

Date

Applied Thermodynamics

DAY-1

The Bridge :-

Real World Application :-

Three forms of energy

- thermal
- Kinetic
- Chemical

→ 1st law of TD is the ~~law~~ law of conservation of energy which is "energy can neither be created nor be destroyed"

DAY-2

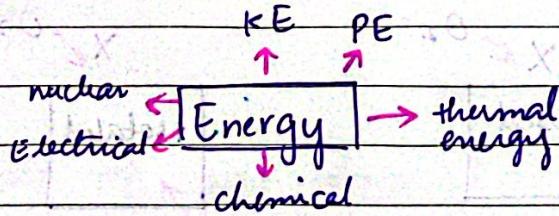
Introduction to thermodynamics :-

Deals with the transfer of energy from one form to another or from one place to another.

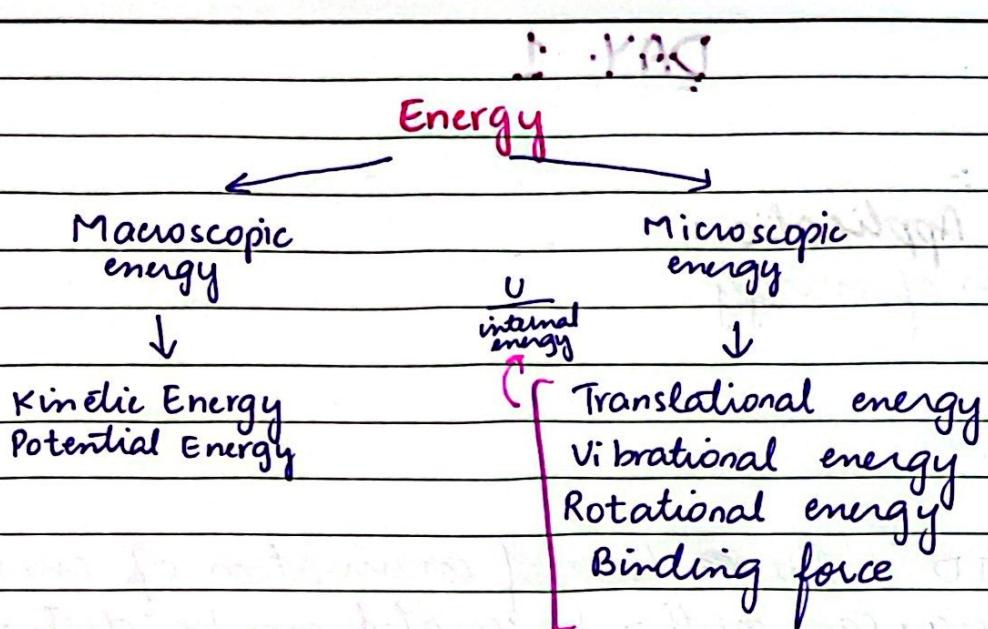
① Energy transfer heat, work and mass :-

① A quantitative property that must be transferred from a body or physical system to perform work or transfer heat.

② Form of energy that is transferred between two bodies due to difference in the temperature



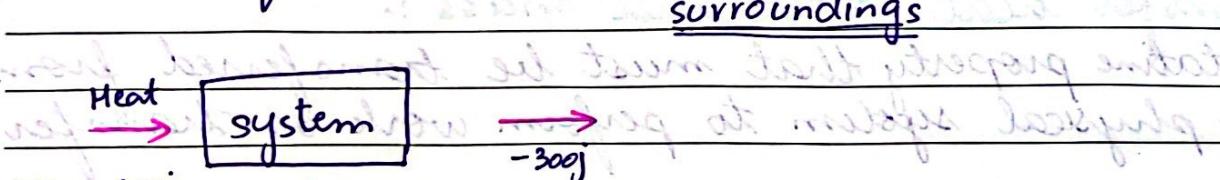
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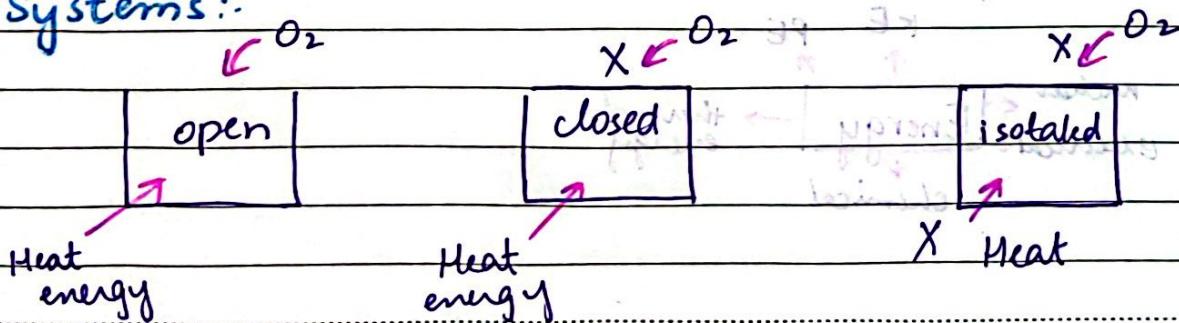
$$\begin{aligned}\text{Total energy} &= KE + PE + U \\ &= \frac{1}{2} mv^2 + \text{constant } U\end{aligned}$$

Mechanisms of energy transfer :-

1. Work done (W) \rightarrow Joule \rightarrow Mechanical energy
2. Heat (q) \rightarrow Joule \rightarrow Thermal energy
3. Mass flow



Systems:-



Date _____

$$\Delta U = q + w \quad (\text{Chem})$$

$$\boxed{\Delta U = q - w \quad (\text{Physics})}$$

Chem

$w = -ve \rightarrow$ work done by the system

$w = +ve \rightarrow$ work done on the system

physics

$|w| = -ve \rightarrow$ work done on the system

$w = +ve \rightarrow$ work done by the system

Heat:-

$q \rightarrow +ve$ (absorb) \rightarrow endothermic

$q \rightarrow -ve$ (release) \rightarrow exothermic

Example:-

100 J of work is done on the system. Increases by 74 J. How much energy is transferred as heat?

Sol.

$$\Delta U = q - w$$

$$74 = q - (-100)$$

$$74 = q + 100$$

$$q = 74 - 100$$

$$\boxed{q = -26 \text{ J}}$$

Example:-

A sample of gas does 150 J of work against its surrounding and loses 90 J of internal energy

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in the process Does the gas lose or gain the heat? And how much?

so1.

$$\Delta U = q - W$$

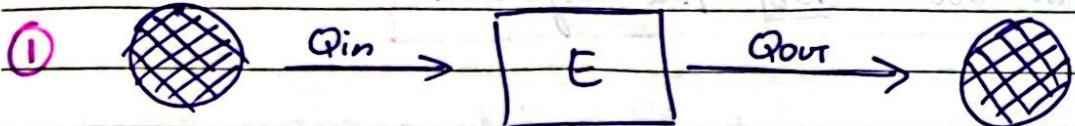
$$-90 = q - 150$$

$$q = 150 - 90$$

$$q = 60 \text{ J} \quad (\text{gain}) \quad (\text{endothermic}) \quad (\text{absorb})$$

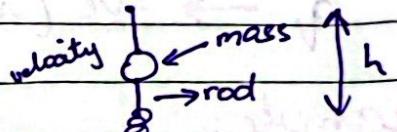
Heat

$$T_2 > T_1 \rightarrow T_3$$



② Work

$$w_{in} \rightarrow E$$



$$E_f = 0$$

③ Mass:
if displacement is zero, then $E_i = E_f$

$$\text{Mass} \rightarrow \begin{cases} \text{Mass} \\ \text{Ein} \end{cases} \rightarrow \begin{cases} \text{Mass} \\ \text{Out} \end{cases}$$

$$(001) - p = pF$$

$$001 + p = pF$$

$$001 - pF = p$$

$$1T \Delta S = -p$$

temperature change by T_{out} will lead to always a negative contribution by T_{out} (320). And positive when it is

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in the process Does the gas lose or gain heat? And How much?

SOL.

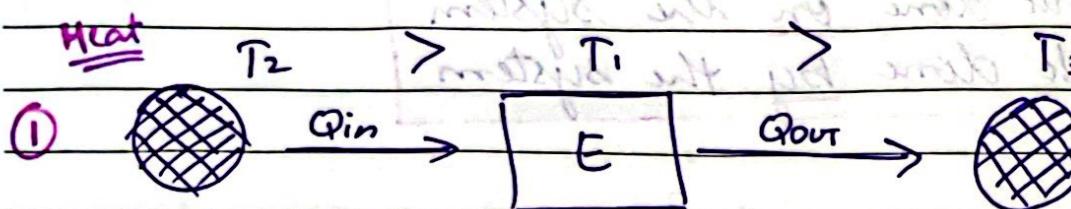
$$\Delta U = q - w$$

$$-90 = q - 150$$

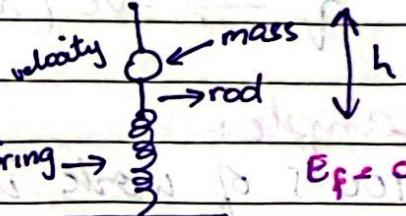
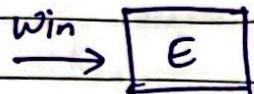
$$q = 150 - 90$$

$$| q = 60 \text{ J} | \text{ (gain) (endothermic) (absorb)}$$

Heat



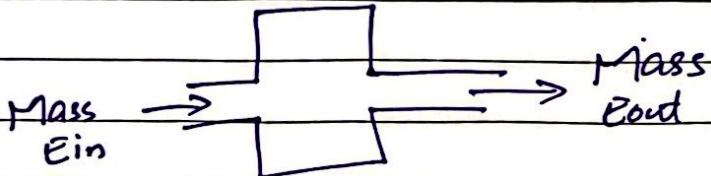
② Work:



$$E_i = mgh$$

$$E_f = 0$$

③ Mass:



$$W - P = U \Delta$$

$$(001-) - p = p \Gamma$$

$$\Delta L + p = p F$$

$$001 - p F = p$$

$$[T \Delta S - 1] p$$

DAY - 3

Properties of Pure Substance:

Pure substance:

A pure substance is defined as a material that has a homogeneous and invariable chemical composition.

Date

Homogeneity :-

The substance is the same throughout, with no regions having a different composition.

Invariable composition :-

The chemical composition doesn't change even when the substance transitions between different phases.

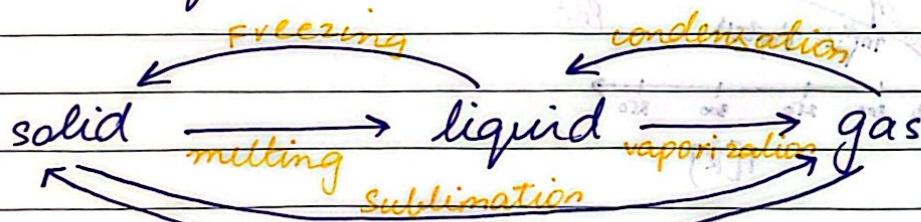
Solid :- Tightly packed molecules

Liquid :- Tightly packed but moveable

Gas :- Freely moveable

Phase Changes And Diagrams

Phase change of a material occurs when it transitions from one phase/state to another.

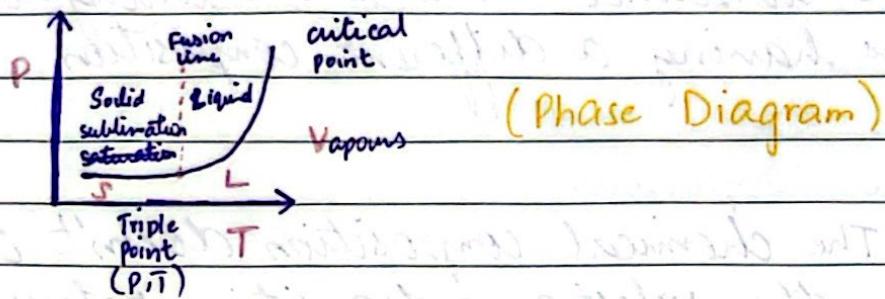


Saturation Temperature :-

The specific temp. at which a substance undergoes a phase change under a given

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pressure. (vaporization, condensation)

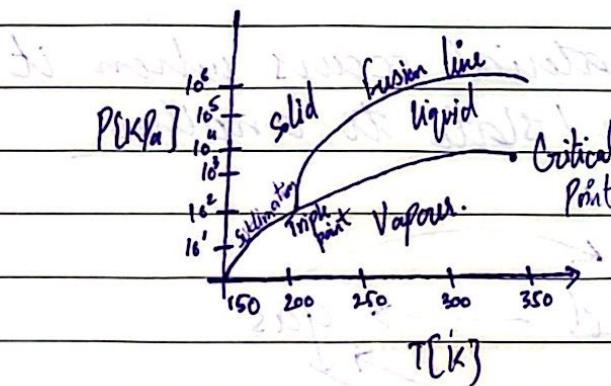


Triple point of water occurs at 0.01°C , 0.6117 kPa

Critical Point:-

It marks the end of vaporization curve on a phase diagram. Beyond this point liquid and gaseous phase becomes indistinguishable.

Critical point of water: 374.14°C and 22.09 MPa



0.01°C is the lowest Temp. in which a water can stay in its lowest state.

QUESTION:- If the pressure is smaller than the smallest

Date

pressure P_{sat} at a given temperature T . What is the phase?

Date

pressure P_{sat} at a given temperature T . What is the phase?

Sol. On google classroom

DAY- 4

The P-V-T surface:-

- Crucial for understanding how substances behave under different conditions (P, V, T)
- Applications \rightarrow Refrigeration, power generation and compressor etc.
- Captures the relationship b/w the pressure, volume and temperature

P-V-T surface of water :-

- Ice - has larger volume than liquid state
- liquid water

The fusion line (solid - liquid) line on pressure - temp diagram has a negative slope indicating the increasing the pressure decrease the freezing point

• pressure \uparrow boiling point \downarrow freezing point \uparrow

P-V-T surface of a typical substance:

shinks on freezing

solid phase have lower volume than liquid phase.

The fusion line (solid - liquid) is on pressure - temp

Date

diagram has a positive slope indicating the increasing in the freezing pressure increases the freezing point

Phase Diagram:-

- P-T diagram
- Fusion line
- Sublimation line
- Triple point
- Critical point

P-VAD

T-V Diagram:-

- Shows how volume changes with temperature at constant pressure illustrating phase change from liquid to vapours.
- Depicts the boiling phase

P-V Diagram:-

- Shows how pressure changes with specific volume at constant temperature

Independent Properties:-

The state of substance can be defined by two independent properties. However, in the two phase regions (during boiling or condensation), pressure and temperature are independent because they are fixed at a saturated point for a given pressure - temperature pair.

DAY- 5

Tables Of Thermodynamics Properties :-

Purpose: Thermodynamics tables provide essential data for various substance that describe their thermodynamic properties (like temperature , pressure , volume ; specific volume , internal energy like enthalpy and entropy) .

Saturated Temperature (T_{sat}) :-

Temperature at which phase change occurs at const T

Saturated Pressure (P_{sat}) :-

Pressure at which phase change occurs at const T.

This pair is not a group of independent properties .

T	P	V _f	V _{lg}	V _g
0	P ₁	V ₁	V ₁₁	V _{g1}
10	P ₂	V ₂	V ₁₂	V _{g2}
20	P ₃	V ₃	V ₁₃	V _{g3}
30	P ₄	V ₄	V ₁₄	V _{g4}
40	P ₅	V ₅	V ₁₅	V _{g5}

- linear interpolation
- Polynomical regression
- Moving average
- Lagrange interpolation

Saturated liquid & vapour tables

Z-VAD

Table B 1.1 :-

- v_f = specific volume of a saturated liquid
- v_g = specific volume of a saturated vapour
- v_{fg} = Difference b/w v_g & v_f

$$v_{fg} = v_g - v_f$$

First column :- temperature

Second Column :- Corresponding saturation pressure (P_{sat})

Table B 1.2 :-

- Contains the same information as in B1.1 but organized by pressure
- Useful

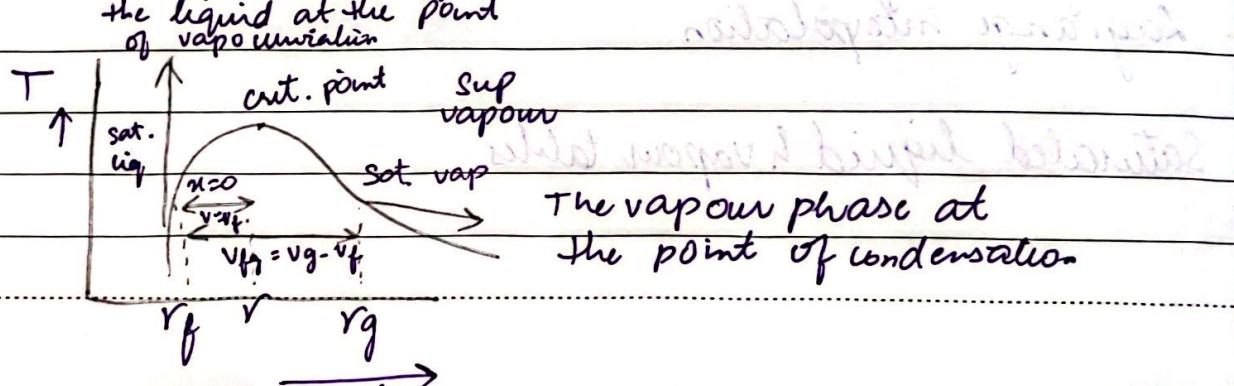
→ Sir was absent on Day 6.

DAY-6

The Two Phase States :-

Two phase state :-

A mixture of two phases of the same substance, such as liquid and vapour, in equilibrium at the same temperature (T) and pressure (P).



Date _____

Specific volume :-

Volume occupied by a unit mass of a substance measure of how much space 1kg of substance occupies.

$$v = \frac{V}{m} \Rightarrow V = rm$$

Specific Volume in Two-phase Mixture :-

Total volume of two-phase mixture is the sum of the volumes of the liquid (V_{lg}) and the vapour (V_{vg})

$$V_{\text{Total}} = V_{lg} + V_{vg} = m_{lg} V_f + m_{vg} V_g$$

Avg. specific volume :

$$v = \frac{V}{m} = \frac{m_{lg} V_f}{m} + \frac{m_{vg} V_g}{m}$$

$$\left(\frac{m_{lg}}{m} = (1-x), \frac{m_{vg}}{m} = x \right)$$

$$v = (1-x)V_f + xV_g$$

$$v = (1-x)V_f + xV_g = V_f - xV_f + xV_g \Rightarrow v = V_f + x(V_g - V_f)$$

$$v = V_f + xV_{fg}$$

Quality :-

is the ratio of mass of vapours to the total mass in a two phase mixture

Range: $0 \leq x \leq 1$

Problem:

calculate the specific volume of a saturated mixture of water at 200°C with a quality of 70%.

Refer: Table B1.1

So

$$\begin{aligned} V &= x V_f g + V_f \\ &= x(V_g - V_f) + V_f \\ &= 0.7(0.12736 - 0.001156) + 0.001156 \\ &= 0.0894988 \text{ m}^3/\text{kg} \end{aligned}$$

Date _____

Range : $0 \leq x \leq 1$

Problem :-

calculate the specific volume of a saturated mixture of water at 200°C with a quality of 70%.

Refer : Table B1.1

Sol :-

$$\begin{aligned} V &= x V_f + V_g \\ &= x(V_g - V_f) + V_f \\ &= 0.7(0.12736 - 0.001156) + 0.001156 \\ &= 0.0894988 \text{ m}^3/\text{kg} \end{aligned}$$

DAY-7

Ideal Gas Law:-

Describes the behaviour of gases under certain conditions. It provides simple correlation among pressure (P), temperature (T) and specific volume (V). It is an approximation and works best under high temperature, low density and low pressure.

Ideal Gas Equation of state :-

$$PV = RT$$

For calculations involving mass / moles :-

$$PV = mRT = nRT$$

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

Date

$$\bar{R} = 8.3145 \frac{\text{KJ}}{\text{kmolK}}$$

$$PV = mRT = n\bar{R}T$$

n is the number of moles

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

- Low pressure
- High temperature
- Low density

Mass flow rate — ideal Gas law

QUESTION:- (Table 8.5)

Mass of air?

Temp: 25°C , $P = 100\text{ kPa}$, Molecular mass = 18.015 kg/mol

Solution: Given $T = 25^\circ\text{C}$, $P = 100\text{ kPa}$

$$PV = mRT \quad (R = 0.2875 \text{ KJ/kg.K})$$

$$m = \frac{PV}{RT}$$

$$m = \frac{100 \times 298}{0.287 \times 298}$$

$$R = \frac{\bar{R}}{M} = \frac{8.3145}{28.97} = 0.287$$

$$\bar{R} = 8.3145$$

QUESTION:-

Tank has a volume = 0.5 m^3

Date

$m = 10 \text{ kg}$ for ideal gas.

molecular mass = 24, $T = 25^\circ\text{C}$

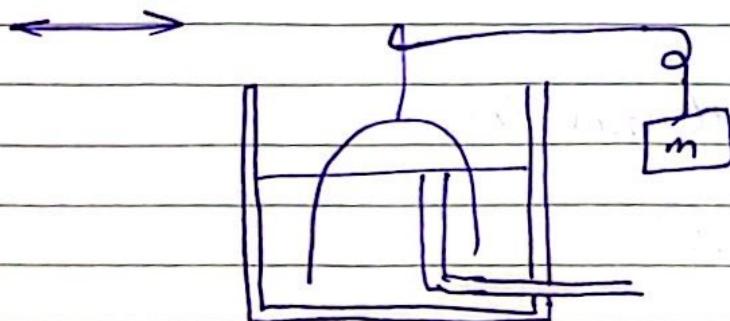
SOL

$$PV = mRT$$

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

$$= \frac{10 \times 0.3456 \times 298}{0.5}$$

$$= 2064 \text{ kPa}$$



A gas bell is submerged with its mass counterbalanced with rope and pulleys. The pressure is 105 kPa and the T is 21°C . Volume increase is measured to be 0.75 m^3 over a period of 185 seconds. What is the volume flow rate and mass flow rate.

$$R = 0.1889 \text{ kJ/kg.K}$$

$$PV = mRT$$

$$\dot{V} = \frac{0.75 \text{ m}^3}{185 \text{ s}} = \frac{\Delta V}{\Delta T}$$
$$= 0.00405 \text{ m}^3/\text{s}$$

Date

$$PV = mRT$$

$$m = \frac{PV}{RT}$$

$$\begin{aligned} &= (105 \text{ kg})(0.00405) \\ &(0.1889 \text{ kg})(294) \\ &= 7.6 \text{ kg} \\ &= 0.00766 \text{ kg/g/s} \end{aligned}$$

DAY-8

Compressibility Factor (z):

To account for the deviations in ideal gas law, compressibility factor is used

$$z = \frac{PV}{RT}$$

$$PV = zRT \quad (z = 1 \rightarrow \text{gas is ideal})$$

$(z \neq 1 \rightarrow \text{Non-ideal behaviour})$

If $z < 1 \rightarrow$ attractive forces b/w molecules dominate causing the gas to be more compressible.

$z > 1 \rightarrow$ Repulsive forces dominate \rightarrow gases resist compression.

- At low pressures, z approaches 1 as pressure approaches 0.
- At high temperatures, for many gases like nitrogen and air, z remains close to 1 up to pressures of around 10 MPa.

This means ideal gas law is still a good approximation even at moderate pressures.

Date _____

Reduced Pressure :-

$$\frac{P_r}{P_c} = \text{critical pressure}$$

Reduced Temp :-

$$\frac{T_r}{T_c} = \text{critical temp}$$

These reduced properties allows us to plot z as function

DATA

Problems

Specific volume v at 200°C with the quality of 70%.

$$v = x v_{fg} + v_f = x(v_g - v_f) + v_f = 0.08948 \text{ m}^3/\text{kg}$$

\therefore By table B.1.1

Compressed liquid

A liquid state at a pressure higher than the saturation pressure for a given temp. OR at a temp. lower than the saturation temp for given pressure.

$$P > P_{\text{sat}} \text{ at a given } T$$

$$T < T_{\text{sat}} \text{ at a given } P$$

$$V < V_g \text{ at a given } T \text{ or } P$$

$$V < V_g \rightarrow \text{Internal Energy}$$

$$h < h_g \rightarrow \text{Enthalpy}$$

Superheated vapors

A liquid state at a pressure lower than the saturation pressure OR at a temp higher than saturation temp

$$P < P_{\text{sat}} \text{ at given } T$$

$$T > T_{\text{sat}} \text{ at given } P$$

$$V > V_g \text{ at given } T \text{ or } P$$

$$V > V_g \rightarrow \text{Internal energy}$$

$$h > h_g \rightarrow \text{Enthalpy}$$

Date

Reduced Pressure:-

$$P_r = \frac{P}{P_c}$$

(P_c : critical pressure)

7.9 m 39

39 = ii
7.9

Reduced Temp:-

$$T_r = \frac{T}{T_c}$$

(T_c : critical temp)

202 00.3 K 1201

OP 821.3

These reduced properties allows us to plot z as function

(After Mid 1)

DAY 9 8-VAC Chapter 3

First Law of Thermodynamics For controlled Mass:-

(law of conservation of energy)

Control Mass:- A fixed mass system mass doesn't change.

Control volume:- A spatial region where mass can enter and exit.

Heat:- Energy transfer due to temp. difference

Work Transfer:- Energy transfer due to the force applied over a distance

Energy Equation For controlled Mass:-

Instantaneous Rate Flow:-

$$\dot{E}_{cr} = \dot{Q} - \dot{W}$$

$$\frac{d \dot{E}_{cr}}{dt} = \dot{Q} - \dot{W}$$

$$\dot{E}$$

- \dot{E} : rate of change of total energy within the control mass.

Date

Sign Convention :-

Heat (δQ) : (+ve) → when heat is entering the system

Work (δW) : (+ve) → Work done by the system

Energy Equation For Finite changes :-

Consider total energy changes over a process from state 1 $\xrightarrow{\text{to}}$ state 2

Starting Point :-

$$dE_{cv} = \delta Q - \delta W$$

Integration over time

$$\int_{t_1}^{t_2} dE_{cv} = \int_{t_1}^{t_2} \delta Q - \int_{t_1}^{t_2} \delta W$$

$$E_2 - E_1 = Q_{1-2} - W_{1-2}$$

↳ Total heat added
from state 1 \rightarrow state 2

Energy Equation (Detailed) :-

$$E_{\text{total}} = U + K.E + P.E$$

$$E_2 - E_1 = (U_2 - U_1) + \frac{1}{2} m(V_2^2 - V_1^2) + mg(h_2 - h_1)$$

QUESTION :-

$$Q = +500 \text{ J}$$

$$W = +200 \text{ J}$$

$$U = 500 - 200$$

$$U = 300 \text{ J}$$

Date _____

State Functions

Depend only on the state of system e.g. H, E

Path Functions

Depend on the specific process path taken!
eg: Q, W

Pressure Volume Work

$$SW = P dV = \frac{F}{dA} dA \cdot ds$$

$$SW = F \cdot ds$$

Isothermal: $T \rightarrow$ same

$$PV = nRT$$

Isothermal equation of an ideal gas in term of work \rightarrow homework

\rightarrow Isothermal Process

Constant Temperature

$$PV = nRT \quad \therefore \text{equation in term of work (homework)}$$

\rightarrow Isobaric Process:-

Constant Pressure

$$W = P(V_2 - V_1)$$

Date

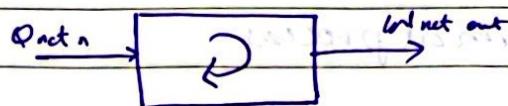
MAKEUP LECTURE DAY - 10

First Law of thermodynamics - Control Mass & Cyclic processes

$$\dot{Q} = \dot{\phi} Q - \dot{\phi} W$$

It implies that there is no net change in the total energy of control mass and the rate of change of energy is zero.

$$\text{cyclic integral of heat transfer} + \dot{\phi} Q = \dot{\phi} W \rightarrow \text{cyclic integral of the work done}$$



QUESTION :-

A engine is absorbing 250 kJ of heat and releasing 150 kJ of energy. Find First law of thermodynamics

SOL :-

$$\eta = \frac{150}{250} \times 100 = 60\%$$

$$\left(\eta = \frac{W_{\text{net.out}}}{Q_{\text{net.in}}} \right)$$

Question :-

$$P_1 = 300 \text{ kPa}, V_1 = 0.05 \text{ m}^3$$

the gas undergoes an isothermal expansion until its volume doubles. During expansion, the gas absorbs 100 J of heat from surroundings.

- ① $P_2 = ?$
- ② Calculate work done by the gas during expansion.
- ③ What is the internal energy change (ΔU)?

Date

WATERJET EJECTION DAV - TO

$$P_1 V_1 = P_2 V_2$$

$$P_2 = 150 \text{ kPa}$$

Work done by the ideal gas

$$W = n R T \ln\left(\frac{V_2}{V_1}\right)$$

$$W = P_1 V_1 \ln\left(\frac{V_2}{V_1}\right)$$

$$W = 10.4 \text{ kPa}$$

for ideal gas under isothermal process

$$\Delta U = 0$$

$$\Delta U = Q - W \Rightarrow \Delta U = -W$$

QUESTION :-

$$\text{Mass} = 1100 \text{ kg}$$

$$\text{K.E} = 400 \text{ KJ}$$

$$V = ?$$

$$KE = \frac{1}{2} m v^2$$

$$V = \sqrt{\frac{2 KE}{m}}$$

$$V = 26.96 \text{ m/s}$$

Date _____

height?

$$P.E = K.E = mgh = \frac{1}{2} mv^2$$

$$h = \frac{PE}{mg}$$

$$= \frac{400000}{(100)(9.8)}$$

$$h = 37.106 \text{ m}$$

Question:-

$$m = 10 \text{ kg}$$

$$\text{liq water} = 100 \text{ kg}$$

$$h = 10.2 \text{ m}$$

same Temp (stage 1)

stone falls into water -

Determine

ΔU , ΔKE , ΔPE , Q -YADU?

enter in water (stage 2)

Just come to rest in bucket (stage 3)

heat transferred to the surroundings that stone & water have same temp (last stage)

Sol:-

- ① $\Delta U = 0$ (Temp const isothermal process) (stage 1-2)
- ② $Q_{1-2} = 0$
- ③ $W_{1-2} = 0$

Date

$$\Delta KE + \Delta PE = 0$$

$$\Delta KE = -\Delta PE$$

$$= -mg(h_2 - h_1)$$
$$= 1 \text{ kJ}$$

stage 2 \rightarrow 3

$$\Delta U + \Delta KE + \Delta PE = 0 - W$$

$$\Delta PE = 0, Q = 0, W = 0$$

$$\Delta U + \Delta KE = 0$$

$$\Delta U = -\Delta KE = -1 \text{ kJ}$$

stage 3 \rightarrow 4

$$\Delta KE = 0 \quad \Delta PE = 0 \quad W = 0$$

$$\Delta U = -1 \text{ kJ}$$

$$Q = -1 \text{ kJ}$$

DAY-11

** Modes Of Heat Transfer :-

Heat :- Energy transferred across the boundary of the system from one body to another (surroundings) due to temperature difference b/w two systems. Heat naturally flows from a system at high temp. to one at a low temperature . If heat doesn't flow \rightarrow thermal equilibrium

units :-

Joule (SI) BTU, calories

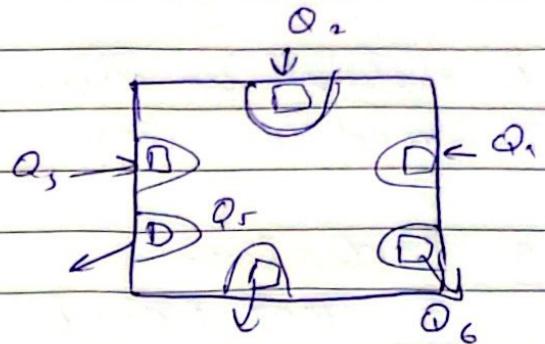
sign convention : Heat into the system : +ve

Heat out of the system : -ve

Date

Path function

$$Q_{\text{total}} = \int s dQ$$



① Conduction :-

Transfer of heat due to the direct contact b/w particles of matter. It happens because higher energy particle (those at higher temp) transfer energy to lower energy molecules (those at lower temp) via molecular collisions.

Fourier's Law of Conduction :-

$$\dot{Q} = -KA \frac{dT}{dx}$$

$$K \text{ (for metals)} = 100 \text{ W/m.K}$$

$$K \text{ (For insulators)} = \text{upto } 0.01 \text{ W/m.K}$$

where

\dot{Q} = rate of heat transfer

K = thermal conductivity of material

A = cross sectional area through heat is transferred

dT/dx = Temperature gradient

② Convection :-

Heat transfer through a moving fluid (liq or gas). It is a combination of bulk motion of fluid and conduction.

Newton's law of cooling :-

$$\dot{Q} = hA \Delta T$$

Convective heat transfer co-efficient

Date

- ① Natural convection
- ② Forced convection

③ Radiation :-

Heat transfer due to electromagnetic waves
and doesn't require any medium.

e.g. Heat from sun that reaches Earth.

Stefan - Boltzman law

$$\dot{Q} = \epsilon \sigma A T_s^4$$

where

ϵ = Emissivity of the surface (0 to 1)

σ = Stefan - boltzman constant (5.67×10^{-8})

A = surface area

T_s = surface temp

Problem:-

Room temp = T_{room} = 20°C

Outside temp = T_{ambient} = -10°C

Outer glass surface temp : T_{out} = 12.1°C

Glass thickness . n = 0.005 m

K = 1.4 W/m. K

A = 0.5 m²

h = 100 W/m². K

Conduction through glass?

Convection from glass to ambient air?

Date

Sol:-

$$Q_{\text{conduction}} = -KA \frac{\Delta T}{\Delta x}$$

$$\Delta T = 20 - 12.1 = 7.9^{\circ}\text{C}$$

$$\Delta x = 0.005 \text{ m}$$

putting the values

$$Q_{\text{conduction}} = -1106 \text{ W}$$

$$Q_{\text{convection}} = h A \Delta T$$

$$\Delta T = 12.1^{\circ}\text{C} - (-10^{\circ}\text{C})$$

$$= 22.1^{\circ}\text{C}$$

putting the values

$$Q_{\text{convection}} = 1105 \text{ W}$$

Extensive vs Intensive Properties :

Extensive properties \rightarrow depends on the amount of matter
(mass, volume, internal energy)

Intensive properties \rightarrow independent of the mass of the system (temp, pressure)

Internal Energy :-

$$U = \text{mass} \times \text{specific internal energy}$$

$$V_{fg} = V_g - V_f$$

Date _____

Internal energy in the liquid-vapour region

$$U = U_{liq} + U_{vap}$$

$x=0$ (saturated liq)

$$V = (1-x)V_f + xV_g$$

$$U = V_f + x(V_g - V_f)$$

$x=1$ (saturated vap)

Date

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DAY-12

Enthalpy :-

Enthalpy ~~contains~~ combines internal energy and pressure-volume work. It is used while analyzing processes that occur at constant pressure. Applications involve boilers, turbines and compressors where heat transfer at constant pressure is common.

Derivation :-

Consider a control mass of gas undergoing equilibrium constant pressure work. The work is only done at boundary of the gas state as it expands or compresses. According to first law of thermodynamics

$$U_2 - U_1 = Q_{12} - W_{12}$$

We assume a constant-pressure, the work done is given by :

$$W_{12} = P(V_2 - V_1)$$

Energy equation (first law of thermodynamics) become

$$U_2 - U_1 = Q_{12} - P(V_2 - V_1)$$

$$Q_{12} = (U_2 - U_1) + P(V_2 - V_1)$$

Date _____

Notice that expression for heat transfer involves a combination of internal energy and pressure volume work. We define a new property called Enthalpy.

$$H = U + PV$$

For constant pressure process, the heat-transfer is :

$$Q_{12} = H_2 - H_1$$

Specific enthalpy:

$$h = U + PV$$

saturated & superheated states:

h_f : enthalpy of saturated liquid

h_g : enthalpy of saturated ~~vapour~~ vapor

h_{fg} : enthalpy of saturated liquid-vapour mixture.

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

this is heat during the phase change of water from liquid to vapour (boiling).

Units : kJ/kg

Applications :

- Boilers and steam turbines:

Constant pressure, the heat added

$$Q_{\text{boilers}} = H_{\text{steam}} - H_{\text{water}}$$

Work done by the turbine :

Date

$$W_{\text{trans}} = H_{\text{out}} - H_{\text{in}}$$

Heat Exchangers:

$$Q = m \cdot (h_{\text{out}} - h_{\text{in}})$$

m is the mass flow rate

Internal energy :

$$U = h - PV$$

Enthalpy is a state property, means it only depends on the state of the substance, not on the path taken to reach that state.

DAV-13

Problem Analysis And Solution Technique :

Step 1:

Make a sketch of the system

Why? Helps in understanding how different aspects of the system interact!

How? Indicate the direction of mass flows, heat transfers, work and external forces.

Example: Piston cylinder system, sketch the system, the gas inside and allows show, any flow of heat or work done

Step 2:

fixed amount
of matter

Define a control mass or control volume

→ specific area through which mass flows

Defining the boundary of the system helps in applying the right laws & equations

Place a close surface around the system or subsystems

Date

you are analyzing. Identify any inflows or outflows of mass, energy and work.

Step 3:-

Apply general conservation laws

Why? These are fundamental to solve thermodynamics problem (conservation of energy, mass, first law of thermodynamics)

How? Energy equation \rightarrow ensure all inflows and outflows are mentioned

$$U_2 - U_1 = Q_{12} - W_{12}$$

Step 4:-

Write down any specific laws

Why? These allow us to handle any specific details about the substance involved in the system (ideal gas or steam etc.)

How? Reference property tables and apply specific laws based on the nature of the process (const. volume, isothermal, adiabatic etc.)

Step 5:-

Solve using diagrams or tables

Why? PV, TV diagrams help visualize the process

How? PV, TV diagrams visualization, state determinations

Step 6:-

Formulate and solve the equations

How? Combine all equations and relationships. Then solve for unknown

Example: $U_2 - U_1 = Q_{12} - P(V_2 - V_1)$

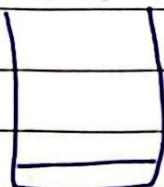
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QUESTION

A vessel with a volume of 5 m^3 contains 0.05 m^3 of saturated liq. water and 4.95 m^3 of saturated vapour at 0.1 MPa . Heat is transferred to the system until it is filled with saturated vapour. Determine the heat transfer for the process.

SOL

Step 1:



$$Q_1 = U_2 - U_1$$

Step 2:-

For a control mass/control volume system constant volume process.

Step 3:-

$$U_2 - U_1 = Q_{12} - W_{12} \rightarrow 0 \text{ when process is constant volume}$$

$$U_2 - U_1 = Q_{12}$$

Step 4:-

$$v_f = 0.001043 \text{ m}^3/\text{kg}$$

$$v_g = 1.0940 \text{ m}^3/\text{kg}$$

$$v_f = 417.36 \text{ kg/m}^3$$

$$v_g = 250.661 \text{ kg/m}^3$$

Mass of saturated liq.

$$m_{liq} = \frac{v_{liq}}{v_f}$$

Date

DAY-14

Concepts

Conservation of Mass:-

"Mass cannot be created or destroyed"
(control volume but not control mass)

For control volume, any change in mass inside the control volume must be accounted for any mass entering or leaving through the control surface. The equation of continuity is

$$\frac{dm_{cv}}{dt} = \dot{E}_{in} - \dot{E}_{out}$$

If $\frac{dm_{cv}}{dt} = 0$, then mass remains constant.

Mass flow Rate Equation :-

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

$$\text{kg/s} = \text{kg/m}^3 \cdot \text{m/s}$$

ρ = fluid Density

A = cross sectional area

V = velocity of the fluid perpendicular to the surface.

Question:-

$$d = 0.2 \text{ m}$$

$$v = 0.1 \text{ m/s}$$

$$T = 25^\circ\text{C}$$

$$P = 150 \text{ kPa}$$

Date

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Mass flow rate -

$$A = \pi r^2 = 0.03 \text{ m}^2$$

$$PV = RT$$

$$V = \frac{RT}{P} = 0.5705 \text{ m}^3/\text{kg}$$

$$R = 0.287 \text{ kJ/kg K}$$

$$\dot{m} = \frac{VA}{V}$$

$$\dot{m} = 0.0055 \text{ kg}$$

Energy Equation for a control volume in thermodynamics:

For control mass, the energy equation is written as

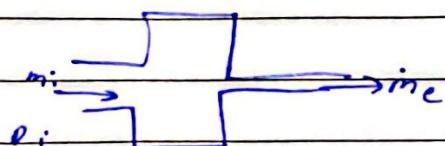
$$E_2 - E_1 = Q_{12} - W_{12}$$

instantaneous form

$$\frac{dE_m}{dt} = \dot{Q} - \dot{W}$$

The energy equation for control volume

$$\frac{dE_{cv}}{dt} = \dot{Q}_{cv} - \dot{W}_{cv} + \sum_{in} (e_i + p_i V_i) - \sum_{out} (e_e + p_e V_e)$$



where,

Date

$$e = U + \underbrace{V}_{IE} + \underbrace{\frac{V^2}{2}}_{KE} + \underbrace{gz}_{PE}$$

PV is work flow
subscripted
'1' → incoming
'e' → outgoing

$$\frac{dE_{cv}}{dt} = Q_{cv} - W_{cv} + \sum m_i \left(h_i + \frac{V_i^2}{2} + g z_i + P_i V_i \right) - \sum m_e \left(h_e + \frac{V_e^2}{2} + g z_e + P_e V_e \right)$$

the total energy for unit mass is

$$U + P_i V_i + \frac{V^2}{2} + gz$$

specific enthalpy $\downarrow h + \frac{V^2}{2}$ → specific PE
 \downarrow specific KE

the energy equation for control volume::

$$\frac{dE_{cv}}{dt} = Q_{cv} - W_{cv} + \sum m_i \left(h_i + \frac{V_i^2}{2} + g z_i \right) - \sum m_e \left(h_e + \frac{V_e^2}{2} + g z_e \right)$$

Applications ::

turbines
compressor
heat exchanger
nozzles.

Date

Steady State Processes:-

Where the properties of the system do not change with time

→ m_1 and m_2 are constant

→ Properties of fluid entering or exiting are constant

→ Energy within control volume doesn't accumulate over time.

Date

Steady State Processes:

Where the properties of the system do not change with time

→ m_1 and m_2 are constant

→ Properties of fluid entering or exiting are constant

→ Energy within control volume doesn't accumulate over time

DAY-15

Heat Exchanger:-

A steady-state heat exchanger is a system in which heat is being transferred.

Example 4.3

$$P_1 = 1 \text{ MPa}$$

$$T_1 = 60^\circ\text{C}$$

$$T_2 = 35^\circ\text{C}$$

$$P_2 = 0.95 \text{ MPa}$$

$$h = 2671.37$$

$$h_g = 32265.46$$

$$\underline{x = 0.99}$$

- We did example 4.3 & 4.4

Date

Ch# 5

DAV - 16

Heat Engines and Refrigerators

Heat Engines :

A device that operates on a thermodynamic cycle, transferring heat from a high temperature reservoir to a low temperature reservoir and producing net positive work.

- steam, gas or other substance undergoes a cyclic process of heating and cooling

Steam power/engine :

- Heat Q_H is absorbed from a high temperature source
- steam flows through the turbine \rightarrow performing work.
- steam is condensed, releasing Q_L heat to a low temp. reservoir

Thermal Efficiency :

It is a measure of how well the heat engine converts heat input into useful work.

$$\eta_{\text{ideal}} = \frac{W}{Q_H} = 1 - \frac{Q_L}{Q_H}$$

(engine)

Q_H = Heat absorbed

Q_L = Heat released

$$W = Q_H - Q_L$$

Efficiency of Real Engines :

Large power plants : 35-50 %

Gasoline engines : 30 - 35 %.

Diesel engines : 30 - 40 %.

Smaller engines : 20 %.

Refrigerators and Heat Pumps:

Refrigerators is a device that uses work to transfer heat from a lower temperature to a higher temperature - it operates on a cycle, similar to a heat pump, with a focus on cooling.

Co-efficient of Performance (COP)

$$\beta = \frac{Q_L}{W} = \frac{Q_L}{Q_H - Q_L} = \frac{1}{\frac{Q_H}{Q_L} - 1} \quad \beta' = \frac{Q_L}{Q_H}$$

Basic Cycle:

- A typical refrigerator uses a vapour compression cycle
- Refrigerant R-134a or ammonia absorbs Q_L in the evaporator at low pressure and temperature.
- Refrigerant releases Q_H at the condenser.

Heat Pump:

When the objective is to heat a space, rather than cool it, it is called heat pump.

$$COP = \beta' = \frac{Q_H}{W} = \frac{Q_H}{Q_H - Q_L}$$

relationship b/w β & β'

$$\beta = \frac{Q_L \beta'}{Q_H}$$

- Reservoir from which heat is transferred, it is called source.
- Reservoir to which heat is transferred is called sink.

DAY-17

Second Law of Thermodynamics :-

- Governs energy transfer and conversion in thermodynamic system
- Introduces concepts of irreversibility and efficiency
- The law has two classical statements
 - ↑ Kelvin Planck statement
 - ↓ Clausius statement

Kelvin Planck Statement :

"It is impossible to construct a device that operates in a cycle and produces no effect other than the raising of a weight (work done) and the exchange of heat with a single thermal reservoir."

Key implications :

- Heat engine cannot be 100% efficiency i.e. $\eta \neq 100\%$.
- $\eta = \frac{W}{Q_H} \neq 100\%$
- Heat must flow from a high temp to a low temp reservoir.

Clausius Statement :

"It is impossible to construct a device that operates in a cycle and produces no effect other than the transfer

of heat from a cooler body to a warmer body "

I Refrigerator/heat pump : Heat cannot flow from cold reservoir to a

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

F1-YAC

$$\text{COP}_{\text{heat pump}} = \frac{Q_H}{W} = \frac{Q_H}{Q_H - Q_L}$$

→ Violation of Clausius statement implies violation of Kelvin-Planck statement

→ The reverse is also true :-

3) Perpetual Motion Machines :

First kind :- Creates energy from nothing, violating the first law of thermodynamics

Second kind :- Converts heat from a single reservoir entirely into work, violating the second law $Q_H = W$

Third kind :- operates indefinitely without friction or work output theoretically impossible.

Reversible Process :

A reversible process is an idealized process that, when reversed, leaves both the system and its surroundings completely unchanged.

→ In reality, all processes are irreversible

→ Irreversible processes deviate from equilibrium

Factors Of Irreversibility

1. Friction

Date

2. Unrestrained Expansion

3. Heat transfer through a finite temp difference.

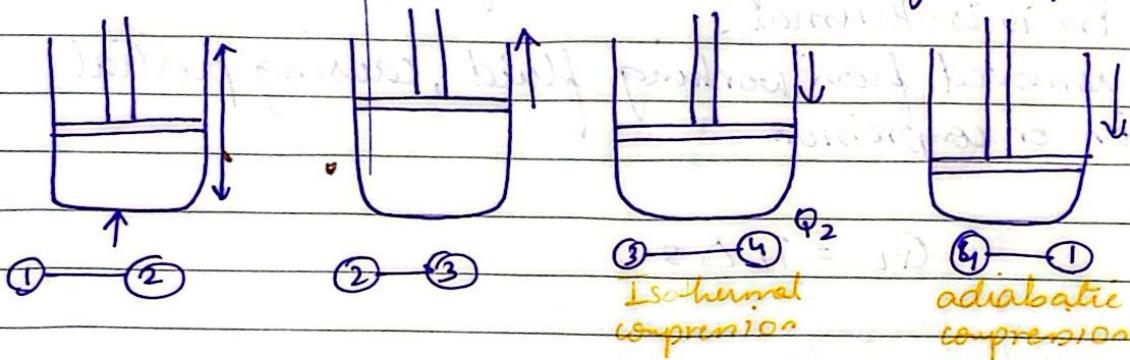
4. Mixing of different substances

DAY - 18

Carnot Cycle:

Carnot cycle consists of 4 reversible processes.

1. Reversible isothermal heat addition at a high temperature
2. Reversible adiabatic expansion from a high temperature to a low temperature
3. Reversible isothermal heat rejection at a low temperature
4. Reversible adiabatic compression back to the high temperature



① Reversible Isothermal heat addition at a high Temperature

- Absorbs Q_H from high temp reservoir.

- Heat transfer takes place

- Working fluid expands, doing work on the surroundings

- May involve a phase change

$$Q_H = T_H \Delta S \rightarrow \text{Change in entropy}$$

- Q and W are positive

② Reversible Adiabatic Expansion :-

- Working fluid expands without exchanging heat with the surroundings
- A diabatic process $Q = 0$
- Temp. of the fluid decreases from T_H to T_L
- Work W done by the system on the surroundings

$$T_H V_2^{\gamma-1} = T_L V_3^{\gamma-1} \quad \gamma = c_p/c_v \text{ (For ideal gas)}$$

③ Reversible Isothermal Heat Rejection :

- Working fluid rejects heat Q_L to low temp. reservoir at constant temp T_L .
- Working fluid temp is infinitesimally higher than T_L
- The process is isothermal.
- Heat is removed from working fluid, causing partial condensation or compression

$$Q_L = T_L \Delta S$$

④ Reversible Adiabatic Compression :

- The working fluid is compressed adiabatically, raising Temp back to T_H .
- Conditions :
 - ① Adiabatic process $Q = 0$
 - ② Reversible work done on the system by surrounding
 - Effect on system : system temperature raise from T_L to T_H

$$T_L V_4^{\gamma-1} = T_H V_1^{\gamma-1}$$

$$U = +W$$

Efficiency of Carnot cycle :-

$$\eta = 1 - \frac{Q_L}{Q_H} = 1 - \frac{T_L}{T_H}$$

Key features :-

- Reversible
- Depends only on the Temperature
- Entropy

$$\Delta S_H = \frac{Q_H}{T_H}, \quad \Delta S_L = \frac{Q_L}{T_L}$$

Application :

- Real world limitations
- No real engine can operate on the Carnot cycle due to irreversibilities
- Carnot cycle is just a benchmark for real engines.

Two properties regarding the efficiency of a Carnot cycle :

1. It is impossible to construct an engine that operates b/w two given reservoirs and is more efficient than a reversible engine operating b/w the same two reservoirs .

$$\eta_{\text{any}} \leq \eta_{\text{reversible}}$$

$\eta_{\text{any}} \rightarrow$ efficiency of any engine operating b/w two reservoirs .

2. All engines that operate on the Carnot cycle b/w two given constant-temperature reservoirs have the same efficiency .

Date

$$\eta_{\text{rev.}} = \eta_{\text{res.}}$$

$$\frac{sT - 1}{HT} = \frac{sD - 1}{HD}$$

intake int no

$$\frac{D - 1.24}{HT} = \frac{D}{HD}$$

intake

leaves at soft slopes toward int no storage and
unpermeable layer of sandstone so that

mining out soft limestone took impeded infiltration



Chapter # 6

Entropy

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

The inequality applies to all possible thermodynamic cycles - whether reversible or irreversible - and is used to define entropy.

Entropy is defined as

$$ds = \left. \frac{\delta Q}{T} \right|_{rev}$$

Entropy change

$$S_2 - S_1 = \int \left. \frac{\delta Q}{T} \right|_{rev}$$

Reversible Heat Engine cycle :-

$$\text{Net heat transfer} \quad \left. \begin{array}{l} \oint \delta Q = \delta Q_H - \delta Q_L > 0 \\ \end{array} \right.$$

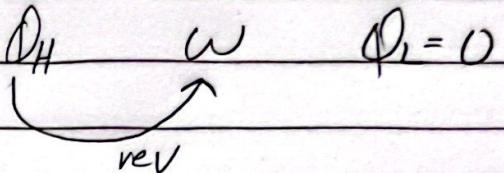
$$\text{net entropy change} \quad \oint \frac{\delta Q}{T} = \frac{\delta Q_H}{T_H} - \frac{\delta Q_L}{T_L} = 0$$

For all reversible cycles

$$S_2 - S_1 = \oint \frac{\delta Q}{T} = 0$$



Irreversible heat Engine

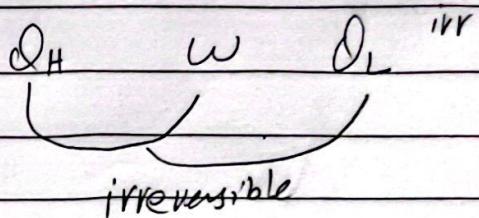


Work:

$$W_{\text{irr}} < W_{\text{rev}}$$

Heat transfer:

$$Q_L^{\text{irr}} > Q_L^{\text{rev}}$$



Net Entropy change

$$\oint \frac{d\theta}{T} = \frac{Q_H}{T_H} - \frac{Q_L^{\text{irr}}}{T_L} < 0$$

For all irreversible cycle:

$$S_2 - S_1 = \oint \frac{d\theta}{T} < 0$$

- High entropy mean energy is scattered and more disorder / randomness.
- Low Entropy energy is more organized.

When heat flows into the system

Entropy increase (+ve) and vice versa.

heat into the system → +ve

heat out of the system → -ve

Date

DAY- 21

Ch# 6 topic 6.1, 6.2, 6.3, 6.4, 6.6

Problem :

Water at 100°C , quality 50% in a rigid box is heated to 110°C . How do the $\rho, V, u, r, \text{ and } s$ change? (increase, decrease or stay the same)

sol

A fixed mass in a rigid box

$V \rightarrow \text{constant}$

$\rho \rightarrow \text{increase}$

$V \rightarrow Q_{in} \rightarrow \uparrow$

$u \rightarrow \uparrow$

$s \rightarrow \uparrow$

Problem :

Q) Determine the entropy for
R-410a, $T = 25^{\circ}\text{C}$, $V = 0.01 \text{ m}^3/\text{kg}$

5) Determine the missing property among ρ, T, s and x for R-410a

a - $T = -20^{\circ}\text{C}$, $V = 0.1377 \text{ m}^3/\text{kg}$

sol

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

$$x = \frac{V_f - V}{V_{fg}}$$

$$x = 0.6377$$

$$s = s_f + x s_{fg}$$

$$s_f = 0.3631$$

$$s_{fg} = 0.6253$$

Date

DAY-1

$$s = 0.7618 \text{ kJ/kgK}$$

b) $v_f < v < v_g$

$v > v_g \rightarrow \text{superheated} \rightarrow \text{undefined}$

$P \rightarrow 200 \text{ kPa}$

$s = 1.1783 \text{ kJ/kgK}$

$$P = 200 \text{ kPa}$$

$$s = 1.409 \text{ kJ/kgK}$$

$$T = ? \quad u = ?$$

$s > s_g \rightarrow \text{superheated}$

$u \rightarrow \text{undefined}$

$T = 60^\circ\text{C}$ is a reasonable guess

frankness $\leftarrow v$

redundant $\leftarrow u$

$T \leftarrow u \leftarrow v$

$T \leftarrow u$

$T \leftarrow 2$

Problem

Determine the missing property among P, v, s and u for CO_2 .

$$T = 20^\circ\text{C} \quad s = 1.49 \text{ kJ/kg.K}$$

④ $u \rightarrow s > s_g \rightarrow 1.04 \rightarrow \text{superheated}$

undefined 1.49

$$\frac{P - 1400}{2000 - 1400} = \frac{1.49 - 1.5283}{1.4438 - 1.5283}$$

$$P = 1671.9 \text{ kPa}$$

$\boxed{P} \boxed{v} \boxed{x} \boxed{s} \boxed{u} = v$

$\boxed{P} \boxed{v} \boxed{x} \boxed{s} = u$

$\boxed{P} \boxed{v} \boxed{x} = s$

$\boxed{P} \boxed{v} \boxed{x} \boxed{s} = u$

Date

DAY-23

The Rankine Cycle :

Idealized thermodynamic cycle for a simple power plant.

2. Process (2-3). Constant heat addition in the boiler

→ Heat is transferred to a fluid at a constant pressure in the boiler.

→ The process converts the compressed liquid (state 2) into vapour (state 3).

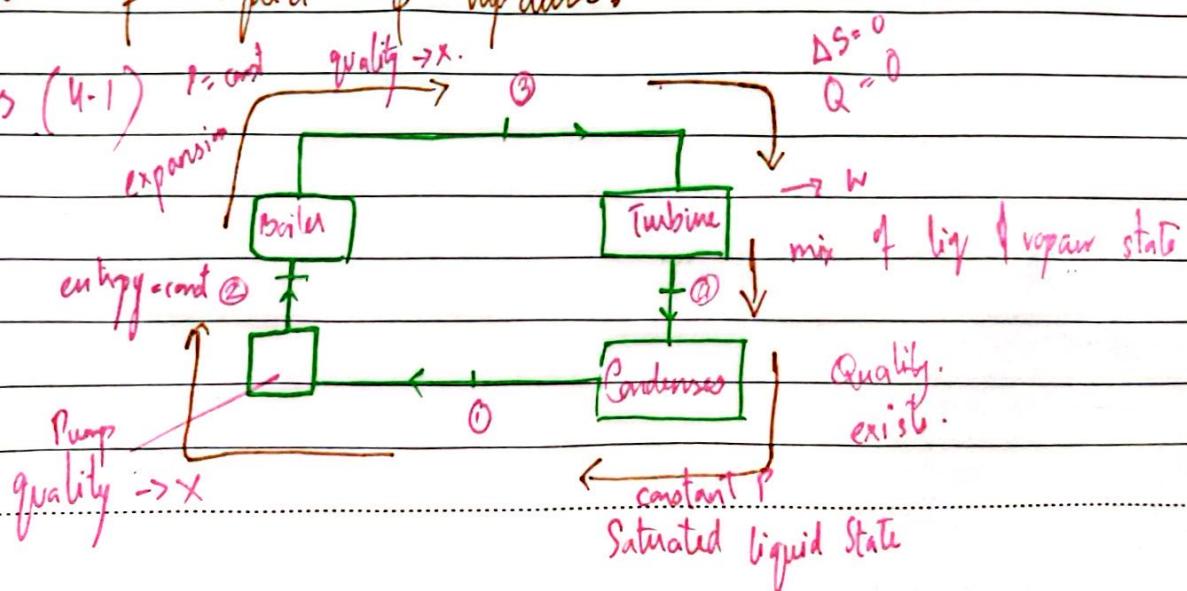
→ If super heating is involved, the fluid moves to state 3'.

3.) Process (3-4) Reversible Adiabatic expansion in the turbine

→ The superheated vapour expands isentropically in turbine producing work.

→ The fluid exits the turbine at state 4 which is a mixture of liquid & vapours.

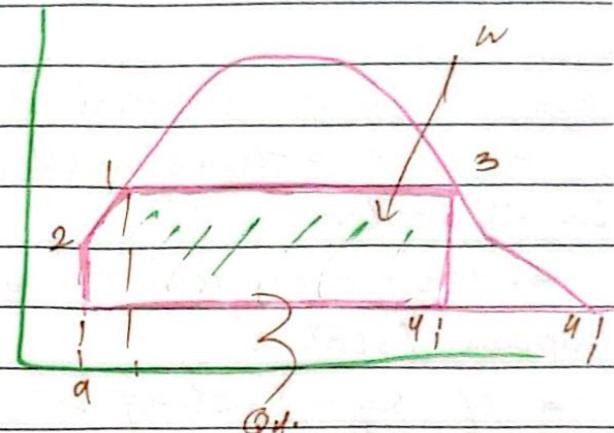
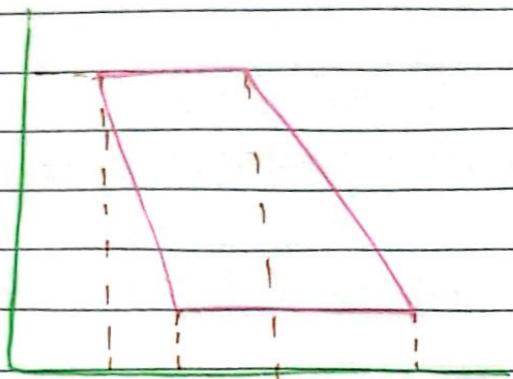
4. Process (4-1)



Date

Process (4-1) : Constant - pressure heat rejection in condenser.

- The working fluid rejects heat at constant pressure in condenser.
- The process brings the fluid back to saturated liquid state at point 1.



efficiency of Rankine Cycle :

$$\eta_{th} = \frac{W_{net}}{q_{in}} = \frac{\text{Area } (1-2-2'-3-4-1)}{\text{Area } (a-2-2'-3-b-a)}$$

Efficiency depends on:

9.2 The Rankine Cycle

- 1- Process (1-2):
- 2- Process (2-3): Constant pressure heat addition in the boiler
 - Heat is transferred to the fluid at a constant pressure in the boiler.
 - The process converts the compressor liquid (state 2) into vapors (state 3)
 - If superheating is involved, the fluid moves to state 3
- 3- Process (3-4): Reversible Adiabatic expansion in turbine
 - The superheated vapour expands isentropically in the turbine, producing work
- 4- Process (4-1): Constant-pressure heat rejection in the condenser
 - The working fluid rejects heat at constant pressure in the condenser.
 - The process brings the fluid back to the saturated liquid state at point 1.

Efficiency of Rankine Cycle:

$$\eta_{th} = \frac{w_{net}}{q_H} = \frac{\text{Area}(1-2-2'-3-4-1)}{\text{Area}(a-2-2'-3-b-a)}$$

Efficiency depends on

→ For heat addition:

9.3. Effect of Pressure and Temp on Rankine Cycle

- ① Reverse adiabatic compression in the pump
($\Delta S=0$, $S \rightarrow \text{const}$, $Q=0$)
- ② Isobaric (const pressure) heat addition ($P \rightarrow \text{const}$)
- ③ Reversible adiabatic expansion in the turbine
($\Delta S=0$, $Q=0$, $S \rightarrow \text{const}$)
- ④ Isobaric (Const pressure) heat rejection ($P \rightarrow \text{const}$)

Efficiency of the Rankine cycle is influenced by:

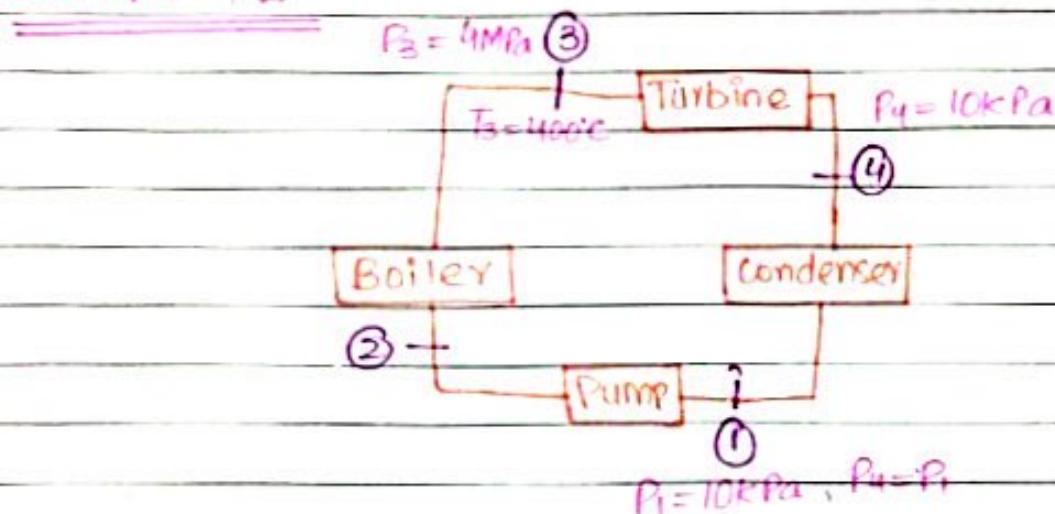
- Condenser pressure (P_4)
- Superheat temp in the boiler (T_3)
- Maximum boiler pressure

Effect of Pressure and Temperature

- Lower condenser pressure
 - ↳ Increases efficiency
 - ↳ Increases turbine exhaust moisture content
- Superheating the steam (boiler)
 - ↳ Increases the efficiency
 - ↳ Improves the turbine exhaust moisture content

- Increasing boiler pressure
- Increases efficiency

Example 9.2



Step 1 Pump work (up)

① Inlet state $P_1 = 10 \text{ kPa}$, saturated liquid

$$h_1 = 191.8 \text{ kJ/kg}, v = 0.001 \text{ m}^3/\text{kg}$$

$$w_p = v(P_2 - P_1) = 4 \text{ kJ/kg}$$

$$\Rightarrow w_p = h_2 - h_1 \Rightarrow h_2 = h_1 + w_p = 195.8 \text{ kJ/kg}$$

$$h_3 = 32123 \text{ kJ/kg}, s_3 = 6.7690 \text{ kJ/kg}$$

$$q_h = h_3 - h_2 = 3017.8 \text{ kJ/kg}$$

Step 3 $P_4 = 10 \text{ kPa}$

$$s_4 = s_3 = 6.7690 \text{ kJ/kg.K}$$

$$s_4 = s_f + x s_{fg}$$

$$x_4 = 0.8159$$

$$h_4 = 2144.1 \text{ kJ/kg}$$