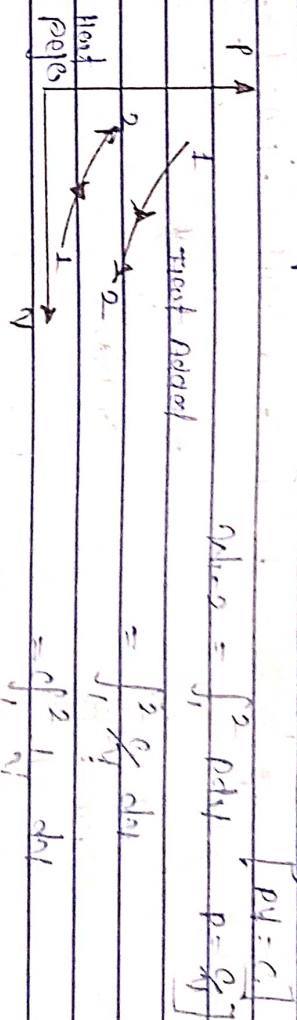
1. Constant volume:



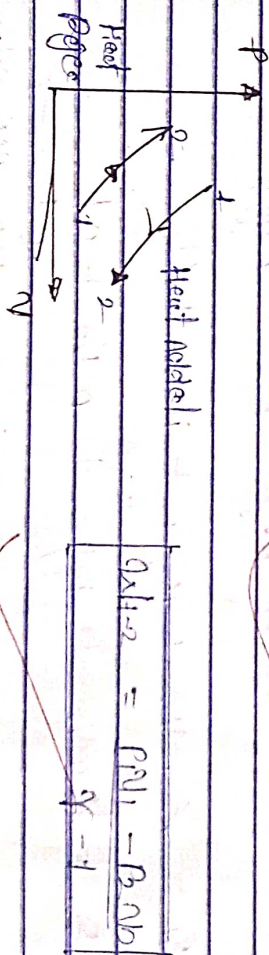
2. Constant pressure:



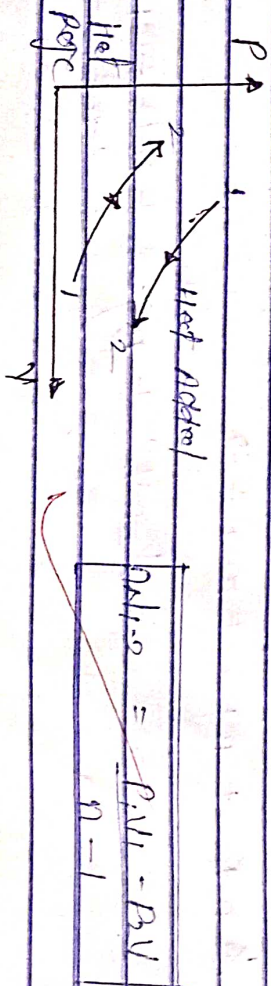
3. Constant temperature: (isothermal)



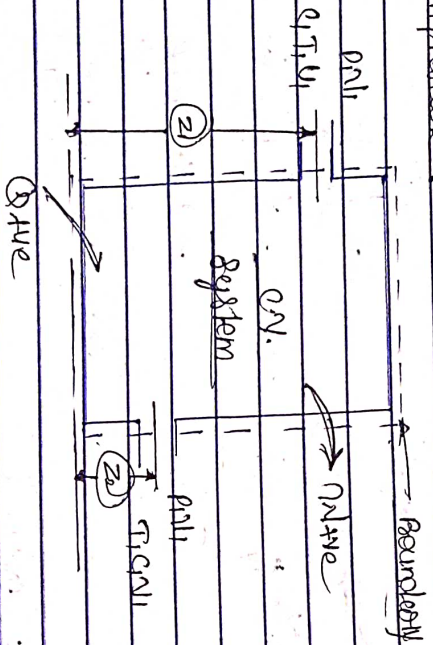
4. Adiabatic: ($pV^\gamma = c$)



5. Polytropic: ($pV^n = c$)



Q10m (2) Explain steady flow energy equation and its application to boiler, turbine, nozzle, compressor.



$$E = k.E + P.E + T.E + \text{Energy}$$

$$E_1 = k.mv^2 + mgz_1 + mv_1 + Q$$

$$E_2 = k.mv^2 + mgz_2 + mv_2 + Q$$

$$E_1 = E_2$$

$$k.mv^2 + mgz_1 + mv_1 + Q$$

$$= k.mv^2 + mgz_2 + mv_2 + mBv + mBv + mv$$

$$\Rightarrow m \left[P_1 + \frac{C^2}{2} + gz_1 + u_1 + v \right] + Q$$

$$= m \left[P_2 + \frac{C^2}{2} + gz_2 + u_2 + v \right] + W$$

$$\Rightarrow m \left[h_1 + \frac{C^2}{2000} + gz_1 \right] + 10$$

$$= m \left[h_2 + \frac{C^2}{2000} + gz_2 \right] + W$$

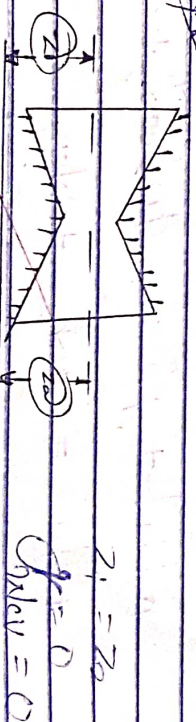
1st law of thermodynamic for open system steady flow energy equation.

$$\left[h_1 + \frac{C_1^2}{2000} + gz_1 + q = h_2 + \frac{C_2^2}{2000} + gz_2 + W \right]$$

- 918 Application:

1.1. Nozzle:

Nozzle is increase the velocity of fluid in expand of pressure or nozzle convert heat energy of fluid into kinetic energy.



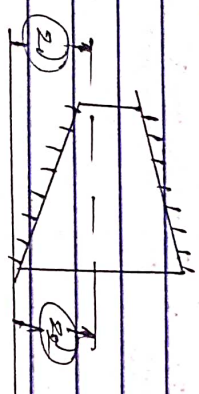
1st law

$$\left[h_1 + \frac{C_1^2}{2000} + \frac{q_1^{2d}}{600} \right] + \dot{q} = \left[h_2 + \frac{C_2^2}{2000} + \frac{q_2^{2d}}{600} \right] + \dot{q}_{out}$$

$$\left[h_1 + \frac{C_1^2}{2000} \right] = h + \frac{C_2^2}{2000}$$

2.) Turbine :

Turbine is a power producing device.



$$z_1 = z_2$$

$$q = 0$$

$$\dot{q}_{out} = +\dot{W}$$

1st law

(S.F.E.E) neglecting kinetic energy and potential energy changes

$$m[h_1] + \dot{q} = m[h_2] + \dot{q}_{out}$$

$$mh_1 = mh_2 + \dot{q}_{out}$$

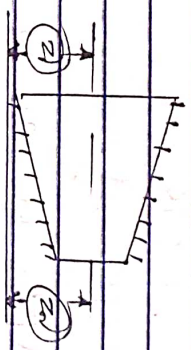
$$\dot{q}_{out} = mh_1 - mh_2$$

$$\dot{q}_{out} = m(h_1 - h_2) \quad \text{KJ/min}$$

$$\dot{q}_{out} = (h_1 - h_2) \quad \text{KJ/kg}$$

3.) Compressor :

Compressor is a power consuming device which is used to increase the pressure of the gas.



$$z_1 = z_2$$

$$q = 0$$

$$\dot{q}_{out} = -\dot{W}$$

1st law

(S.F.E.E) neglecting kinetic energy and potential energy changes

$$m[h_1] + \dot{q} = m[h_2] + \dot{q}_{out}$$

$$mh_1 = mh_2 - \dot{q}_{in}$$

$$\dot{q}_{in} = mh_2 - mh_1$$

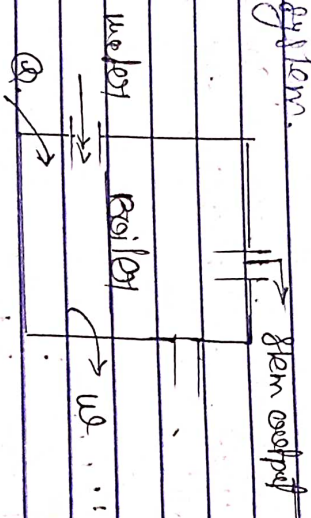
$$\dot{q}_{in} = m(h_2 - h_1) \quad \text{KJ/kg}$$

$$\dot{W}_{in} = h_2 - h_1 \quad \text{KJ/kg}$$



4.) Boiler :

A boiler is a device which supply heat to the water and generate steam in this system there is no any change in p.e. also there is no work done by the system.



$\Delta K.E. = 0$, $\Delta P.E. = 0$, $\Delta x = 0$

But, $h_1 + \frac{C_v^2}{2000} + \frac{g z_1}{1000} + \gamma = h_2 + \frac{C_v^2}{2000} + \frac{g z_2}{1000} + \gamma$

$h_1 + \gamma = h_2$

$\gamma = h_2 - h_1$ * γ

Ques 3)

A cyclic heat engine operates between a source temp. of 800°C and a sink temp. 30°C. what is the least rate of heat rejection



per unit output of the engine. Also find efficiency.

Sol: Given that

T_1 (Source) = 800°C = 1073 K

T_2 (Sink) = 30°C = 303 K

$Q_1 = 1 \text{ kJ/s}$

$n = 2$

$Q_{rej} = 2$

we know that

$n = 1 - \frac{Q_{rej}}{Q_1}$

Qm

$2 = 1 - \frac{T_2}{T_1}$

$n = 1 - \frac{303}{1073}$

1073

$n = 0.71$

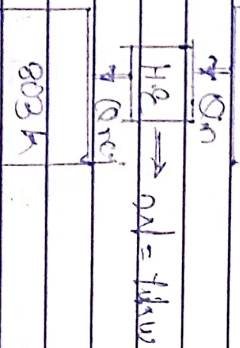
$n = 71\%$ Ans

and $n = 0.71$

com

$0.71 = 1$

Qm



$$\frac{Q_m}{0.71} = \frac{1}{1.408} \text{ mdfth.}$$

$$\text{and } Q_{\text{reg}} = 2.$$

$$Q_{\text{il}} = Q_m - Q_{\text{reg}}$$

$$1 = 1.408 - Q_{\text{reg}}$$

$$Q_{\text{reg}} = 1 - 1.408$$

$$[Q_{\text{reg}} = 0.408] \text{ mdfth. And}$$

Ques (4) Define Boyle's law & Charles law and prove that $pV = nRT$ for an ideal gas where R is the gas constant.

Boyle's law: Boyle's law states that the pressure of a gas is inversely proportional to its volume at constant temperature.

Charles law: Charles law states that the volume of a gas is directly proportional to its absolute temperature at constant pressure.

Boyle's law

$$P \propto \frac{1}{V}$$

$$P \propto \frac{1}{V}$$

$$\text{where } P = \text{pressure or force per unit area}$$

$$V = \text{volume or space}$$

Charles law:

Charles law states that the volume of a gas is directly proportional to its absolute temperature at constant pressure.

Boyle's law: Boyle's law states that the pressure of a gas is inversely proportional to its volume at constant temperature.

Boyle's law

$$P \propto \frac{1}{V}$$

$$P \propto \frac{1}{V}$$

by combination

$$P \propto \frac{1}{V}$$

$$\Rightarrow [P \propto \frac{1}{V}] \text{ equation (1)}$$

$$\text{where } P = \text{absolute pressure}$$

$$V = \text{volume}$$

$$n = \text{moles}$$

$$T = \text{absolute temperature}$$

$$R = \text{universal gas constant}$$

$$n = \text{no. of moles (n)} = \frac{\text{mass (m)}}{\text{molecular weight (M)}}$$

$$\text{molecular weight (M)}$$

$$n = \frac{m}{M} \Rightarrow m = nM$$

for eqn (1)

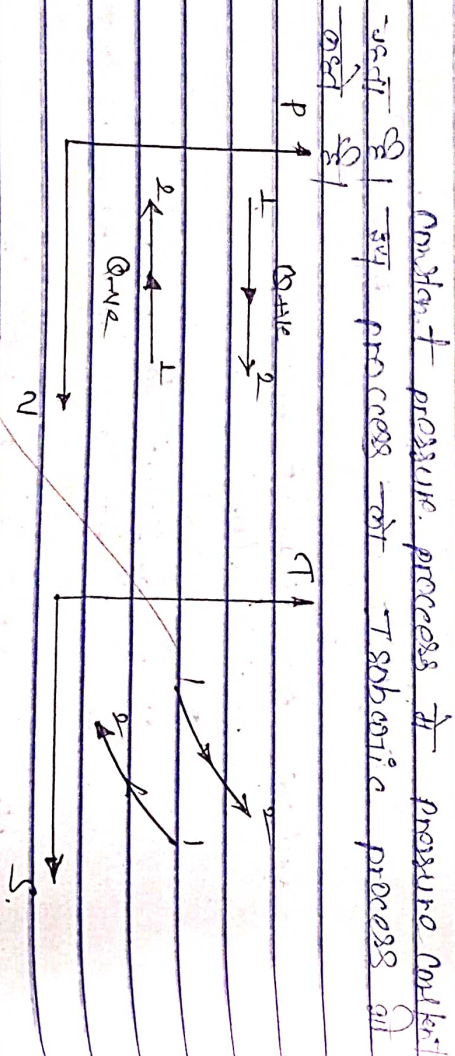
$$PV = nRT$$

$$\Rightarrow PV = nRT$$

where $nMR = R$ universal gas constant

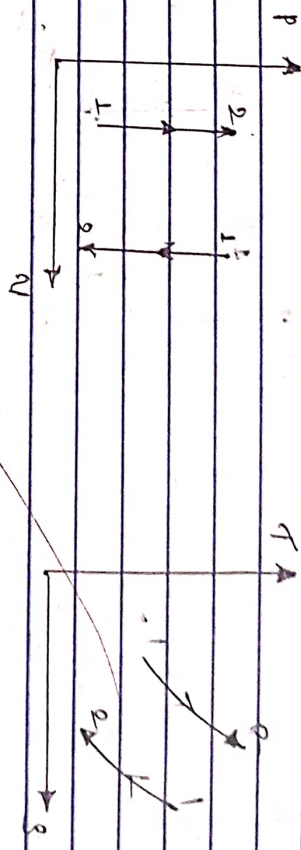
Ques (5) explain Ideal gas process: Isobaric, Isochoric, Isothermal, Adiabatic and polytropic with P-V & T-S diagram.

1. Isobaric or constant pressure:

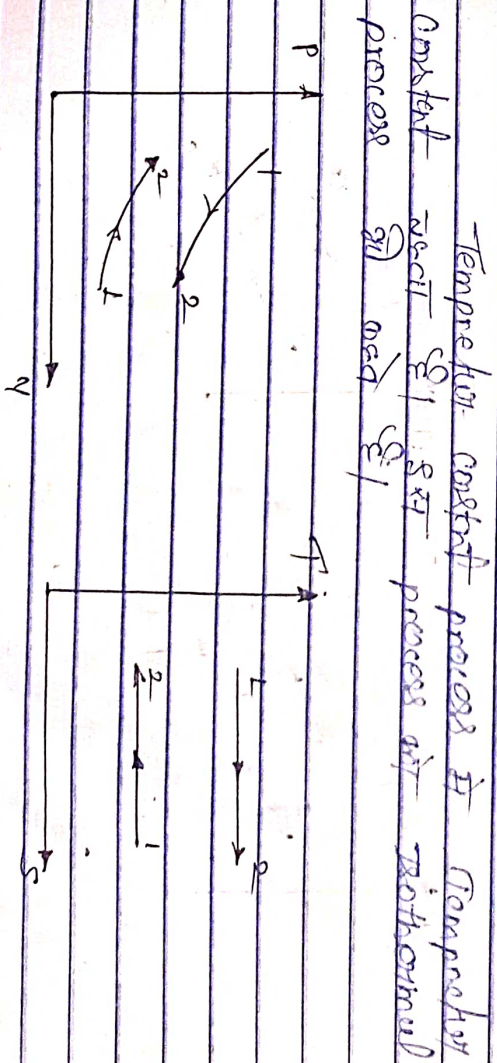


2. Isochoric or constant volume:

constant volume process or volume constant

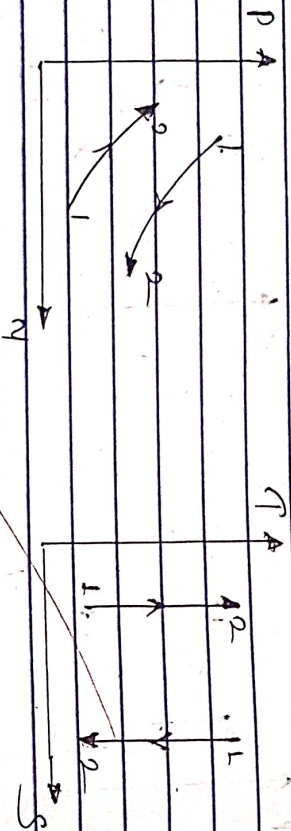


3. Isothermal or temperature constant:

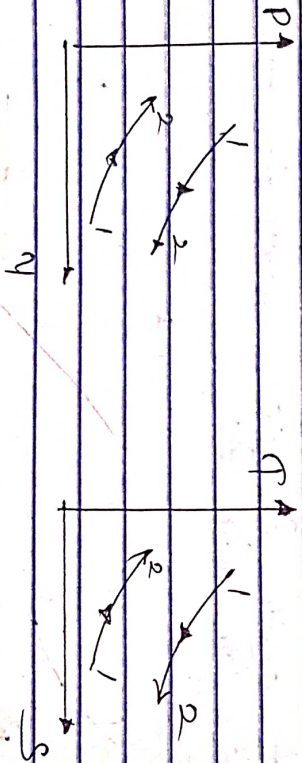


4.) Isochoric Process:

Isochoric process is $T \sim V$
 alignment is $\sim$ vertical axis V and T
 and process is adiabatic process in V and T



5.) Polytropic process:



Q.1) 0.1 m³ of air at a pressure of 1.5 bar is expanded isothermally to 0.5 m³ and heat supplied during the process.

Self Given Proof:

$$V_1 = 0.1 \text{ m}^3$$

$$V_2 = 0.5 \text{ m}^3$$

$$P_1 = 1.5 \text{ bar}$$

$$P_2 = ?$$

$$P_1 V_1 = mRT_1 \quad (1)$$

$$P_2 V_2 = mRT_2 \quad (2)$$

$$\Rightarrow P_1 V_1 = P_2 V_2$$

$$\Rightarrow P_2 = \frac{P_1 V_1}{V_2}$$

$$\Rightarrow P_2 = \frac{1.5 \times 0.1}{0.5}$$

$$\Rightarrow P_2 = 0.3 \text{ bar}$$

and Heat transfer.

$$Q_{1-2} = \frac{P_1 V_1 \ln V_2}{\gamma}$$

$$Q_{1-2} = \frac{1.5 \times 10^2 \times 0.1 \ln (0.5)}{1.4}$$

$$Q_{1-2} = -24.141 \text{ kJ}$$

~~35/12/23~~

Unit - 02

IC Engine
(Internal Combustion Engine)

Chemical energy of fuel	→	Combustion	→	Heat	→	Expand work
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Engine Nomenclature:

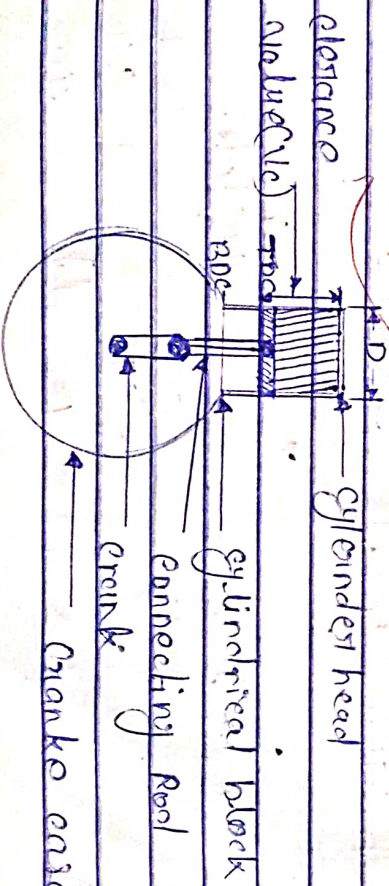
1. Dead centre: location where piston reverses its direction.

1. Top dead centre (TDC)

3. Bottom dead centre (BDC)

1. TDC: when piston is nearest to the cylinder head.

2. BDC: when the piston is farthest from the cylinder.



When cylinder is add top dead centre then valve of the cylinder is minimum and this minimum value is known as clearance value.

3.) ^(P) Bore: inner diameter of cylinder.

3.1 Stroke (L): distance between TDC and BDC.

4.) ^(C) Swept Volume: Volume displaced by the piston when it moves from TDC to BDC.

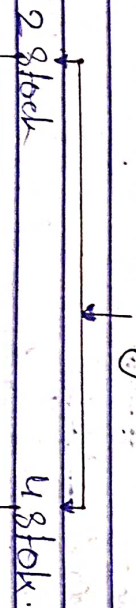
$$V_s = \frac{\pi}{4} D^2 L$$

Note: One revolution of Crank = 2 stroke of the piston.

$$L = 2r$$

$$R = \text{Crank radius}$$

Classification of I.C. engine :-



S.T. (Petrol) C.T. (Diesel) ST (Petrol) CT (Diesel)

where,

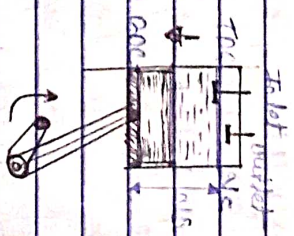
S.T. = Spark ignition
C.T. = Compression ignition

Working of 4 stroke engine :-

Heat required 4 stroke of the piston to complete one cycle of operation in the engine cylinder. The 4 stroke of an engine sucking fuel - air mixture (petrol mixture) with proper quantity of air in the compressed form as charge.

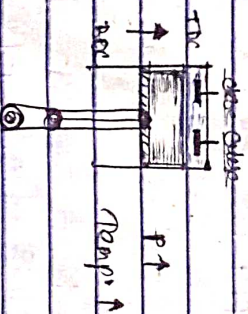
1. Suction stroke:

In this stroke inlet valve opens and charge is sucked into the cylinder as the piston moves downward from TDC. It continues till the piston reaches BDC.



2. Compression stroke:

In this stroke both the inlet and exhaust valves are closed and the charge is compressed as the piston moves upward from BDC to TDC as a



result at compression. The pressure and temperature of the charge increases considerably. This completes the combustion at the crankshaft.

3. Expansion stroke:

Or working stroke:

During compression stroke, the piston rises. The charge is ignited with the help of spark plug at ending.

Increases the pressure and temperature of the product at combustion but the piston practically remains stationary due to the high pressure.

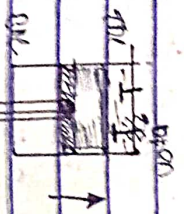
The piston is pulled down with a stroke force the build the gases expand due to high speed expansion.

During this expand sum of heat energy produced and therefore into mechanical work during working stroke both the valves are closed and piston moves from TDC to BDC.

4. Exhaust stroke:

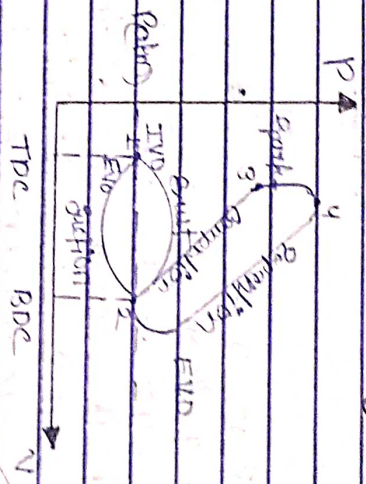
During this stroke the

exhaust valve is open as piston moves from BDC to TDC. The pressure of piston pushes out the



product of combustion from the engine cylinder and are exhaust through the exhaust valve into the atmosphere. This completes the cycle and the engine cylinder is ready to start the charge again.

Actual Indicator diagram:



The above diagram shows the actual indicator diagram of the engine cycle.

TDC = Top Dead Center

BDC = Bottom Dead Center

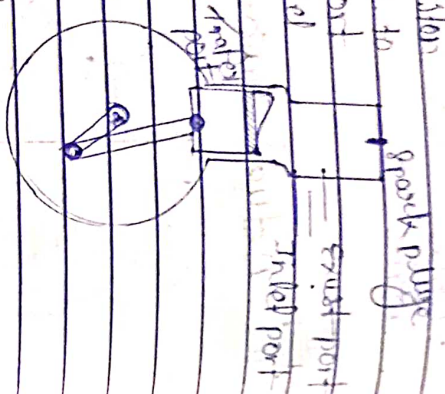
IGN = Ignition

EXP = Expansion

Valving of 2-stroke Cycle:

1. Suction stroke:

In this stage the piston while going down to bottom BDC to TDC sweeps both the transfer port on exhaust port the free air fuel mixture flow into the engine cylinder from the crank case.



2. Compression stroke:

In this stage the piston while moving a first round the transfer port and then exhaust port after that the fuel is compressed as the piston moves up toward TDC. In this stage the inlet port open and fresh fuel air mixture inlet into crank case.

3. Expansion stroke:

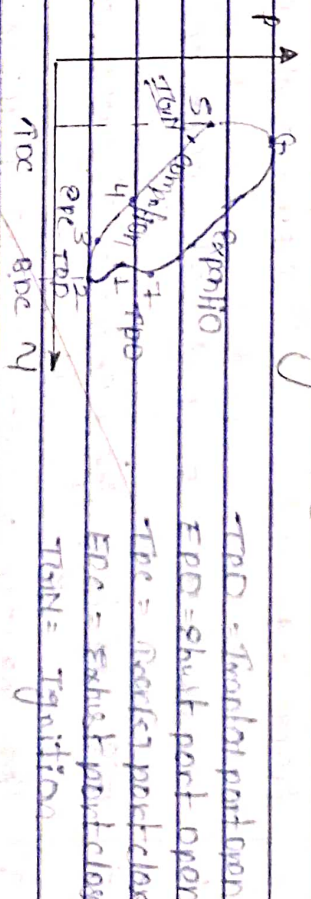
Shortly before the piston reaches BDC the charge is cylinder with the help of spark plug due to which in pressure the piston is forced down toward the heat burns gases expand due to high speed of piston down this.

pressure zone of the heat energy produce is transfer into mechanical work.

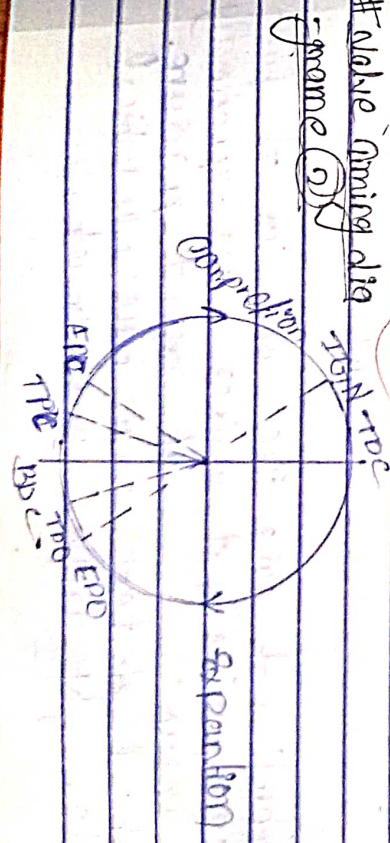
4. Exhaust stroke:

In this stage the exhaust port is open as the piston moves down toward the pressure of combustion from the engine cylinder are exhaust through the exhaust port into the atmosphere is complete the cycle and the engine cylinder is ready to start the charge again.

Actual Indicator diagram:



Valve timing diagram



Difference between S.T. and C.T. engine:

S.No.	S.T.	C.T.
1.	Petrol engine draws a mixture of fuel and air during suction stroke.	A diesel engine draws only air during suction stroke.
2.	The charge is ignited the help of spark plug.	The compression at the end of compression stroke compresses air is usually high to ignite the fuel. (About 600°C)
3.	Compression ratio approximately from 16 to 18.	Compression ratio approximately from 15 to 25.
4.	It works on Otto cycle.	It works on Diesel cycle.
5.	These are high speed engine. They are low speed engine.	
6.	The maintenance cost is less.	The maintenance cost is more.
7.	The combustion of fuel takes place approximately at constant volume.	The combustion of fuel takes place approximately at constant pressure.
	Exhaust valve is closed, exhaust stroke, mechanical efficiency, 10%.	Exhaust valve is closed, exhaust stroke, mechanical efficiency, 10%.

Indicated power:

The indicated power is the power actually developed by the engine cylinder.

Single cylinder	T.P. = $P_m \times L \times A \times n$
	GO

for multiple cylinder	I.P. = $k \cdot P_m \times L \times A \times n$
	GO

where k = No. of cylinder

P_m = Actual mean effective pressure

L = length of stroke

A = Area of piston

N = Speed of the engine in rpm

n = No. of working stroke/cycle

where at $n = N$ (2 stroke)

$n = \frac{N}{2}$ (4 stroke)

Efficiency of S.T. engine:

It is the ratio of work done to the energy supply to an engine.

1. Mechanical efficiency:

It is the ratio of brake

power at the indicated power

$$\eta_m = \frac{B.P.}{I.P.}$$

$$B.P = T.P - f.p$$

where $B.P = \text{Break power}$

$T.P = \text{Indicated power}$

$f.p = \text{friction power}$

3) Overall efficiency:

Let R be the ratio of work done at the crank shaft in a given time to the energy supplied by the fuel during the same time.

Let $W.P = \text{mass of fuel consumed}$
 $CV = \text{calorific value of fuel}$

$$\eta_o = \frac{B.P \times 3600}{W.P \times CV}$$

a) Thermal efficiency:

Let η is the ratio of actual volume of charge admitted during the suction stroke to the swept volume of the piston.

Break power:

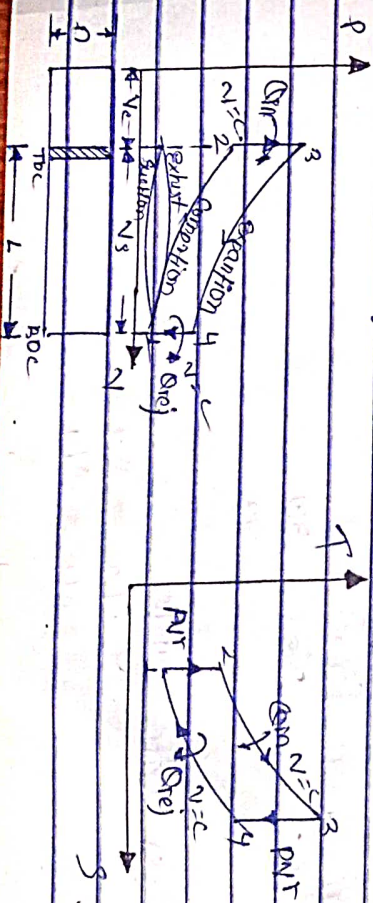
The break power is the power available at the crank shaft. The break power at T.C. engine is usually measured by means of break mechanism.

$$B.P = \frac{2\pi N T}{60}$$

where $T = \text{Torque in N-m}$

Air standard Otto cycle:

Air cycle is system of gas gain heat at constant volume or Otto cycle used.



Process 2-3 = Constant volume heat addition

$$Q_{in} = m C_v (T_3 - T_2)$$

Process 4-1 = Constant volume heat rejection

$$Q_{rej} = m C_v (T_4 - T_1)$$

Efficiency:

$$\eta = 1 - \frac{Q_{rej}}{Q_{in}} = 1 - \frac{m C_v (T_4 - T_1)}{m C_v (T_3 - T_2)}$$

$$\eta = 1 - \frac{(T_4 - T_1)}{(T_3 - T_2)}$$

$$\eta = 1 - \frac{T_1 \left(\frac{T_4}{T_1} - 1 \right)}{T_2 \left(\frac{T_3}{T_2} - 1 \right)}$$

equation (1)

Compression ratio (r)

$$r = \frac{V_2 + V_3}{V_1} = \frac{V_1}{V_2}$$

Expansion ratio (r_e)

$$r_e = \frac{V_4}{V_3}$$

For Otto cycle

$$r_2 = r_3$$

$$r_1 = r_4$$

So, $[r = r_e]$

Process 1-2 = Reversible Adiabatic Compression

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

Process 3-4 Reversible adiabatic expansion

$$\frac{T_3}{T_4} = \left(\frac{V_4}{V_3} \right)^{\gamma-1} = (r)^{\gamma-1}$$

$$\Rightarrow \frac{T_2}{T_1} = \frac{T_3}{T_4}$$

$$\Rightarrow \frac{T_4}{T_1} = \frac{T_3}{T_2}$$

from equation (1)

$$\eta = 1 - \frac{T_1 \left(\frac{T_4}{T_1} - 1 \right)}{T_2 \left(\frac{T_3}{T_2} - 1 \right)}$$

Temperature formula

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

$$\eta = 1 - \frac{1}{(r)^{\gamma-1}}$$

Mean effective pressure (M_{ep})

$$M_{ep} = \frac{W_{net}}{V_{sup} - V_{net}} = \frac{W_{net}}{V_{net}}$$

$$\text{Compression } M_{ep} = \frac{W_{net}}{V_1 - V_2}$$

$$\text{Expansion } M_{ep} = \frac{W_{net}}{V_4 - V_3}$$

Option:- In an Otto cycle the temperature at the beginning and end of heating the compression and 816 K and 596 K.

$$\text{Sol: } T_1 = 816 \text{ K} \quad T_2 = 596 \text{ K}$$

$$n = ? \quad \gamma = ?$$

Compression ratio

$$(\gamma)^{\gamma-1} = \frac{P_2}{P_1}$$

$$\frac{P_2}{P_1}$$

$$(\gamma)^{1.4-1} = \frac{596}{816}$$

$$316$$

$$\gamma = \left(\frac{596}{816} \right)^{\frac{1}{0.4}}$$

$$\gamma = 4.88$$

Ans

$$\eta = \frac{1-1}{(\gamma)^{\gamma-1}}$$

$$\eta = \frac{1-1}{(4.88)^{1.4-1}}$$

$$\eta = \frac{1-1}{(4.88)^{0.4}}$$

$$\eta = 0.47$$

$$\eta = 47\% \quad \text{Ans}$$

Ques

An engine working on the Otto cycle is supplied with air at 0.1 MPa, 35°C. The compression ratio is 8. Heat supplied is 0.100 kJ/kg. Calculate the maximum pressure and temperature at cycle, the cycle efficiency and the mean effective pressure. Take $R = 0.287 \text{ kJ/kg} \cdot \text{K}$, $\gamma = 1.4$.

Sol:-

$$\text{Given } P_1 = 0.1 \text{ MPa}$$

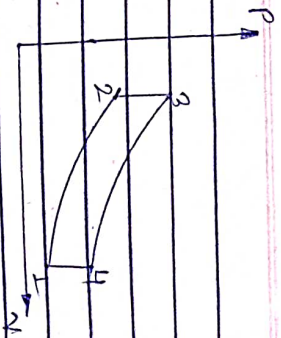
$$P_2 = 0$$

$$T_1 = 35^\circ\text{C} + 273 = 308 \text{ K} \quad T_2 = ?$$

$$\gamma = 1.4$$

$$n = 1.4$$

$$Q_{in} = 0.100 \text{ kJ/kg} \cdot \text{K} \quad m_{ep} = ?$$



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

$$T_2 = (8)^{1.4-1} \times 308$$

$$T_2 = 707.5 \text{ Kelvin}$$

$$Q_{in} = m C_v (T_3 - T_2)$$

$$(P V_1)^\gamma = (P V_2)^\gamma$$

$$9100 = 1 \times 0.719 (T_3 - 707.5)$$

$$\left(\frac{V_1}{V_2}\right)^\gamma = \left(\frac{P_2}{P_1}\right)$$

$$T_3 = 9100 + 707.5$$

$$1 \times 0.719$$

$$(8)^{1.4} = \frac{P_2}{0.1}$$

$$T_3 = 3632.29 \text{ Kelvin}$$

$$P_2 = 1.84 \text{ MPa}$$

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

$$V = 1 - 1$$

$$(\frac{P}{P_1})^{\frac{1}{\gamma-1}}$$

$$707.6 = \left(\frac{P_2}{0.1}\right)^{\frac{1.4-1}{1.4}}$$

$$= 1 - \frac{1}{(8)^{1.4-1}}$$

$$\left(\frac{707.6}{308}\right)^{\frac{1.4}{1.4-1}} \times 0.1 = P_2$$

$$= 0.5647$$

$$P_2 = 1.84 \text{ MPa}$$

$$= 56\%$$

$$V = V_{net}$$

$$Q_{in}$$

$$0.5647 = \frac{Q_{net}}{9100}$$

$$Q_{net} = 1195.47$$

$$P V_1 = m R T_1$$

$$V_1 = \frac{m R T_1}{P_1}$$

$$V_1 = 1 \times 0.287 \times 308$$

$$0.1 \times 10^3$$

$$= 1195.47$$

$$0.88 - 0.11$$

$$V_1 = 0.88 \text{ m}^3$$

$$m_{cp} = 1540.09$$

$$P V_2 = m R T_2$$

$$V_2 = \frac{m R T_2}{P_2}$$

$$V_2 = 1 \times 0.287 \times 707.5$$

$$1.84 \times 10^3$$

$$V_2 = 0.11 \text{ m}^3$$

$$m_{cp} = \frac{Q_{net}}{V_1 - V_2}$$

Q. An engine working on the Otto cycle as a cylinder diameter of 150 mm and a stroke of 225 mm the clearance volume is $1.25 \times 10^{-3} \text{ m}^3$ find the air standard efficiency of the engine and $\gamma = 1.4$

$$\text{Soln: Given data } V_{cl} = 1.25 \times 10^{-3} \text{ m}^3$$

$$D = 150 \text{ mm} = 0.150 \text{ m}$$

$$L = 225 \text{ mm} = 0.225 \text{ m}$$



$C_{M1} = 6.118$



$$r = \frac{V_2 + V_3}{V_1} = \frac{(3.936 + 1.25) \times 10^{-3}}{1.25 \times 10^{-3}}$$

$$V_3 = \frac{\pi}{4} D^2 \times h \quad r = 4.18$$

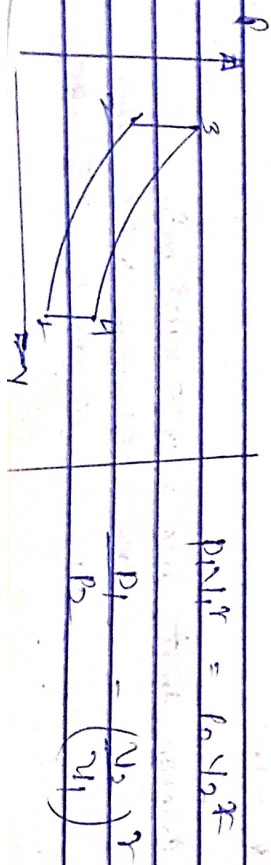
$$V_3 = \frac{\pi}{4} \times (0.15)^2 \times 0.225 \text{ and } n = \frac{1-1}{(4.18)^{0.4}}$$

$$V_3 = 3.936 \times 10^{-3} \text{ m}^3 \quad n = 0.4356$$

$$n = 43.56\%$$

Q10:- In Otto cycle air at 1 bar and 290K is compressed isentropically and the pressure is 15 bar the heat is added at constant volume until the pressure rises to 40 bar calculate the air standard efficiency and mp of process for the cycle.

Sol: Given $P_1 = 1 \text{ bar}$ $T_1 = 290 \text{ K}$
 $P_2 = 15 \text{ bar}$ $P_3 = 40 \text{ bar}$



$$P_1 V_1^r = P_2 V_2^r$$

$$\frac{P_1}{P_2} = \left(\frac{V_2}{V_1} \right)^r$$

$$r = \frac{V_1}{V_2} = \left(\frac{P_2}{P_1} \right)^{\frac{1}{\gamma}} \quad n = \frac{1-1}{(r)^{\gamma-1}}$$

$$r = \left(\frac{15}{1} \right)^{\frac{1}{1.4}} \quad n = \frac{1-1}{(6.91)^{1.4-1}}$$

$$r = 6.91$$

$$n = 0.5384$$

Process 1-2

$$\frac{T_2}{T_1} = (r)^{\gamma-1}$$

$$V_1 n = m R T_1$$

$$T_2 = (6.91)^{1.4-1} \times 290$$

$$V_1 = 1.290 \times 0.287 \times 10^{-3}$$

$$T_2 = 608.33 \text{ K}$$

$$V_1 = 0.832 \text{ m}^3$$

Process 2-3

$$\frac{P_2}{P_3} = \left(\frac{V_3}{V_2} \right)^{\gamma}$$

$$P_2 V_2 = m R T_2$$

$$T_3 = \frac{P_3}{P_2} \times T_2$$

$$V_2 = 1.290 \times 0.287 \times 0.33$$

$$T_3 = 1675.55 \text{ K}$$

15

$$Q_{in} = m C_v (T_3 - T_2)$$

$$= 1 \times 0.708 (1675 - 608)$$

$$T_3 = 1675.55 \text{ K} \quad = 751.05 \text{ K}$$

$$Q_{in,net} = \frac{n \times C_{in}}{C_{eff}} \quad \cdot \quad mcp = \frac{Q_{in,net}}{V_1 - V_2}$$

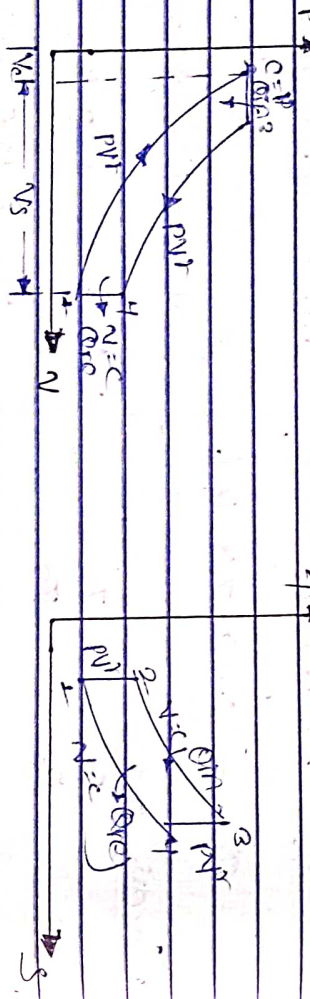
$$= 0.5395 \times 751.05 = 404.44$$

$$= 404.44$$

$$mcp = 566.27 \text{ kPa}$$

$$mcp = 568 \text{ bar}$$

Air standard Diesel cycle:-



Process 2-3 Constant pressure heat addition

$$Q_{in} = mcp (T_3 - T_2)$$

Process 4-1 Constant volume heat rejection

$$Q_{rej} = mcv (T_4 - T_1)$$

$$\text{Efficiency } (\eta) = \frac{Q_{in} - Q_{rej}}{Q_{in}}$$

$$= \frac{1 - Q_{rej}}{Q_{in}}$$

$$C_{in}$$

$$\eta = 1 - mcv (T_4 - T_1)$$

$$mcp (T_3 - T_2)$$

$$\left[\because r = \frac{C_p}{C_v} \right]$$

$$\eta = 1 - \frac{1}{r} \left(\frac{T_4 - T_1}{T_3 - T_2} \right)$$

$$r = \left(\frac{T_3 - T_2}{T_4 - T_1} \right)$$

Equation (1)

Compression ratio (r)

$$r = \frac{V_1}{V_2} = \frac{V_4 + V_5}{V_3}$$

Cut-off ratio (r_c)

$$r_c = \frac{V_3}{V_2}$$

$$V_2$$

Expansion ratio (r_e)

$$r_e = \frac{V_4}{V_3} = \frac{V_1}{V_3}$$

$$V_3$$

$$r_e = \frac{V_1}{V_2} \times \frac{V_2}{V_3}$$

$$V_2$$

$$\left[\begin{matrix} T_c = r \\ r_c \end{matrix} \right]$$

Process 1-2 poly. adiabatic compression

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

$$T_2 = T_1 \times (r)^{\gamma-1} \quad \text{--- (I)}$$

Process 2-3 (P = C)

$$\frac{T_3}{T_2} = \frac{V_2}{V_3} = (r_c)$$

$$T_3 = T_2 \times (r_c)$$

$$T_3 = T_1 \times (r)^{\gamma-1} \cdot r_c \quad \text{--- (II)}$$

Process 3-4 poly. adiabatic expansion

$$\frac{T_3}{T_4} = \left(\frac{V_4}{V_3} \right)^{\gamma-1} = (r)^{\gamma-1}$$

$$\frac{T_3}{T_4} = (r_c)^{\gamma-1}$$

$$\Rightarrow T_4 = T_3 \times (r_c)^{\gamma-1}$$

$$T_4 = T_1 (r)^{\gamma-1} \times r_c \times (r_c)^{\gamma-1}$$

$$T_4 = T_1 \times r_c^{1+\gamma-1}$$

$$T_4 = T_1 \times (r_c)^\gamma$$

from eqn (I)

$$\text{Hence } \left[n = 1 - \frac{(T_4 - T_1)}{r (T_3 - T_2)} \right]$$

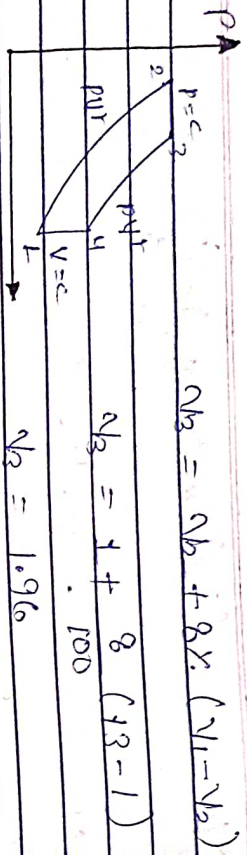
$$n = 1 - \frac{(T_1 r_c^\gamma - T_1)}{r (T_1 \times (r_c)^\gamma \times (r)^{\gamma-1} - T_1 \times (r)^{\gamma-1})}$$

$$\text{Hence } \left[n = \frac{1}{r \times (r_c)^{\gamma-1} / (r_c - 1)} \right]$$

Ques:- In a diesel engine the compression ratio is 13:1 and the fuel is cut off at 8% of the stroke find the air standard efficiency of the engine take r for air is 1.4

Sol:-

$$\text{Given } \gamma = \frac{V_1}{V_2} = \frac{13}{1} \Rightarrow 13$$



$$V_3 = V_2 + 8\% (V_1 - V_2)$$

$$V_3 = 1 + \frac{8}{100} (1.3 - 1)$$

$$V_3 = 1.096$$

$$P = 1 - (1.96)^{1.4} (1)$$

$$1.4 \times 1.304 (1.96 - 1)$$

$$\eta = 58.3\%$$

Ques 1- In an ideal diesel cycle the temperature at the beginning and in of compression are 57°C and 140°C respectively. The temperature at the beginning and of expansion are 1950°C and 840°C respectively. Determine the ideal efficiency of the cycle. Take $\gamma = 1.4$

If the compression ratio is 14 at the pressure at the beginning of the compression is 1 bar calculate the maximum pressure in the cycle

8-11 Given that

$$T_1 = 57^\circ\text{C} + 273 = 330 \text{ Kelvin}$$

$$T_2 = 140^\circ\text{C} + 273 = 413 \text{ Kelvin}$$

$$T_3 = 1950^\circ\text{C} + 273 = 2223 \text{ Kelvin}$$

$$T_4 = 840^\circ\text{C} + 273 = 1113 \text{ Kelvin}$$

$$P_1 = 1 \text{ bar and } \gamma = 1.4$$

$$P_2 = ? \text{ and } \eta = ?$$

$$P_1 V_1^\gamma = P_2 V_2^\gamma$$

$$\left(\frac{V_1}{V_2}\right)^\gamma = \frac{P_2}{P_1}$$

$$P_2 = (1.4)^{1.4} \times 1$$

$$P_2 = 40.23 \text{ bar}$$

$$\eta = 1 - \left(\frac{T_4 - T_1}{T_3 - T_1}\right)$$

$$1.4 \times (2223 - 846)$$

$$P_2 = (1.4)^{1.4} \times P_1$$

$$\eta = 56.68\%$$

$$P_2 = (1.4)^{1.4} \times 1$$

$$\eta = 56.68\%$$

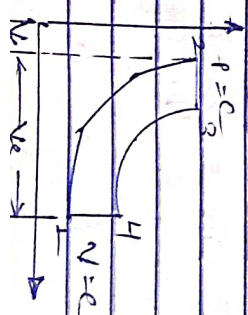
Ques 1- An ideal diesel cycle engine has a diameter 180 mm and stroke 200 mm. The clearance volume is 10% of the swept volume determine the compression ratio (γ) and the air standard efficiency of the engine if the cut off takes place at 6% of the stroke.

8-11 Given that

$$\text{Diameter } 180 \text{ mm}$$

$$\text{Stroke } 200 \text{ mm}$$

$$V_c = 10\% \text{ of } V_s$$





$$V_B = \frac{\pi D^2 L}{4}$$

$$V_B = \frac{\pi (0.180)^2 \times 0.900}{4}$$

$$V_B = 3.53 \times 10^{-3} \text{ m}^3$$

$$V_C = 10\% V_B$$

$$= \frac{10}{100} \times 3.53 \times 10^{-3}$$

$$V_C = 0.353 \times 10^{-3} \text{ m}^3$$

$$V = V_B + V_C$$

$$V = (3.53 + 0.353) \times 10^{-3}$$

$$V = 3.88 \times 10^{-3}$$

$$V_2 = V_1 + 0.565$$

$$V_2 = 4.45 \times 10^{-3}$$

$$V_B = V_B + 0.5(V_1 - V_2)$$

$$V_B = 0.353 + 0.5(3.53)$$

$$V_B = 0.565 \times 10^{-3} \text{ m}^3$$

$$n = \frac{1 - (V_C/V_1 - 1)}{V_1 - 1}$$

$$= \frac{1 - (0.16^{1.4} - 1)}{1.4 \times 11^{1.4} - 1}$$

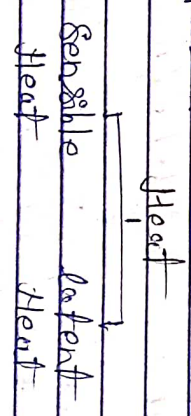
$$= 57.53\%$$

Unit - 03

Pure Substances

Pure substance :-

A substance that has fixed chemical composition through out irrespective of phase is called pure substance such as water, air and nitrogen.



Sensible heat :- heat associated with temperature change.

$$[Q = mc\Delta T]$$

$$[Q = 1 \times 4.18 (100 - 0)]$$

$$Q = 418 \text{ kJ/kg}$$

Latent heat :- heat associated with phase change

$$[Q = mL]$$

$$[Q = 1 \times 2256]$$

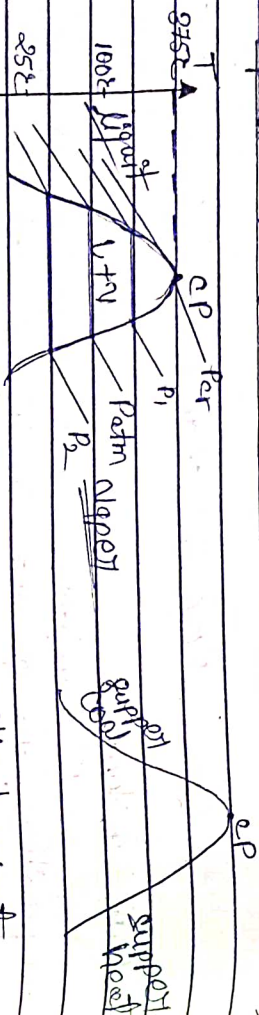
$$Q = 2256 \text{ kJ/kg}$$

(TCE) $\rightarrow$ water

$$Q_1 = 1 \times 395$$

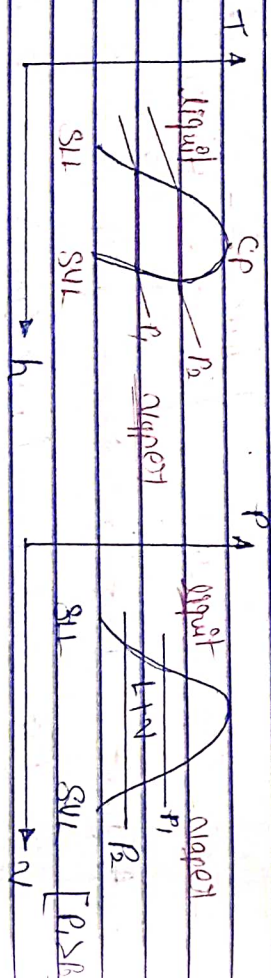
$$Q_2 = 325 \text{ kJ/kg}$$

phase transition motion of pure substance (water)

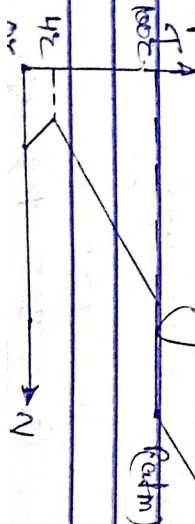


CP = Critical point
 SL = Saturated liquid line
 SVL = Saturated vapor line
 $P_1 > P_{atm} > P_2$

Critical point: Critical point is a point where saturated liquid line and saturated vapor line meet the slope of upper arm of critical point zero (0)



Temp. - Volume diagram :-

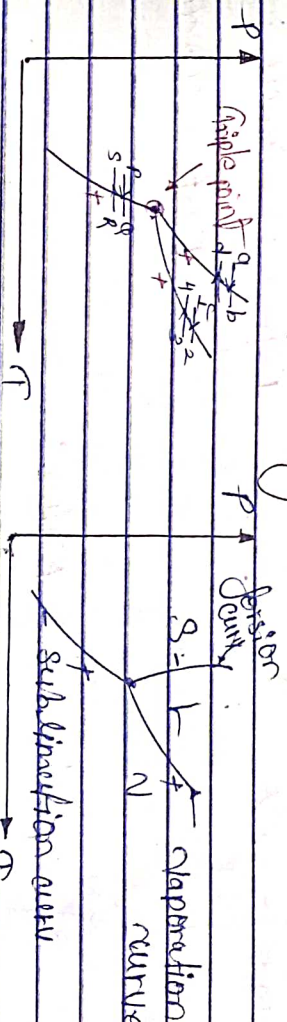


Note :-

Ice water
 Ice is float on water

Note: Volume of water is minimum at 4°C and we know that density is reciprocal of specific volume so at 4°C temperature density of water is maximum

Pressure - Temp. diagram :-



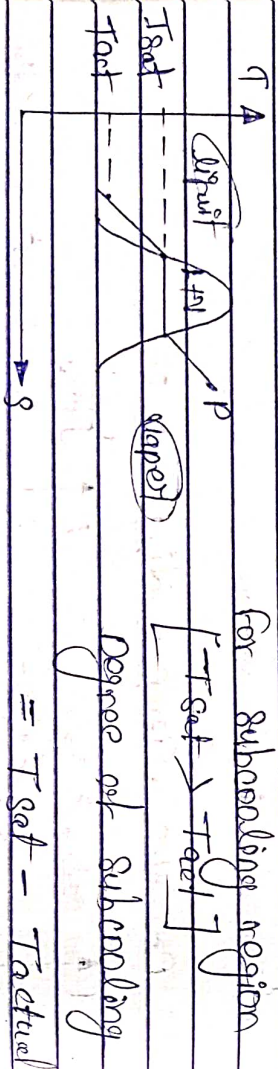
Normal substance N-S sublimation

- a → b : melting (liquidification)
- c → d : freezing (solidification)
- 1 → 2 : Vaporization
- 3 → 4 : Condensation
- R → Q : Sublimation
- R → S : Ablimation

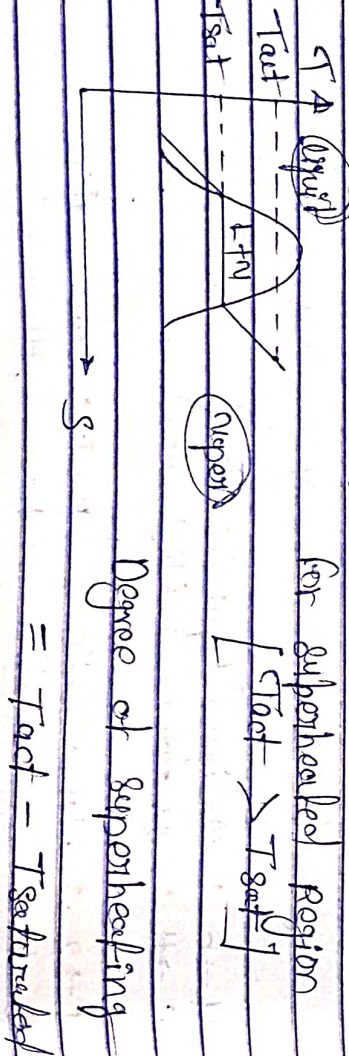
Any substance if it is heated below its triple point pressure than solid directly converted into vapor and this process is known as sublimation.

Nucleus Region on T-S diagram:-

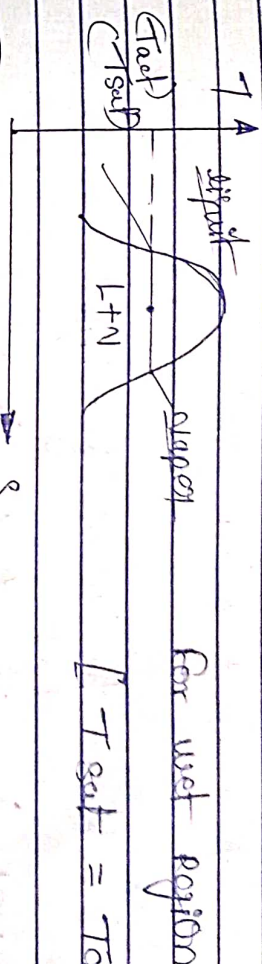
1.) Subcooled Region:



2) Superheated Region:



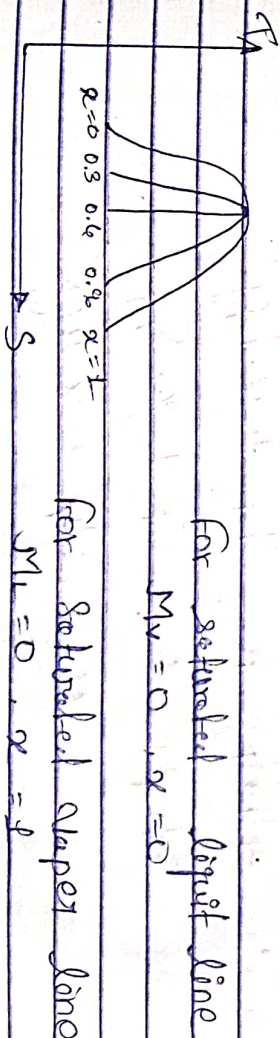
3.) Wet Region:



4.) Dryness fraction:

It is defined as the ratio of mass of vapor to the total mass of mixture (wet steam).

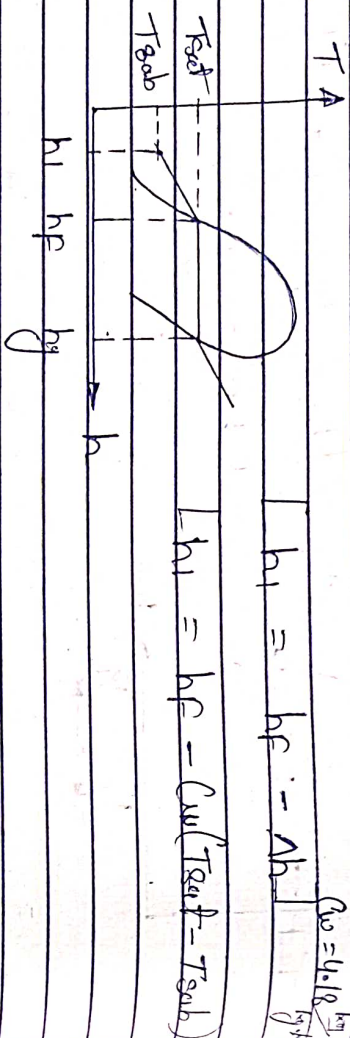
$$x = \frac{M_v}{M_L + M_v}$$



Note: Dryness fraction is also known as quality of steam.

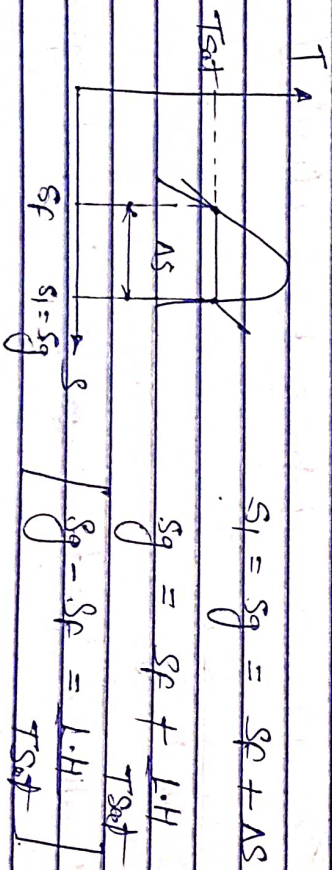
$$\text{Dryness fraction} = \frac{M_v}{M_L + M_v}$$

Case IV: when point is on sub-cooled region:

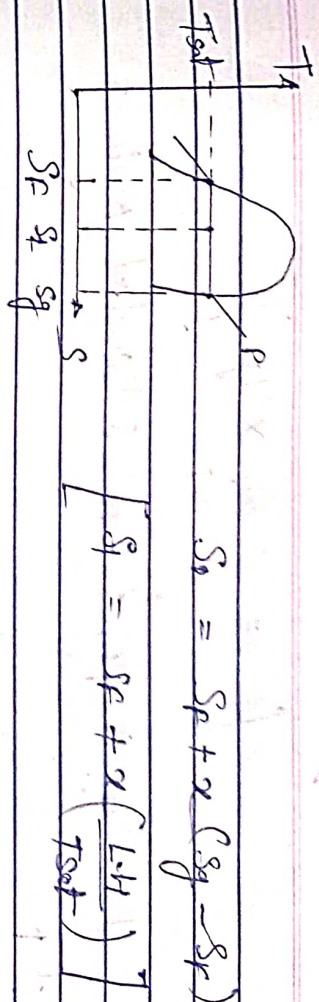


Entropy of various region:

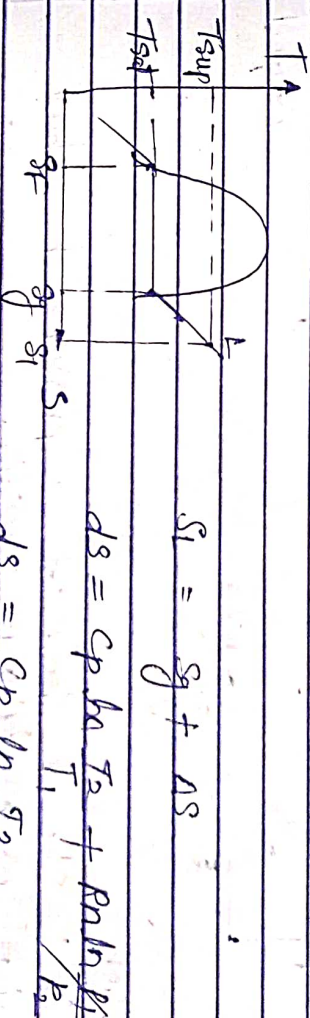
Case I: when point is saturated vapor line:



Case II: when point is wet region:

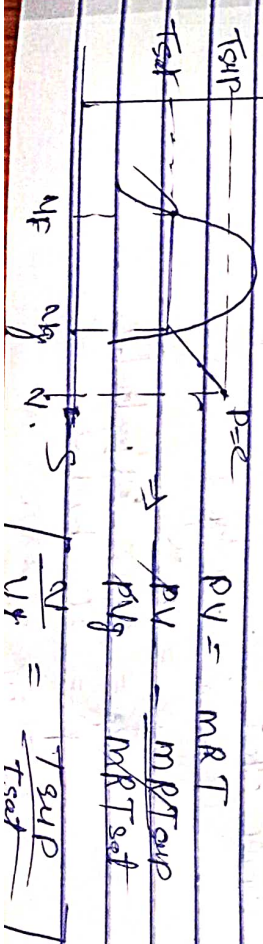


Case III: when point is in superheated region:



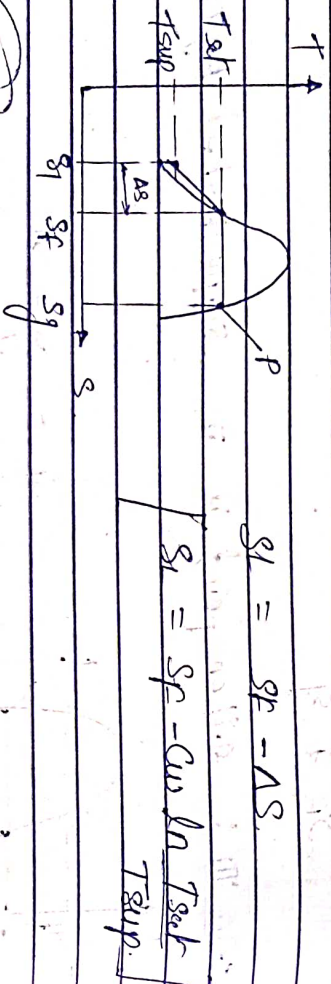
$s_l = s_g + C_{wl} \ln \frac{T_{sup}}{T_{sat}}$

Case IV: (continued) when point on subcooled region:



$$N = T_{\text{sup}} \times N_g$$

Case V : when point on subcooled region :



2-14

Q: On: 2 kg of steam at a pressure of 20 bar exist in the following condition.

- 1.) inlet steam with a dryness fraction at $x = 0.9$
 - 2.) dry & saturated steam.
 - 3.) Superheated steam with temperature 250°C
- calculate a) enthalpy (h), b) Volume, c) Entropy (s)
- Assumed Cp for $2.302 \text{ kJ/kg}^\circ\text{K}$ superheated.

Soll : Given that

$$m_{\text{a}} g = 2 \text{ kg}$$

$Q_p = 2.302 \text{ kg/mg kel.}$

$p = 20 \text{ bar}$

$$T_{\text{sup}} = 280^\circ\text{C}$$

1.) Orbit - beam :

~~Set~~ from steam table
page No. - 12
table No. - 2
by P.S. Khosla

$$\begin{aligned} P_1 &= 20 \text{ bar} \\ T_{32} &= 212.4^\circ\text{C} \\ h_f &= 908.5 \\ h_g &= 2797.2 \end{aligned}$$
$$\text{Enthalpy: } h = hf + \alpha (y_g - y_f)$$

$$h = 908.5 + 0.9 (2797.2 - 908.5)$$

$$h = 2608.33 \text{ kJ/kg}$$

and $h = M \times h$

$$h = 2 \times 10^{-8} \cdot 33$$

$$h = \underline{\underline{5216.66 \text{ kg}}}$$

$$\text{Volume} \therefore V = V_1 + 2(V_2 - V_1)$$

$$N = 0.001177 + 0.9(0.09955 - 0.001177)$$

$$\frac{m^2}{s} = 0.0892197$$

$$\text{ord } \alpha = m \times n$$

$$2 = 2 \times 0.0897127$$

$$\alpha = 0.1794254 \text{ m}^3$$

~~from~~ from steam table

Entropy: $S = S_f + x(S_g - S_f)$

$$S = 0.447 + 0.9(6.337 - 0.447)$$

$$S = 5.948 \text{ kJ/kg.kel}$$

and $S = m \times S$

$$S = 2 \times 5.948$$

$$S = 11.896 \text{ kJ/kel}$$

2) Dry and saturated steam:

$$1.) \quad h = h_g = 2797.2 \text{ kJ/kg}$$

$$h = 2 \times 2797.2$$

$$h = 55944.4 \text{ kJ}$$

$$11.) \quad sf = 0.9 = 0.00955 \text{ m}^3/\text{kg}$$

$$sg = 2 \times 0.00955$$

$$g = 0.1991 \text{ m}^3$$

$$11.) \quad S = S_g = 6.337 \text{ kJ/kg.k}$$

$$S = 2 \times 6.337$$

$$S = 12.674 \text{ kJ/kel}$$

3) for superheated:

$$1. \quad h = h_g + C_{pv}(T_{sup} - T_{sat})$$

$$= 2797.54 + 2.302(250 - 212.4)$$

$$h = 2884.0552 \text{ kJ/kg}$$

$$h = 2 \times 2884.0552$$

$$h = 5768.1104 \text{ kJ}$$

$$2.) \quad S = S_g + C_{p \ln} \left(\frac{T_{sup}}{T_{sat}} \right)$$

$$S = 6.337 + 2.302 \ln \left(\frac{523}{485.4} \right)$$

$$S = 6.50874 \text{ kJ/kg.kel}$$

$$S = 2 \times 6.50874$$

$$S = 13.01748 \text{ kJ/kel}$$

$$v = v_g \times \left(\frac{T_{\text{sep}}}{T_{\text{sat}}} \right)$$

$$v = 0.09955 \times \left(\frac{523}{484.4} \right)$$

$$v = 0.10726 \frac{\text{m}^3}{\text{kg}}$$

$$V = m \times v$$

$$V = 2 \times 0.10726$$

$$V = 0.21452 \text{ m}^3$$

Ans

Ques: Calculate the entropy of 4 kg of steam at a pressure of 8 bar and dryness fraction 0.8.

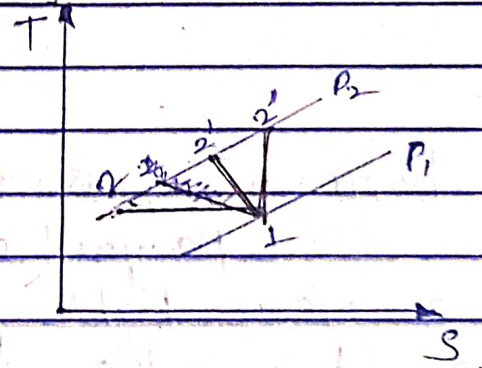
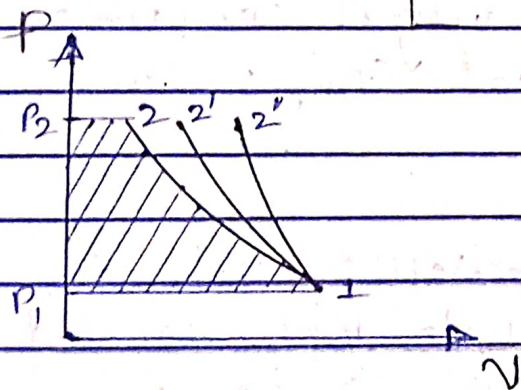
Unit - 05

Air Compressors

What Compressor:- Compressor is power consuming device used to increase the pressure of gases or compression convert mechanical energy into pressure energy of gases.

Compression work

$$W = \int_1^2 v \cdot dp$$



1-2, Isothermal Compression

1-2', Adiabatic Compression

1-2'', Polytropic Compression

The compression process may be isothermal or adiabatic or any polytropic process depending on type of Application.

The work input required will minimum for isothermal processes

Types of Compression

Displacement Type

Increase in pressure is achieved by decrease in volume of the gas. achieved by the displacement of the gas.

Exa:- Reciprocating Compressor

Dynamic Type

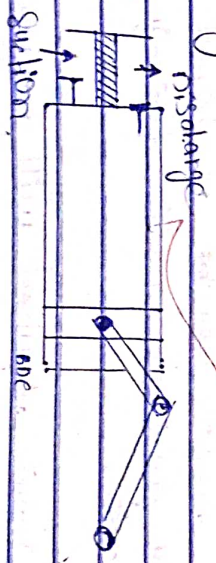
Increase in pressure is achieved by dynamic action. energy imparted to the gas by rotation of rotor is converted into pressure energy.

Exa:- Centrifugal compressor & Axial compressor

Reciprocating Compressor:-

Reciprocating compressor is able to produce very high pressure upto 1000 bar but volume flow rate is very less. (0.1 to 100 m³/min)

Reciprocating compressors are used in refrigeration system, air conditioning, mining work, chemical industry, air filling station etc.

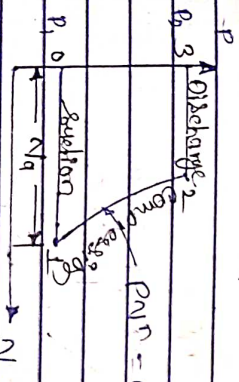


Formulae

The construction of compressor at a piston cylinder arrangement which has one end on suction side and other end on discharge side. This valve was spring loaded. At a certain pressure, which operates due to pressure difference across the valve.

The various problems associated with reciprocating compressor are load discharge and percent efficiency.

Work input required without clearance volume:-



$$\frac{P_1}{P_2} = \left(\frac{V_2}{V_1}\right)^{\gamma}$$

$$P_1 V_1^{\gamma} = P_2 V_2^{\gamma}$$

$$\left(\frac{P_1}{P_2}\right)^{\frac{1}{\gamma}} = \frac{V_2}{V_1}$$

$$Q_{2in} = n (P_2 V_2 - P_1 V_1)$$

$$Q_{2in} = n \cdot P_1 V_1 \left(\frac{P_2}{P_1} \frac{V_2}{V_1} - 1 \right)$$

$$Q_{2in} = n \cdot P_1 V_1 \left(\frac{P_2}{P_1} \frac{V_2}{V_1} - 1 \right)$$

$$Q_{2in} = n \cdot P_1 V_1 \left(\frac{P_2}{P_1} \frac{V_2}{V_1} - 1 \right)$$

$$Q_{2in} = n \cdot P_1 V_1 \left(\frac{P_2}{P_1} \frac{V_2}{V_1} - 1 \right)$$

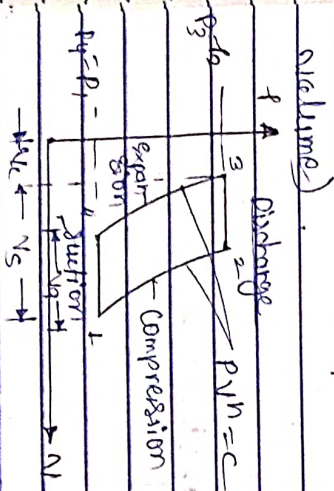
$$Q_{2in} = n \cdot P_1 V_1 \left(\frac{P_2}{P_1} \frac{V_2}{V_1} - 1 \right)$$

$$Q_{2in} = n \cdot P_1 V_1 \left(\frac{P_2}{P_1} \frac{V_2}{V_1} - 1 \right)$$

required increases.

Volumetric efficiency:-

It is defined as the ratio of actual volume of gas taken into the cylinder during suction stroke to the piston displacement volume. (Swept volume)



$$\eta_v = \frac{V_1 - V_2}{V_1 - V_3}$$

$$\eta_v = 1 + \frac{V_c}{V_s} \left(\frac{P_2}{P_1} \right)^{\frac{1}{\gamma}} - \frac{V_c}{V_s}$$

$$P_1 V_1^\gamma = P_2 V_2^\gamma$$

$$\eta_v = \frac{V_1 - V_2}{V_1 - V_3} = \frac{V_1}{V_3} \left(\frac{P_2}{P_1} \right)^{\frac{1}{\gamma}} - \frac{V_2}{V_3}$$

$$\eta_v = \frac{V_1 - V_2}{V_1 - V_3}$$

$$\eta_v = \frac{V_1 - V_2}{V_1 - V_3}$$

$$\eta_{vol} = \frac{V_s + V_c}{V_s} \left(\frac{P_2}{P_1} \right)^{\frac{1}{\gamma}} - \frac{V_c}{V_s}$$



$$\frac{V_4}{V_3} = \left(\frac{P_3}{P_4} \right)^{\frac{1}{\gamma}} = \left(\frac{P_2}{P_1} \right)^{\frac{1}{\gamma}}$$

From eqn (1)

$$\eta_v = 1 - c \left[\left(\frac{P_2}{P_1} \right)^{\frac{1}{\gamma}} - 1 \right]$$

where

$$c = \text{clearance ratio}$$

$$c = \frac{V_c}{V_s}$$

1) For fixed value of P_1 as P_2 is increased volumetric efficiency decreases.

2) With increase of clearance ratio volumetric efficiency decreases.

Multi-stage Compression:-

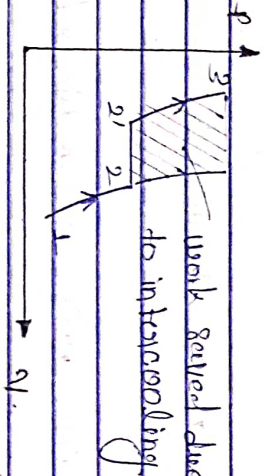
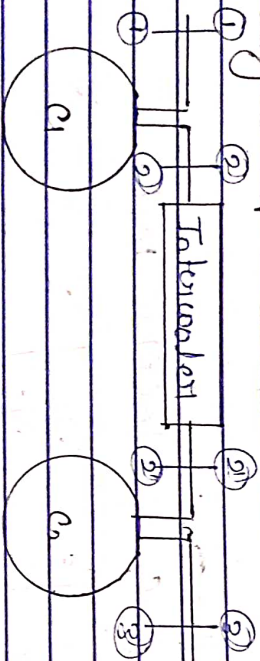
In single-stage compression as pressure ratio increases volumetric efficiency decreases.

Even at pressure ratio of $\gamma_p = \left[\frac{P_2}{P_1} + 1 \right]^\gamma$ the volumetric efficiency zero.

It means after a pressure limit multi stage in compression.

In between the stage if we use intercooling then compression work can be reduced.

Two stage compression :-



$$W_{\text{min}} = W_{C1} + W_{C2}$$

$$\Rightarrow W_{\text{min}} = n \cdot \text{MARTI} \left[\left(\frac{P_2}{P_1} \right)^{\frac{n-1}{n}} - 1 \right] + n \cdot \text{MARTI} \left[\left(\frac{P_3}{P_2} \right)^{\frac{n-1}{n}} - 1 \right]$$

For ideal intercooling,

$$\left. \begin{aligned} T_{2'} &= T_1 \\ P_{2'} &= P_2 \end{aligned} \right\}$$

$$W_{\text{min}} = n \cdot \text{MARTI} \left[\left(\frac{P_2}{P_1} \right)^{\frac{n-1}{n}} - 1 \right] + n \cdot \text{MARTI} \left[\left(\frac{P_3}{P_2} \right)^{\frac{n-1}{n}} - 1 \right]$$

$$W_{\text{min}} = n \cdot \text{MARTI} \left[\left(\frac{P_2}{P_1} \right)^{\frac{n-1}{n}} - 1 + \left(\frac{P_3}{P_2} \right)^{\frac{n-1}{n}} - 1 \right]$$

for given value of P_1, P_2, T_1, n & n .

$$W_{\text{min}} = f(P_2) \text{ only}$$

for minimum W_{min} .

$$\frac{d W_{\text{min}}}{d P_2} = 0$$

for minimum work input

$$\text{Finally } \left[P_2 = \sqrt{P_1 \cdot P_3} \right]$$

$$\Rightarrow P_2^2 = P_1 \times P_3$$

$$\left[\frac{P_2}{P_1} = \frac{P_3}{P_2} \right]$$

for minimum work input, with ideal intercooling the pressure ratio of each compression must be same.

IF (N) no. of stages are used in multistage

compression then the pressure ratio of each stage will be equal for minimum work input.

$$P_0 = P_8 = P_4 = P_5 = \dots = P_{n+1} = P_1$$

$$P_0 = k \cdot P_1$$

$$P_0 = k \cdot P_0 = k^2 \cdot P_1$$

$$P_4 = k \cdot P_3 = k^2 \cdot P_0 = k^3 \cdot P_1$$

$$P_{n+1} = k^n \cdot P_1$$

$$k = \left(\frac{P_{n+1}}{P_1} \right)^{\frac{1}{n}}$$

$$q_{lin} = n \cdot \text{marrT} \left[\left(\frac{P_{n+1}}{P_1} \right)^{\frac{n-1}{n}} - 1 \right]$$

$$q_{lin} = n \cdot \text{marrT} \left[\left(k^{\frac{n-1}{n}} - 1 \right) \right]$$

for minimum work input

$$q_{del} = q_{del} = q_{del} = q_{del}$$

$$q_{lin} = N \cdot n \cdot \text{marrT} \left[\left(\frac{P_{n+1}}{P_1} \right)^{\frac{n-1}{n}} - 1 \right]$$

(1) A single stage reciprocating air compression is required pressure 4 bar. If air from 1 bar to 4 bar the inlet temperature is 27°C compute the work requirement in the following cases -

- (1) Isothermal compression
- (2) Compression with $\gamma = 1.4$
- (3) Isentropic compression.

Given that: $P_1 = 1 \text{ bar}$

$$P_2 = 4 \text{ bar}$$

$$m = 1 \text{ kg}$$

$$T_1 = 27^\circ\text{C} = 273 + 27 = 300 \text{ K}$$

(1) Isothermal compression

$$q_{lin} = P_1 \ln \left(\frac{P_2}{P_1} \right)$$

$$q_{lin} = P_1 \ln \left(\frac{P_2}{P_1} \right)$$

$$= 1 \times 1 \times 0.287 \times \ln \left(\frac{4}{1} \right)$$

$$q_{lin} = 119.35 \text{ kJ}$$



② Polytropic Compression with $PV^{1.2} = C$

$$Q_{in} = \frac{n}{n-1} m R T_1 \left[\left(\frac{P_2}{P_1} \right)^{\frac{n-1}{n}} - 1 \right]$$

$$Q_{in} = \frac{1.2}{1.2-1} \times 4 \times 0.287 \times 300 \left[\left(\frac{4}{1} \right)^{\frac{1.2-1}{1.2}} - 1 \right]$$

$$Q_{in} = 134.27 \text{ kJ}$$

③ Isoentropic Compression (Adiabatic)

$$Q_{in} = \frac{\gamma}{\gamma-1} m R T_1 \left[\left(\frac{P_2}{P_1} \right)^{\frac{\gamma-1}{\gamma}} - 1 \right]$$

$$Q_{in} = \frac{1.4}{1.4-1} \times 4 \times 0.287 \times 300 \left[\left(\frac{4}{1} \right)^{\frac{1.4-1}{1.4}} - 1 \right]$$

$$Q_{in} = 146.45 \text{ kJ}$$

④ A single stage reciprocating air compressor has a bar of 500mm and 9 stroke of 300mm heat recites air at 1 bar and 30°C and delivers at 5.5 bar if the compression follows $PV^{1.3} = C$ and clearance volume is 5% of swept stroke volume.

$$V_1 = V_c + V_s \quad V_s = \frac{\pi}{4} d^2 L$$

$$V_1 = 5\% V_s$$

(1) determine the mean effective pressure.
(2) Power required to drive the compressor if it runs at 500 rpm.

Sol Given data

$$\text{Stroke length} = 300 \text{ mm} = 0.3 \text{ m}$$

$$\text{Stroke diameter} = 500 \text{ mm} = 0.5 \text{ m}$$

$$PV^{1.3} = C \quad P_1 = 1 \text{ bar}, P_2 = 5.5 \text{ bar}$$

$$T_1 = 30^\circ \text{C}, V_c = 5\% V_s$$

$$V_1 = \frac{\pi}{4} D^2 L = \frac{\pi}{4} \times (0.5)^2 \times (0.3)$$

$$= 9.42 \times 10^{-3} = 0.00942 \text{ m}^3$$

$$\text{and } V_2 = \frac{5 \times 0.00942}{100} = 4.71 \times 10^{-4} = 0.000471 \text{ m}^3$$

$$V_1 = V_c + V_s$$

$$= 0.00047 + 0.00942$$

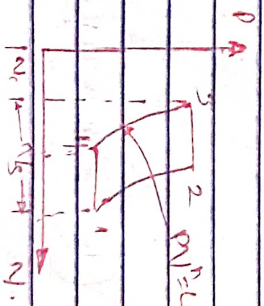
$$V_1 = 9.89 \times 10^{-3}$$

$$= 0.0098 \text{ m}^3$$

$$M_{ep} = w$$

Stroke volume

$$Q_{in} = \frac{n}{n-1} \times P_1 (V_1 - V_2) \left[\left(\frac{P_2}{P_1} \right)^{\frac{n-1}{n}} - 1 \right]$$



$$P_3 V_3^{1.3} = P_4 V_4^{1.3}$$

$$\left(\frac{V_4}{V_3}\right)^{1.3} = \frac{P_3}{P_4}$$

$$\left(\frac{V_4}{0.00042}\right)^{1.3} = \left(\frac{5.5}{1}\right)$$

$$V_4 = 0.00174 \text{ m}^3$$

$$P_1 = 1 \text{ bar} = 10^5 \text{ Pa}$$

$$P_1 V_1^{1.3} = P_2 V_2^{1.3} \left[\left(\frac{P_2}{P_1} \right)^{\frac{n-1}{n}} - 1 \right]$$

$$Q_1 = 1.3 \times P_1 V_1 \left[\left(\frac{P_2}{P_1} \right)^{\frac{n-1}{n}} - 1 \right] = 1.3 \times 1 \times 10^5 (0.000989 - 0.00174) \left[\left(\frac{5.5}{1} \right)^{\frac{1.3-1}{1.3}} - 1 \right]$$

$$Q_1 = 1402 \text{ N-m}$$

$$\# \text{ mep} = \frac{1402}{0.000942}$$

$$= 180679. \text{ N/m}^2 = 1.80679 \text{ bar}$$

$$\text{Power} = Q_1 \times \frac{N}{60}$$

$$= 1402 \times 500 = 14183.33 \text{ kW}$$

Q.10:- A piston the minimum work required to compress 1 kg of air from 1 bar 27°C to 16 bar in two stages if the law of compression is $PV^{1.25}$ and intercooling is perfect. Take $R = 287 \text{ J/kg-K}$

Given that

$$P_1 = 1 \text{ bar}, P_2 = 16 \text{ bar}$$

$$Q_1 = 200 \text{ kcal, mass} = 1 \text{ kg}$$

$$PV^{1.25} = C$$

$$\Rightarrow \left[\frac{P_2}{P_1} \right]^{\frac{n-1}{n}} = \left[\frac{P_2}{P_1} \right]^{\frac{1.25-1}{1.25}} \Rightarrow P_2 = \sqrt[1.25]{1 \times 16}$$

$$\Rightarrow P_2 = 4 \text{ bar}$$

$$Q_{\text{in}} = N \cdot n \times m R T_1 \left[\left(\frac{P_2}{P_1} \right)^{\frac{n-1}{n}} - 1 \right]$$

$$Q_{\text{in}} = 2 \left[\frac{1.95}{1.25-1} \times 1 \times 287 \times 300 \left(\left(\frac{4}{1} \right)^{\frac{1.25-1}{1.25}} - 1 \right) \right]$$

$$Q_{\text{in}} = 275096.31 \text{ N-m}$$

Isothermal efficiency :-

It is the ratio of work (or power) required to compress the air isothermally to the actual work required to compress the air for the same pressure ratio.

$$\eta_e = \frac{\text{Isothermal power}}{\text{Indicated power}}$$

$$\eta_e = \frac{\text{Isothermal work alone}}{\text{Indicated work alone}}$$

Over all isothermal efficiency :-

It is the ratio of isothermal power to the shaft power or brake power at the motor required to drive the compressor.

$$\eta_o = \frac{\text{Isothermal power}}{\text{Shaft or Brake power}}$$

Ex - A two stage compressor takes in 0.03 m³ of air/min at a pressure of 1.05 bar and temperature of 20°C. At delivery the pressure of air is 8.44 bar. The compression is carried out in each stage according to the law $PV^{1.2} = C$ the air is cooled to 20°C initial temperature in intercooler neglecting clearance find the minimum power required for

Given the compression

Ex - Given that

$$V_1 = 2.92 \text{ m}^3, P_1 = 1.05 \text{ bar}$$

$$T_1 = 20^\circ\text{C} = 295 \text{ K}, P_2 = 8.44 \text{ bar}$$

$$PV^{1.2} = C$$

$$P_2 = \sqrt[n]{P_1 \times P_3} = \sqrt[1.2]{1.05 \times 8.44} = 2.977$$

$$V_{1m} = \frac{N \cdot V \times P_1 V_1}{n-1} \left[\left(\frac{P_2}{P_1} \right)^{\frac{n-1}{n}} - 1 \right]$$

$$V_{1m} = 2 \times \left[\frac{1.2}{1.2-1} \times 1.05 \times 10^5 \times 2.92 \right] \left[\left(\frac{2.97}{1.05} \right)^{\frac{2-1}{1.2}} - 1 \right]$$

$$V_{1m} = 623984.88 \text{ N-m/min}$$

$$V_{1m} = 623984$$

$$60$$

$$W_{1m} = 11.238 \text{ kW}$$

(11.238)

Ex - The following data is volume flow rate = 8.

Inlet condition 100 kPa, 20°C, pressure ratio = 8.

Motor speed = 400 rpm, clearance volume 8%.

at swept volume, polytropic index = 1.28.

Calculate 1) swept volume 2) Discharge temperature

3) Indicated power.

$$\left[\gamma = \frac{P_2}{P_1} \right]$$

Self Given sheet

Volume flow rate $\dot{V}_2$, $P_2 = 800 \text{ kPa}$

Inlet condition $(P_1) = 100 \text{ kPa}$

Temperature $(T_1) = 20^\circ\text{C} + 273 = 293 \text{ K}$

Pressure ratio $= \gamma$

meter speed = 400 rpm

Polytropic exponent = 1.28

Clearance volume 8% of swept volume

$$\text{① } \dot{V}_2 = \frac{\pi D^2 L}{4} = \frac{\pi}{4}$$

$$V_1 = V_c + V_s$$

$$T_2 = 461.76 \text{ K}$$

$$\Rightarrow V_1 = 8\% V_s + V_s$$

$$\text{and } P_1 V_1^n = P_2 V_2^n$$

$$\Rightarrow 8 = 0.08 V_s + V_s$$

$$100 \times 8^{1.28} = 800 \times V_2^{1.28}$$

$$\Rightarrow 88 = 1.08 V_s \Rightarrow$$

$$[V_2 = 1.575]$$

$$\Rightarrow V_1 = 7.40$$

$$\frac{P_2 V_2}{P_1 V_1} = \frac{T_2}{T_1}$$

$$\text{② } T_2 = ?$$

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

$$\frac{T_2}{293} = \left(\frac{8}{1} \right)^{\frac{1.28-1}{1.28}}$$

$$\frac{T_2}{293} = (8)^{\frac{1.28-1}{1.28}}$$

$$\frac{T_2}{293} = 1.575$$

$$T_2 = 461.76$$

$$T_2 = 195.90 \text{ K}$$

$$V_{\text{in}} = \frac{V}{n-1} \left[\left(\frac{P_2}{P_1} \right)^{\frac{n-1}{n}} - 1 \right]$$

$$V_{\text{in}} = \frac{1.28}{1.28-1} \times 100 \times 10^{-3} \times 8 \left[\left(\frac{8}{1} \right)^{\frac{1.28-1}{1.28}} - 1 \right]$$

$$V_{\text{in}} = 210644.23 \text{ N-m}$$

$$\# \text{ Power} = \frac{V_{\text{in}} \times N}{60}$$

$$= 210644.23 \times 400$$

$$60$$

$$= 140427.47 \text{ W}$$

$$\underline{\underline{Ans}}$$

Ques 10/11/24

Unit - 06

Heat Transfer

Basis of Heat transfer -

Capacity to something is known as energy every molecule have some activity heat mean molecule heat energy.

The microscopic summation of all forms of energy known as internal energy is depend on temperature and pressure.

Temperature is not an energy, it is a measurement of energy.

The energy transfer due to temperature difference known as heat transfer. (Heat or heat transfer or heat like or heat loss have same meaning).

Heat is not a fluid or substance.

① First law of thermodynamic state that energy can neither be created nor be destroyed but it convert one form to another form.

It is a quantity oriented law which decide



How much input required to get electrical output
first law did not comment on direction of heat transfer.

② Second law of quality created which states that heat transfer takes place from higher temperature to lower temperature (naturally).

Why to study Heat Transfer:-

Thermodynamic explain direction of heat transfer but thermodynamics did not comment duration of process. It means how much time required to reach particular temperature.

Thermodynamic did not explain how heat transfer takes place. It means thermodynamics did not explain modes of heat transfer.

In such cases due to insulation heat loss increases but thermodynamic did not explain effect of insulation on heat transfer (creation thickness of insulation)

Thermodynamics did not explain internal heat transfer.

Thermodynamics also can not divide size of equipment.

The class of limitation even come by new subject known as heat transfer.

Note:- Thermodynamic related with energy transfer (take or supply) and heat transfer deals with rate of energy transfer (W/sec or watt).

Modes of Heat Transfer

Stationary Medium Steady medium No medium.

Conduction Convection Radiation

Steady Unsteady without phase change with phase change

Conduction:-

Free Boiling Condensation

Hot (T₁) Cold (T₂)

Conduction is mode of heat transfer between high energy particles to the low energy particles.

Conduction takes place in a stationary medium due to temperature gradient.

Conduction takes place in solid, liquid and gases.

Conduction is the transfer of heat from one part of a substance to another part of same substance or from one substance to another in physical contact with it without appreciable displacement of individual forming the substance.

Convection :-

Heat transfer takes place due to movement of fluid known as convection.

Energy exchange due to molecular collision is known as diffusion.

The energy transferred due to bulk motion of fluid known as convection.

The convection is due to combination of diffusion and advection.

If the fluid motion develops by wind, mechanical devices like fan, pump, blower etc. then it is called forced convection.

If the fluid motion develops due to natural reason then it is considered as free or natural convection.

In case of forced convection convective mode of heat transfer is high compare to free convection.

Radiation :-

The energy transfer takes place due to electromagnetic waves known as radiation heat transfer.

Radiation does not require any medium.

Radiation is a fastest mode of heat transfer.

Radiation is the transfer of heat through space or rather by means other than conduction or convection. All bodies radiate heat. In a dark body emits more heat than it emits in normal condition. radiant energy required no

medium for propagation but heat can pass through a vacuum.

Ques

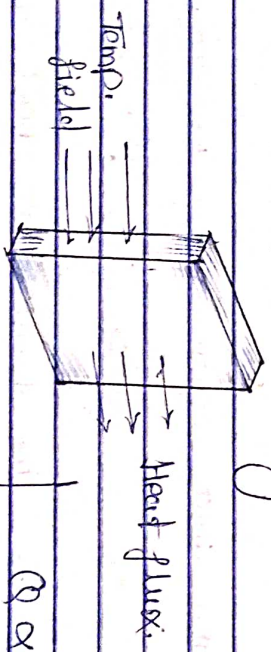
Fourier Law of Heat Conduction:

The rate at which

Conduction between two isothermal surface is directly proportional to perpendicular area and temperature difference and inversely proportional to thickness.

In other words Fourier law state that rate of heat conduction is directly proportional to perpendicular area and temperature gradient.

Fourier law gives new property of material known as thermal conductivity



$$Q \propto A \Delta T$$

$$Q \propto A \text{ (} \Delta T, \Delta x \text{ fixed)}$$

$$Q \propto \Delta T \text{ (} A, \Delta x \text{ fixed)}$$

$$Q \propto \frac{1}{\Delta x} \text{ (} A, \Delta T \text{ fixed)}$$

$$Q = -k A \Delta T$$

$$k = \frac{Q}{A \frac{\Delta T}{\Delta x}} \text{ (unit m}^2 \text{ s}^{-1} \text{ K}^{-1} \text{)}$$

where

$$\text{Heat flux (} q \text{)} = \frac{Q}{A} \text{ (} \text{W m}^{-2} \text{)}$$

$$q = k \frac{\Delta T}{\Delta x}$$

where q = Heat flux

k = Thermal conductivity

ΔT = Temperature gradient

Thermal conductivity of medium:

It is material property which indicate ability of material to conduct heat

Thermal conductivity also defined as it is a quantity of rate of heat conduction takes place for a unit area unit temperature difference unit thickness.

$$\text{Therefore } [k = Q]$$

Higher thermal conductivity means material is good conductor of heat

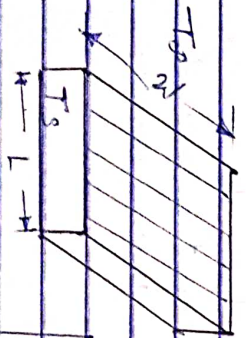
Thermal conductivity is strongly different on molecular structural arrangement.

Thermal Diffusivity (α):
It is slope of a ratio of heat conducted through a medium to a heat storage capacity of medium. It is expressed as

$$\alpha = \frac{Q_{\text{conducted}}}{Q_{\text{storage}}} = \frac{k}{\rho c_p}$$

Newton's law of cooling:-

The convective rate of heat transfer is directly proportional to temperature difference between surface and fluid, surrounding fluid and surface area.



$$A_s = wL$$

$$\Delta T = T_s - T_\infty$$

$$\Rightarrow h = \frac{Q}{A_s \Delta T} \quad \left(\frac{\text{Watt}}{\text{m}^2 \text{K}} \right)$$

$$Q \propto A_s, \quad Q \propto \Delta T$$

$$T \propto \Delta T, \quad A_s = \text{const}$$

$$\Delta T = \frac{1}{h}$$

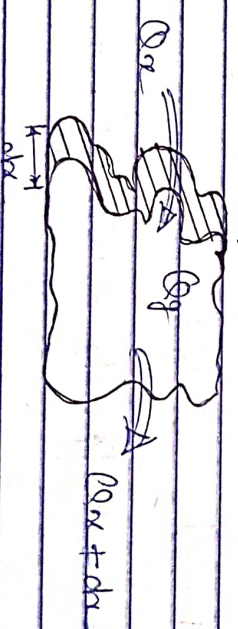
$$\therefore h = \text{convective}$$

where, h = heat transfer between surface and surrounding fluid.

1) h is independent of rough of heat transfer.
2) h is directly of rate of convection heat transfer takes for a unit area, unit temperature difference.

3) h is not a property of fluid. It is an experimental determin value which is complex nature.

1-dimensional heat conduction equation:-



$$Q_x = -kA \frac{\Delta T}{\Delta x}$$

$$\text{Heat generated} = \rho q A dx$$

$$\text{Heat leaving} = Q_x + Q_{x+dx} = Q_x + \frac{A}{dx} (Q_x) dx$$

$$\text{Heat stored} = Q_{\text{stored}} = Mc \Delta T = \rho V c \Delta T$$

$$= \rho c \Delta T \cdot A dx$$

$$\Rightarrow Q_m + Q_g - Q_{\text{out}} = Q_{\text{stored}}$$

$$\Rightarrow Q_m - Q_{\text{out}} + Q_g = Q_{\text{stored}}$$

$$\Rightarrow \left[Q_x - \left(Q_x + \Delta (Q_x) dx \right) \right] + Q_g A dx = \rho c A \Delta T dx$$

$$\Rightarrow -\Delta (Q_x) dx + Q_g A dx = \rho c A \Delta T dx$$

$$\left[\because Q_x = -k A \Delta T \right]$$

$$\Rightarrow \frac{\Delta}{\Delta x} (k A \Delta T) dx + Q_g A dx = \rho c A \Delta T dx$$

$$\left[\because k = \text{constant} \right]$$

$$\Rightarrow k A \frac{\Delta}{\Delta x} (A \Delta T) dx + Q_g A dx = \rho c A \Delta T dx$$

[$\because$ divide by $k A dx$]

$$\Rightarrow \frac{1}{A} \frac{\Delta}{\Delta x} (A \Delta T) + \frac{Q_g}{k} = \frac{\rho c}{k} \Delta T$$

$$\Rightarrow \left[\frac{1}{A} \frac{\Delta}{\Delta x} (A \Delta T) + \frac{Q_g}{k} = \frac{\rho c}{k} \Delta T \right]$$

Space variable Heat generation Time

1-D and $k = \text{constant}$

$$\Rightarrow \frac{\Delta^2 T}{\Delta x^2} + \frac{Q_g}{k} = \frac{1}{\alpha} \frac{\Delta T}{\Delta t} \quad \text{Equation}$$



Exm 9.6: Cold air from atmosphere is circulated through an air heating system, where the temperature of air is increased from 7.2°C to 21.2°C without any pressure. If the heat consumption of warm air at 21.2°C is 250 m^3 calculate how much heat must be imparted to the air?

What will be the change in entropy of air circulated per hour? Assume perfect value of the specific heat of air.

Sol Given that

$$T_1 = 7.2^\circ\text{C} = 7.2 + 273 = 280.2\text{ K}$$

$$T_2 = 21.2^\circ\text{C} = 21.2 + 273 = 294.2\text{ K}$$

$$V_1 = V_2 = 1.013\text{ km}^3$$

$$M_1 = 250\text{ m}^3$$

$$Q = mC_p (T_2 - T_1)$$

$$P V_1 = m R T_1$$

$$1.013 \times 10^{13} \times 250 = m \times 0.287 \times 294.2$$

$$m = \frac{1.013 \times 10^{13} \times 250}{0.287 \times 294.2}$$

$$m = 1020\text{ kg}$$

$$\therefore Q = mC_p (T_2 - T_1)$$

$$Q = 1020 \times 1.005 (294.2 - 280.2)$$

$$= 14351.4\text{ kJ}$$

Ans.

$$S_2 - S_1 = mC_p \ln \frac{T_2}{T_1}$$

$$= 1020 \times 1.005 \ln \left(\frac{294.2}{280.2} \right)$$

Ans.

$$S_2 - S_1 = 50\text{ kJ/K}$$

Ans.

Unit - 04



Question 1:- 0.05 m^3 of air at a pressure of 8 bar and temperature 280°C expands to eight times the original volume and the final temperature after expansion is 25°C . Calculate change of entropy of air during the process. Assume $C_p = 1.005 \text{ kJ/kg K}$ and $C_v = 0.712 \text{ kJ/kg K}$.

Sol. Given that

$$\text{Volume}_1 = 0.05 \text{ m}^3 \quad V_2 = 8 \times 0.05 \text{ m}^3$$

$$P_1 = 8 \text{ bar} \quad = 0.4 \text{ MPa}$$

$$T_1 = 280^\circ \text{C} = 280 + 273 = 553 \text{ K}$$

$$C_p = 1.005 \text{ kJ/kg K}$$

$$C_v = 0.712 \text{ kJ/kg K}$$

$$T_2 = 25^\circ \text{C} = 25 + 273 = 298 \text{ K}$$

$$S_2 - S_1 = m \left[C_v \ln \frac{T_2}{T_1} + R \ln \frac{V_2}{V_1} \right]$$

$$R = C_p - C_v = 0.293 \text{ kJ/kg K}$$

$$P_1 V_1 = m R T_1$$

$$8 \times 10^2 \times 0.05 = m \times 0.293 \times 553$$

$$m = 0.977 \text{ kg}$$

$$\text{Formula } S_2 - S_1 = m \left[C_v \ln \frac{T_2}{T_1} + R \ln \frac{V_2}{V_1} \right]$$

$$S_2 - S_1 = 0.977 \left[0.712 \ln \frac{298}{553} + 0.293 \ln \frac{0.4}{0.05} \right]$$

$$= 0.977 \times 0.16907$$

$$= 0.0417 \text{ kJ/K}$$

Ans

Q.10(a) :- 0.5 kg of a perfect gas is heated from 100°C at a constant pressure of 0.8 bar. It is then cooled at 100°C at constant volume. Find the overall change in entropy. Take $C_p = 1.25 \text{ kJ/kg K}$ and $C_v = 0.75 \text{ kJ/kg K}$.

Sol Given: $m = 0.5 \text{ kg}$

$$T_1 = 100^\circ\text{C} = 100 + 273 = 373 \text{ K}$$

$$T_2 = 300^\circ\text{C} = 300 + 273 = 573 \text{ K}$$

$$T_3 = 373 \text{ K}$$

$$P_1 = P_2 = 0.8 \text{ bar}$$

$$n_b = n_3$$

$$S_2 - S_1 = m C_p \ln \frac{T_2}{T_1}$$

$$= 0.5 \times 1.25 \times \ln \frac{573}{373}$$

$$= 0.214 \text{ kJ/K}$$

$$S_3 - S_2 = m C_v \ln \frac{T_3}{T_2}$$

$$= 0.5 \times 0.75 \times \ln \frac{373}{573}$$

$$= -0.154 \text{ kJ/K}$$

$$S_2 - S_1 = (S_2 - S_3) + (S_3 - S_1)$$

$$= -0.154 + 0.214$$

$$= 0.06 \text{ kJ/K}$$

11.9



Q.3) A certain quantity of a perfect gas is heated in a reversible isothermal process from 1 bar and 40°C to 10 bar. Find the work done per kg of gas and the change in entropy per kg of gas. (Take $R = 287 \text{ J/kg}^\circ\text{K}$)

Sol Given that

$$P_1 = 1 \text{ bar}$$

$$P_2 = 10 \text{ bar}$$

$$T_1 = 213 \text{ K} = 40^\circ\text{C} + 273^\circ$$

$$T_1 = T_2$$

$$m = 1 \text{ kg}$$

$$Q_{1-2} = P_1 V_1 \ln \frac{V_2}{V_1} \quad [\because P_1 V_1 = P_2 V_2]$$

$$= m R T_1 \ln \frac{V_2}{V_1} \quad \left[\frac{P_2}{P_1} = \frac{V_1}{V_2} \right]$$

$$= m R T_1 \ln \frac{P_1}{P_2}$$

$$= 1 \times 287 \times 213 \ln \frac{1}{10}$$

$$= -206.84 \text{ kJ}$$

$$\text{and } S_2 - S_1 = m R \ln \frac{P_1}{P_2}$$

$$=$$

$$= 1 \times 287 \times 213 \ln \left(\frac{1}{10} \right)$$

$$= -206.84 \text{ kJ/kg}^\circ\text{K}$$

4.13



Q.13) A 0.568 m^3 capacity insulated vessel of oxygen at a pressure of 2 bar is stirred by an internal paddle unit the pressure becomes 0.4 bar . find out

1. Heat transferred
2. Work output
3. Change in entropy per kg.

Take $C_p = 0.657 \text{ kJ/kg K}$
and $R = 0.260 \text{ kJ/kg K}$.

Sol Given first

$$\text{Volume} = 0.568 \text{ m}^3$$

$$P_1 = 2 \text{ bar}$$

$$P_2 = 0.4 \text{ bar}$$

$$C_p = 0.657 \text{ kJ/kg K}$$

$$R = 0.260 \text{ kJ/kg K}$$

$$m = ?$$

1) Heat transfer (adiabatic)

$$Q = 0$$

$$2) P_1 V_1 = m R T_1$$

$$2 \times 10^2 \times 0.568 = 1 \times 0.260 \times T_1$$

$$\Rightarrow T_1 = \frac{2 \times 10^2 \times 0.568}{1 \times 0.260}$$

$$T_1 = 436.97 \text{ K}$$

$$T_2 = 524.2 \text{ K}$$

$$dW = m C_v (T_2 - T_1)$$

$$= 1 \times 0.657 (524 - 437)$$

$$= 57 \text{ kJ}$$

$$3) S_2 - S_1 = 0$$

Ans

4.13

Q.13) 0.2 kg of air with $= 1.5 \text{ bar}$ and $T_1 = 300 \text{ K}$ is compressed to a pressure of 15 bar according to the law $pV^{1.25} = \text{constant}$ determine

1) Initial and final pressure of air, 2) Work done on or by the air, 3) Heat flow to or from the air and 4) change of entropy during which it is increase or decrease.

Given $m = 0.2 \text{ kg}$
 $p_1 = 1.5 \text{ bar} = 0.15 \times 10^6 \text{ N/m}^2$

$T_1 = 300 \text{ K}$
 $p_2 = 15 \text{ bar}$

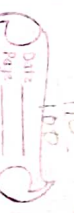
$pV^{1.25} = \text{constant}$

$$\frac{T_2}{T_1} = \left(\frac{p_2}{p_1} \right)^{\frac{n-1}{n}}$$

$$T_2 = \frac{p_1 V_1 T_1}{p_2} \quad T_1 \times \left(\frac{p_2}{p_1} \right)^{\frac{n-1}{n}}$$

$$T_2 = \frac{1.5 \times 10^2 \times 300 \times (1.5)^{\frac{1.25-1}{1.25}}}{15 \times 10^2}$$

$$T_2 = 475.04 \text{ K}$$



$$p_1 V_1 = n R T_1$$

$$1.5 \times 10^2 \times V_1 = 0.2 \times 0.287 \times 300$$

$$V_1 = \frac{0.2 \times 0.287 \times 300}{1.5 \times 10^2}$$

$$V_1 = 0.115 \text{ m}^3$$

$$p_1 V_1^n = p_2 V_2^n$$

$$1.5 \times 10^2 \times (0.115)^{1.25} = 15 \times 10^2 \times V_2^{1.25}$$

$$V_2^{1.25} = \frac{1.5 \times 10^2 \times (0.115)^{1.25}}{15 \times 10^2}$$

$$V_2^{1.25} = 0.09 \times 10^{-3}$$

$$V_2 = (0.09 \times 10^{-3})^{\frac{1}{1.25}}$$

$$V_2 = 0.018 \text{ m}^3$$

$$p_1 V_1^{-1.2} = \frac{p_1 V_1}{n-1} = \frac{p_2 V_2}{n-1}$$

$$= \frac{1.5 \times 10^2 \times 0.115 - 15 \times 10^2 \times 0.018}{1.25-1}$$

$$Q_{1-2} = -39 \text{ kJ}$$

$$Q_{1-2} = du + w_{1-2} = m c_v (T_2 - T_1) - 39$$

$$Q_{1-2} = 0.2 \times 0.718 (475.04 - 300) - 39$$

$$Q_{1-2} = 25 \text{ kJ}$$