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S.Y. Diploma : Sem. IV [ME/MH/MI]

Thermal Engineering

Prelim Question Paper Solution

1. (a) (i) Thermodynamic

It is defined as "region in a space, upon which attention is focused for the study of work and heat transfer and conversion, i.e., for the study of thermodynamic process".

1. (a) (ii) Extensive Property : "The properties, which are dependent on mass, are called as extensive properties". For example : Volume and energy.

Intensive Property : "The properties, which are independent of mass, are called intensive properties". For example : Pressure, temperature and specific volume.

1. (a) (iii) Thermodynamic Work

- In thermodynamics, work is defined as, "the energy transferred (without the transfer of mass) across the boundary of a system, because of an intensive property difference other than temperature, that exists between system and surrounding".
- Here, intensive property difference is pressure difference between system and surrounding

  Note : 1 N.m = 1 J

  1 kJ = 1×10^3 J

  1 MJ = 1×10^6 J

  1 GJ = 1×10^9 J

1. (a) (iv) Zeroth's Law of Thermodynamics

- When two bodies having different temperature are brought in contact with each other, after some time, both bodies attain same temperature. When this state of equal temperature is attained, then the bodies are said to be in thermal equilibrium.
- Take three bodies namely A, B and C. Suppose A and C are in thermal equilibrium. Similarly let B and C are also in thermal equilibrium, then Zeroth's law states that bodies A and B are also in thermal equilibrium.
- Thus, according to Zeroth's law, if two systems are each in thermal equilibrium with a third system, then the two systems are also said to be in thermal equilibrium with each other.

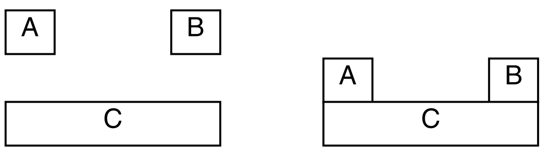


Fig. : Zeroth law of thermodynamics

1. (a) (v) Charle's law

It states that, the volume of a given mass of gas is directly proportional to temperature, when pressure is constant.

i.e. $V \propto T$ when P is constant

i.e. $\frac{V}{T}$ = constant

or $\frac{V_1}{T_1} = \frac{V_2}{T_2} = \frac{V_3}{T_3}$ = constant

1. (a) (vi) Sensible Heat

- It is the type of heat, which can be sensed by thermometer.
- It is calculated by measuring the temperature difference, when either heat is supplied or rejected.
- It is given by

  Sensible heat $= m\, C_p\, \Delta T$

  where m = mass of working substance in kg

  C_p = specific heat in kJ/kg °C or kJ/kg K

  ΔT = temperature difference in °C or K
- During this type of heat addition or heat rejection, no phase change take place.

Latent Heat

- It is defined as, "the quantity of heat required for phase change of working substance at constant temperature".
- For example, latent heat of vapourization of water is the amount of heat required to convert 1 kg of water at 100 °C into dry saturated steam at 100 °C. It is denoted by h_{fg}.

1. (a) (vii) Mach Number

It is defined as, "the ratio of actual velocity (V) to the sonic velocity (C)".

Mathematically, $M = \frac{V}{C}$

where V = Actual velocity

and C = Sonic velocity

1. (a) (viii) Vacuum Efficiency

The vacuum efficiency is defined as 'the ratio of actual vacuum to the ideal vacuum'.

Mathematically, $$\eta_v = \frac{\text{Actual vacuum}}{\text{Ideal vacuum}} = \frac{\text{Barometric pressure} - \text{Actual pressure}}{\text{Barometric pressure} - \text{Ideal pressure}}$$

1. (b) (i) Difference between Forced Convection and Natural Convection

	Natural Convection	Forced Convection
1)	Here, heat transfer is due to temperature difference.	In addition to temperature difference, here velocity of circulation of fluid is improved for effective heat transfer.
2)	Here, buoyancy force is responsible for heat flow.	Here, external force created by fan, blower, etc., is responsible for heat flow.
3)	Low heat transfer coefficient.	High heat transfer coefficient.
4)	Use is limited due to low heat transfer rate.	It is mostly used in practice due to high heat transfer rate.

1. (b) (ii) Value of index (n)

We have, $$P_1V_1^n = P_2V_2^n$$

$$\therefore \quad \left(\frac{V_2}{V_1}\right)^n = \frac{P_1}{P_2}$$

Taking log on both sides,

$$\log_e\left[\left(\frac{V_2}{V_1}\right)^n\right] = \log_e\left(\frac{P_1}{P_2}\right)$$

$$\therefore \quad n\ \log_e\left(\frac{V_2}{V_1}\right) = \log_e\left(\frac{P_1}{P_2}\right)$$

$$\therefore \quad n \times \log_e\left(\frac{150\times10^{-6}}{750\times10^{-6}}\right) = \log_e\left(\frac{100\times10^{3}}{780\times10^{3}}\right)$$

$$\therefore \quad n \times (-1.6094) = (-2.0541)$$

$$\therefore \quad n = 1.276$$

Work done during compression

$$W_{1-2} = \frac{P_1V_1 - P_2V_2}{n-1}$$

$$= \frac{(100\times10^3\times750\times10^{-6})-(780\times10^3\times150\times10^{-6})}{1.276-1}$$

$$= -152.17 \text{ J}$$

Negative sign indicates that, work is done on the gas.

Heat rejected during polytropic compression

$$Q_{1-2} = \frac{\gamma-n}{\gamma-1} \times \text{work done}$$

$$= \frac{1.4-1.276}{1.4-1} \times (-152.17)$$

$$= -47.17 \text{ J}$$

Negative sign indicates, heat is rejected by the gas during compression.

1. (b) (iii) PPM-II

- "The device, in which total amount of heat supplied is converted into work, is called as PMM–II". It violates Kelvin-Plank statement. Its efficiency is 100%, as the total amount of heat supplied is converted into work. Refer Figure (a).
- Also, the device, in which, no input work is supplied to the device, so as to transfer heat from cold body to hot body, is called as PMM-II. It violates the Clausius statement. Refer Figure (b).

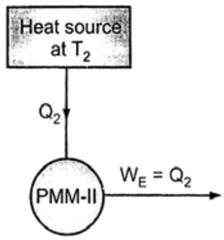


Fig. (a) : PMM-II violating Kelvin-Plank statement.

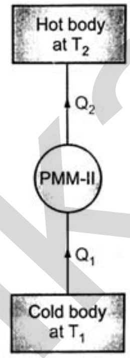


Fig. (b) : PMM-II violating Clausius statement.

2. (a)

- There are certain quantities like heat and work, which cannot be located on a graph by a point, but are given by area on that graph. In this case, the area on the graph, pertaining to a particular process, is a function of path of process. Such quantities are called as path functions.
- Referring to the figure, it is possible to take a system from point 1 to point 2 in several ways, such as A, B, C. i.e. 1-A-2, 1-B-2 or 1-C-2.

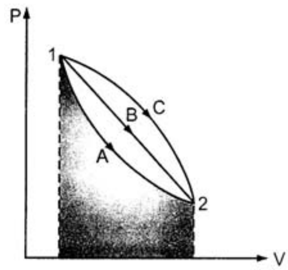


Fig.

- Since the area under each curve represents work involved in each process, therefore work involved depends upon the path followed by the process and does not depend upon the end states. Thus, work can be called as path function.
- The thermodynamic quantities, which are dependent of the path followed between two end states of process and independent of two end states of process are path functions. Example : work, heat. Shaded area shows the work involved during path A.
- They are in-exact differentials. Their change cannot be written as difference between their end states.

  Thus, $\int_1^2 dQ \neq Q_2 - Q_1$, but is shown as Q_{1-2}, i.e. an in-exact differential.
- Thermodynamic properties are point functions, because for a given state, there is definite value for each property. Therefore, they are called as point functions OR in other words, when the properties (point functions) can be located on a graph (co-ordinate axes), they are called as point functions.

- Their change can be written as difference between their end states.

  Thus, $\int_1^2 dV = V_2 - V_1$, i.e. an exact differential.
- The change in thermodynamic property during a change of state is independent of path followed and depends only upon initial and final states. Example : pressure, volume and temperature.

2. (b) Given data : $T_1 = -3\ °C = -3 + 273 = 270\ K$

$T_2 = 27\ °C = 27 + 273 = 300\ K$

Refrigerating effect or cooling load = Q_1 = 6.3 kJ/sec.

Procedure :

1) COP of system (Refrigerator)

We have, $(COP)_R = \dfrac{T_1}{T_2 - T_1} = \dfrac{270}{300 - 270}$

$= 9$

2) Power required to operate the refrigerator

$(COP)_R = \dfrac{R.E.}{W.D.}$

$\therefore \quad W.D. = \dfrac{R.E.}{COP} = \dfrac{6.3}{9}$

$= 0.7$ kJ/sec or kW

2. (c) Difference between Heat Pump and Refrigerator

	Heat Pump	Refrigerator
(i)	The function of heat pump is to supply more and more amount of heat to hot body from cold body. It has nothing to do with the temperature of cold body.	The function of refrigerator is to absorb more and more amount of heat from cold body and give it to hot body. It has nothing to do with temperature of hot body.
(ii)	It works between hot body temperature and atmospheric temperature.	It works between cold body temperature and atmospheric temperature.
(iii)	$(COP)_P = \dfrac{\text{Amount of heat supplied to hot body}}{\text{Work done}}$	$(COP)_R = \dfrac{\text{Amount of heat extracted from cold body}}{\text{Work done}}$
(iv))	In terms of heat, $(COP)_P = \dfrac{Q_2}{Q_2 - Q_1}$	In terms of heat, $(COP)_R = \dfrac{Q_1}{Q_2 - Q_1}$
(v)	In terms of temperature, $(COP)_P = \dfrac{T_2}{T_2 - T_1}$	In term of temperature, $(COP)_R = \dfrac{T_1}{T_2 - T_1}$
(vi)	For same temperature limits, COP of heat pump is more than COP of refrigerator.	For same temperature limits, COP of refrigerator is less than COP of heat pump.

2. (d) **Isothermal Process on P-V and T-S**

- If the temperature of gas remains constant during expansion or compression, the process is called as isothermal process.
- Suppose a gas is contained in a cylinder piston arrangement, initially at temperature T_1, pressure P_1 and volume V_1.
- In the state of equilibrium at 1, there is no transfer of heat between system and surrounding, as both are at same temperatures.
- Now, if the piston is moved slightly and slowly in upward direction, the gas will expand in volume and accordingly pressure and temperature will decrease.
- Due to decrease in temperature, heat transfer takes place from surrounding to system, thereby increasing temperature of gas and once again system is restored to its original position.
- Isothermal process is possible only, when the piston is moved very slowly i.e. quasi-static process, but in actual practice, this is not possible. Hence, it is an impractical process.

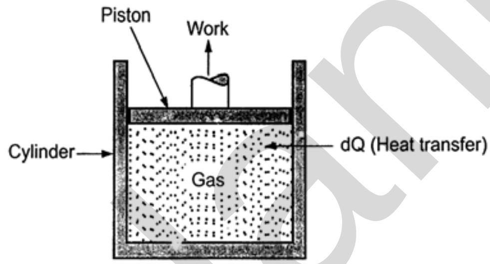


Fig. : Cylinder-piston arrange showing isotherm process.

P-V-T relationship

$$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$$

We get $P_1V_1 = P_2V_2$ $[\because T_1 = T_2]$

i.e. $PV = \text{constant}$

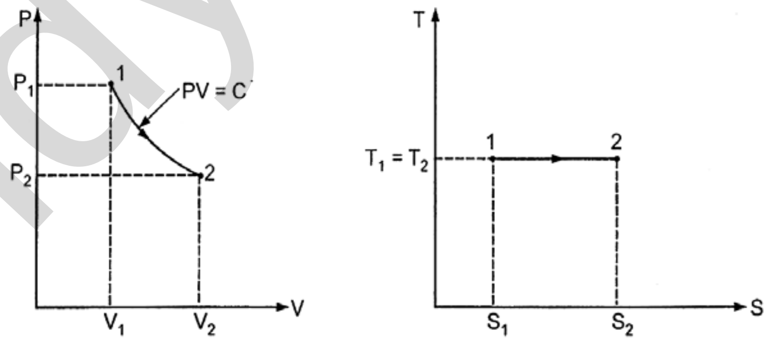


Fig. : P-V and T-S diagrams.

2. (e) Given data : $V_1 = 2.5\ m^3$, $P_1 = 8\ bar = 8 \times 10^5\ N/m^2 = P_2$

$T_1 = 180\ °C = 180 + 273 = 453\ K$

$V_2 = 2V_1$, $C_P = 1\ kJ/kg\ K$, $C_V = 0.715\ kJ/kg\ K$

Procedure : By general gas equation,

$$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$$

As $P_1 = P_2$ $\quad T_2 = \frac{V_2}{V_1} \times T_1 = \frac{2V_1}{V_1} \times 453 = 906\text{ K} \quad [\because V_2 = 2V_1]$

Also, $\quad C_P - C_V = R$

$\therefore \quad 1 - 0.715 = R$

$\therefore \quad R = 0.285\text{ kJ/kg K} = 285\text{ J/kg K}$

We have, $\quad P_1V_1 = mRT_1$

$\therefore \quad 8 \times 10^5 \times 2.5 = m \times 285 \times 453$

$\therefore \quad m = 15.49\text{ kg}$

(i) Change in internal energy :

$$dU = mC_V (T_2 - T_1)$$
$$= 15.49 \times 0.715 \times (906 - 453) = 5017.13\text{ kJ}$$

(ii) Work transferred :

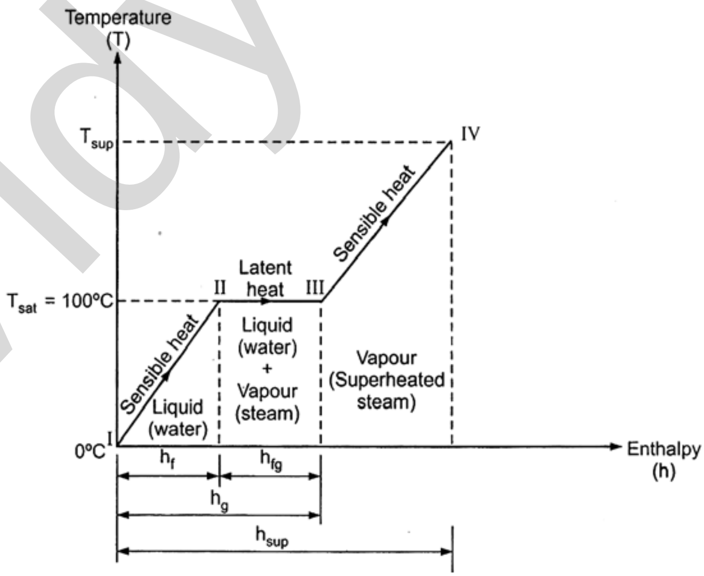
$$dW = mR (T_2 - T_1)$$
$$= 15.49 \times 0.285 \times (906 - 453) = 1999.83\text{ kJ}$$

(iii) Change in Enthalpy :

$$= h_2 - uh_1$$
$$= (u_2 + P_2V_2) - (u_1 + P_1V_1) = (u_2 - u_1) + (P_2V_2 - P_1V_1)$$
$$= 5017.13 \times 10^3 + mR(T_2 - T_1) = 5017.13 \times 10^3 + 1999.53 \times 10^3$$
$$= 7016.96\text{ kJ}$$

2. (f) Steam Generation Process

Pure substance can be in solid, liquid or gaseous states, or in mixture of phases. When heat is added to the pure substance or removed from the pure substance, it may change its phase. Let 1 kg of water at 0 °C and at atmospheric pressure is to be converted into steam. The heat is added to the water in following stages.



1) I - II

- The water at 0 °C is heated to 100 °C i.e. boiling point of water at atmospheric pressure. The temperature rise can be sensed by thermometer, therefore the heat added is called as sensible heat of water (fluid) and denoted by h_f.
- Also, no phase change occurs, i.e. water (liquid phase) will exist.

2) II - III

- Now the water in liquid phase at 100 °C is further heated, but as the water is in saturated state, its temperature does not increase, but liquid is transformed or vapourized to vapour form i.e. phase changes from liquid to gas.
- The heat added during this cannot be sensed by thermometer and therefore called as latent heat of vapourization of water, denoted by h_{fg}.

3) III - IV

- Now, the steam is in dry saturated state i.e. no moisture is present in the steam. When heat is further added to dry saturated vapour, it is converted into superheated steam.
- Temperature of superheated steam is called as superheated temperature.

3. (a) Thermal Power Plant

- It is an ideal cycle for comparing the performance of steam power plants. The schematic diagram of a steam engine or a turbine plant is as shown in figure.

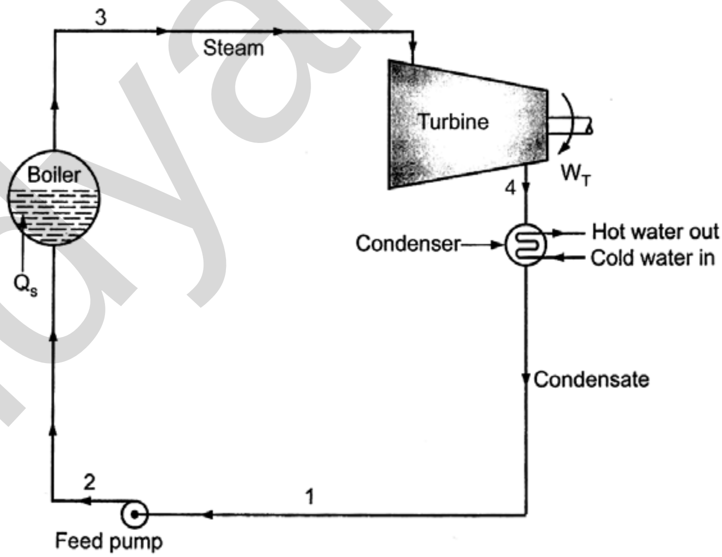
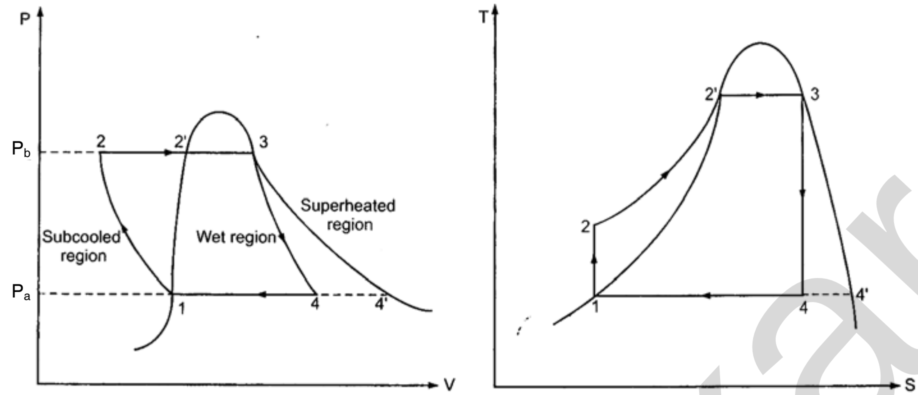


Fig. : Steam Turbine Power Plant.

- Consider 1 kg of saturated water at pressure P_1 and absolute temperature T_1 as represented by point 1. The cycle is represented on P-V and T-S diagrams.



(a) Rankine cycle on P-V (b) Rankine cycle on T-S diagram

Fig.

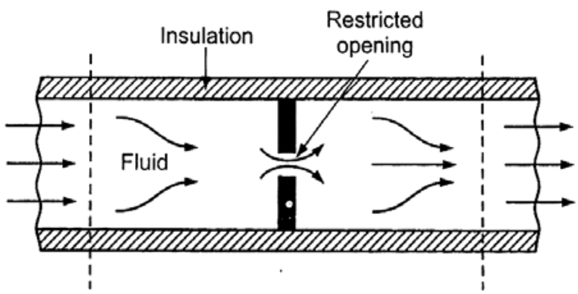
- The cycle is completed by the following processes :
  (a) *Process 1-2* : Pumping of feed water from condenser to boiler by increasing pressure P_c and P_b.
  (b) *Process 2-3* : Isobaric heat addition to convert feed water into superheated steam.
  (c) *Process 3-4* : Reversible adiabatic expansion of steam in turbine from P_b to P_c.
  (d) *Process 4-1* : Isobaric condensation of exhaust steam to water.

$$\text{Efficiency of Rankine cycle} = \frac{\text{Work developed in turbine}}{\text{Heat absorbed in boiler}} = \frac{W_T}{Q_s}$$

$$= \frac{h_3 - h_4}{h_3 - h_2}$$

3. (b) Throttling Process
Constant Enthalpy Process

- This is also called as *throttling process*, in which, fluid is forced out by its pressure through restricted opening or aperture.
- Due to narrowness of aperture, frictional resistance occurs between the fluid and sides of aperture and the velocity of outgoing fluid almost reduces to zero. This converts kinetic energy into heat energy due to friction.
- Hence, if steam initially is wet, it is throttled starting drying. And if it is dry, becomes superheated. During throttling process, pressure reduces from P_1 to P_2.



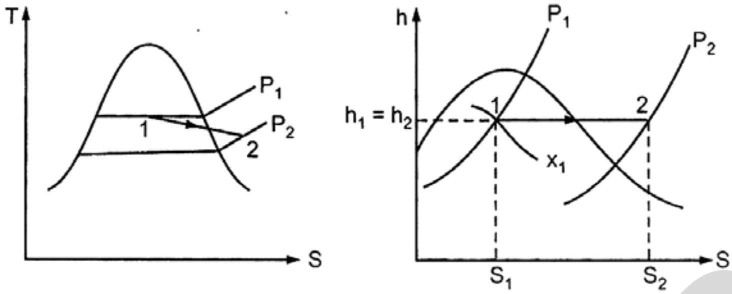


Fig. : Throttling process.

- Considering, one kg of wet steam is throttled from initial state 1 to final state 2, the steady flow equation is modified as follows,

  $\therefore \quad h_1 + gz_1 + \dfrac{C_1^2}{2} + q_{1\text{-}2} = h_2 + gz_2 + \dfrac{C_2^2}{2} + w_{1\text{-}2}$

  Neglecting the change in kinetic energy (As C_1 and C_2 are very low, hence $\dfrac{C_2^2}{2}$ and $\dfrac{C_1^2}{2}$ can be neglected) and Change in potential energy (As datum level is same, z_1 and z_2 are equal), above equation becomes,

  $\therefore \quad h_1 + q_{1\text{-}2} = h_2 + w_{1\text{-}2}$

  Also, No heat transfer and work done takes place, therefore $q_{1\text{-}2} = 0$ and $w_{1\text{-}2} = 0$.

  $\therefore \quad h_1 = h_2$

  i.e. enthalpy remains constant.
- During this process, pressure and temperature are decreased, whereas, there is an increase in volume and entropy of steam.

3. (c) Give data : m = 1 kg, P = 10 bar, $T_w = 50°C$
$C_{p\,(water)} = 4.126$ kJ/Kg-K, $C_{p\,(steam)} = 2.1$ kJ/Kg-K

Procedure : From steam table, corresponding to pressure of 10 bar,

T_{sat} in °C	V_g in m^3/kg	Enthalpy in kJ/kg		
		h_f	h_{fg}	h_g
179.9 °C	0.1943	762.6	2013.6	2776.2

Procedure : Initial enthalpy of water, $h_1 = m\,C_{p\,(water)}\,T_w$
$= 1 \times 4.126 \times (50 - 0)$
$= 206.3$ kJ/kg

Case 1) 30% dry :

Final enthalpy of wet steam, $h_2 = h_f \times xh_{fg}$

$\therefore \quad h_2 = 762.6 + (0.3 \times 2013.6)$
$= 1366.68$ kJ/kg

$\therefore$ Quantity of heat required $= h_2 - h_1$
$= 1366.68 - 206.3$
$= 1160.38$ kJ/kg

Case 2) Dry saturated :

Final enthalpy of dry steam $= h_g$

$\therefore$ $h_2 = 2776.2$ kJ/kg

$\therefore$ Quantity of heat required $= h_2 - h_1$

$= 2776.2 - 206.3$

$= 2569.9$ kJ/kg

3. (d) Types of Nozzle

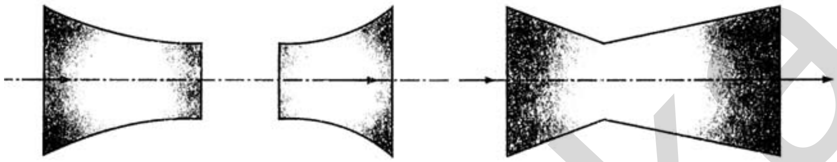


Fig. : Types of nozzle.

1) **Convergent nozzle :** When the cross-sectional area of a nozzle decreases continuously from entrance to exit, it is called as convergent nozzle. This type of nozzle is useful upto a pressure ratio of 0.58 with use of saturated steam. This is known as critical pressure ratio.
2) **Divergent nozzle :** When the cross-sectional area of a nozzle increases continuously from entrance to exit, it is called as divergent nozzle.
3) **Convergent-divergent nozzle :** When the cross-sectional area of nozzle first decreases from its entrance to throat and then increases from its throat to exit, it is called as convergent-divergent nozzle.

3. (e) Classification of Steam Turbines

Steam turbines can be classified in the following ways :

1) According to the working principle :
   (a) Impulse turbine
   (b) Reaction turbine
   (c) Combined impulse and reaction turbine

2) According to number of stages of expansion of steam :
   (a) Single stage steam turbine
   (b) Multistage steam turbine

3) According to position of shaft :
   (a) Horizontal turbine
   (b) Vertical turbine

4) According to pressure of steam supplied :
   (a) High pressure
   (b) Medium pressure
   (c) Low pressure

5) According to direction of steam flow :
   (a) Axial flow
   (b) Radial flow
   (c) Tangential flow

6) According to exhaust steam pressure :
   (a) Condensing type
   (b) Non-condensing type

7) According to method of governing :
   (a) Throttle
   (b) Nozzle
   (c) Bypass

3. (f) Velocity Compounding

- Steam coming from the boiler is expanded in a stationary nozzle from inlet pressure to condenser pressure.
- So the pressure in the nozzle drops, and the kinetic energy of the steam increases due to increase in velocity.
- A portion of this available energy is absorbed by a row of moving blades. The steam (whose velocity has decreased, while moving over the moving blades) then flows through the second row of blades, which are fixed.
- The function of these fixed blades is to re-direct the steam flow without altering its velocity to the next row of moving blades, where again work is done on them and steam leaves the turbine with a low velocity. Figure shows a cut-away section of such a stage and changes in pressure and velocity as the steam passes through the nozzle, fixed and moving blades.

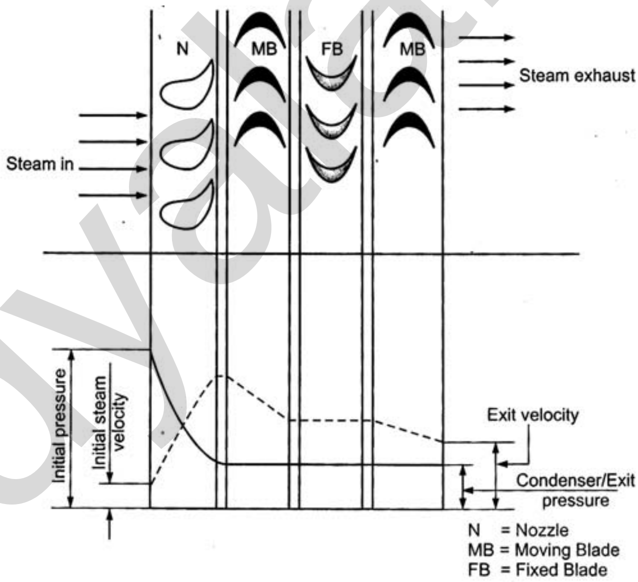


Fig. : Velocity compounding.

- Though this method has the advantage that, the initial cost is low due to lesser number of stages, but it has the drawback of low efficiency.

Advantages of Velocity Compounding :

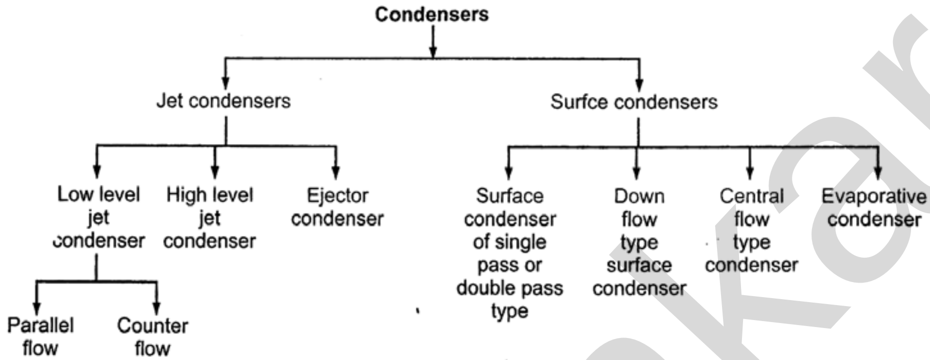
(a) Only 2-3 stages are required, so initial cost is less.
(b) Space required is less.
(c) As the pressure inside housing is less due to total pressure drop occurring in nozzle, the turbine housing need not be made stronger.

Disadvantages of Velocity Compounding :

(a) Friction losses are more due to high velocity of steam.

(b) With increase in number of stages, the blade efficiency decreases.

4. (a) Classification of Steam Condensers



4. (b) Natural Draught Cooling Tower

- The hot water falls down in radial sprays from a height and atmospheric air enters from the base of tower. The partial evaporation of water takes place, which reduces the temperature of circulating water.
- This cooled water is collected in the cooling water tank at the base and this cold water is pumped into the condenser.
- Cooling towers require a draught of air for evaporation of water sprayed.
- In natural draught type, the circulation of air is produced by the pressure difference and hence density difference of heated air inside the cooling tower and surrounding air, i.e. outside the cooling tower.

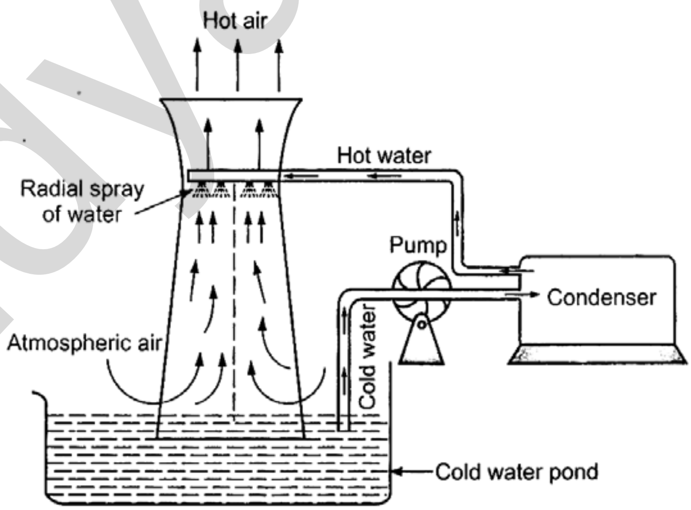


Fig. : Natural draught cooling tower.

4. (c) **Fourier's Law of Heat Transfer**

- It states that, "the rate of change of heat flux due to conduction in any direction is directly proportional to the temperature gradient present in that direction".

$$\therefore \quad \frac{Q}{A} \propto \frac{dT}{dx}$$

$$\therefore \quad \frac{Q}{A} = -K\frac{dT}{dx}$$

$$\therefore \quad Q = -KA\frac{dT}{dx}$$

where, Q = Heat flow in watt

A = The area normal to the direction of heat flow in m^2

$\frac{dT}{dx}$ = Temperature gradient in K/m or °C/m

K = Constant of proportionality and is called as **thermal conductivity** of the material in W/mK.

- The negative sign in equation implies that, heat flows from hot body to cold body, i.e., in the direction decreasing temperature.
- In the Cartesian co-ordinate system for heat flow in 'X' direction,

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

- In the cylindrical co-ordinate system, for radial heat flow,

$$Q = -KA\frac{dT}{dr}$$

4. (d) **Black Body**

- A *black body* is an idealized physical body, that absorbs all electromagnetic radiations falling on it.
- Because of its perfect absorptivity at all wavelengths, a black body is also the best possible emitter of thermal radiation.
- A perfect black body does not exist in practice.
- The concept of black body is an idealization, with which, the radiation characteristics of real bodies can be conveniently compared.
- To make practically a perfect black body, a hollow sphere with small opening is used.
- When ray enters the hollow body through an opening, a part of it is absorbed and part is reflected inside. The reflected radiation will not find outlet and will again incident on the inner surface.

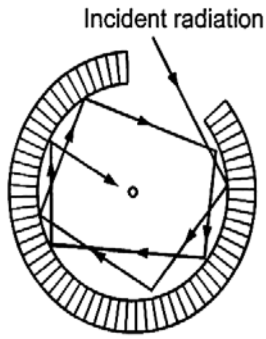


Fig. : Black body.

- Due to this sequence of reflection, almost complete incident radiation will be absorbed and none will come out. Therefore, hollow sphere with a small opening acts like a black body.

- A black body has following properties :
  (a) It absorbs all incident radiation falling on it and does not transmit or reflect irrespective of wavelength and direction.
  (b) It emits maximum amount of thermal radiations at all wavelengths at any specificed temperature.

4. (e) **Shell and Tube type heat exchangers**

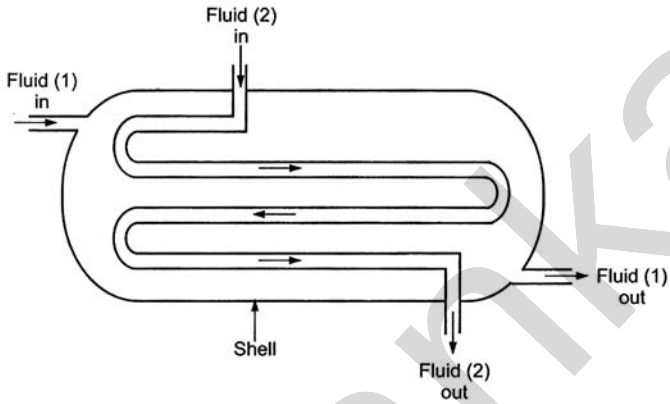


Fig. : "Single pass on both side" Shell and tube type heat exchanger.

- In this type of heat exchanger, one of the fluids flows through a bundle of tubes enclosed by a shell.
- This fluid is called as tube side fluid.
- The other fluid enters the shell and flows over the surface of tubes and is called as 'shell side fluid'.
- The transfer of heat takes place between these two fluids across the tube walls from inlet to outlet.

Advantages of Recuperators :
1) Easy to construct.
2) More economical.
3) More surface area for heat transfer.
4) Most suitable for stationary plants.

Disadvantages of Recuperators :
1) Less heat transfer coefficient.
2) Less generating capacity.

4. (f) **Applications of Heat Exchanger**
1) Dairy industry.
2) Food industries.
3) Refrigeration and air-conditioning
4) Steam and gas turbine power plants
5) Internal combustion engines
6) Milk chiller of pasteurizing plant

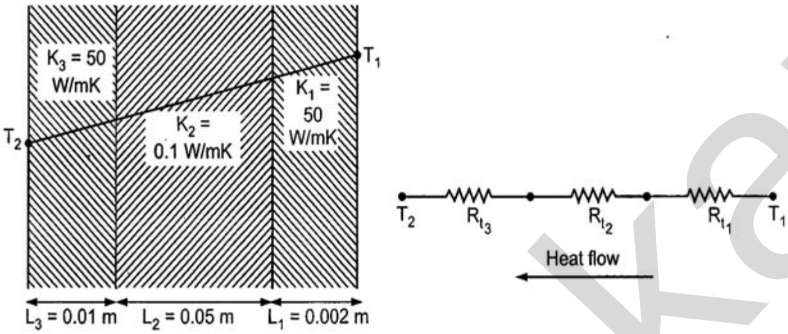
5. (a) Given data: $L_1 = 1.5 \text{ mm} = 0.0015 \text{ m}$ $\quad$ $L_2 = 2 \text{ cm} = 0.02 \text{ m}$

$L_3 = 10 \text{ mm} = 0.01 \text{ m}$

$T_1 = 24\ °C = 24 + 273 = 297 \text{ K}$ $\quad$ $T_2 = -15\ °C = -15 + 273 = 258 \text{ K}$

$K_1 = 23.2 \text{ W/mK}$ $\quad$ $K_2 = 0.14 \text{ W/mK}$

$K_3 = 0.052 \text{ W/mK}$



(a) Refrigerated van wall $\qquad$ (b) Electrical analogy

Procedure: Heat flows from high temperature to low temperature. Therefore, here heat flows from outer surface to inner surface.

$$\frac{Q}{A} = \frac{T_1 - T_2}{R_{t_1} + R_{t_2} + R_{t_3}}$$

$$\therefore \qquad \frac{Q}{A} = \frac{297 - 258}{\left[\frac{L_1}{K_1} + \frac{L_2}{K_2} + \frac{L_3}{K_3}\right]} = \frac{297 - 258}{\left[\frac{0.0015}{23.2} + \frac{0.02}{0.14} + \frac{0.01}{0.052}\right]} = 116.33 \text{ W/m}^3$$

5. (b) Isobaric Process

- "If the pressure of gas remains constant during the process, the process is called as constant pressure or isobaric process".
- Suppose, the gas is heated at constant pressure, in a frictionless cylinder-piston arrangement.
- Due to heat supplied, the temperature of gas increases and gas will expand. The volume of gas will increase keeping the pressure constant. i.e. piston will start moving upwards. Hence the mass M will be lifted upwards producing work.
- Let Q be the heat supplied and W be the work produced.

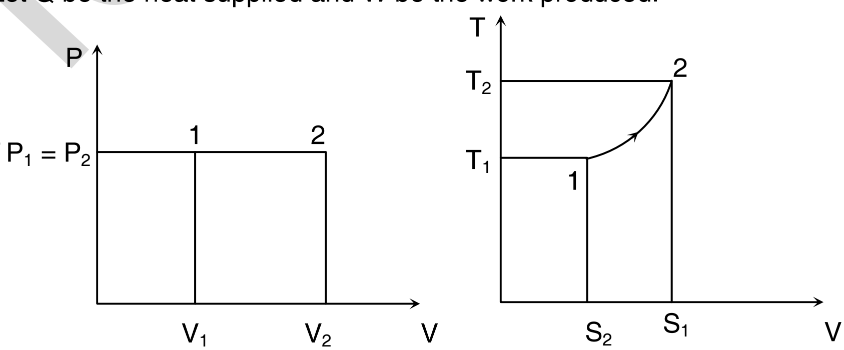


Fig. : P-V and T-S diagrams

1. **P-V-T relationship :** From the general gas equation,

$$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2} \qquad (\because\ P_1 = P_2)$$

$$\frac{V_1}{T_1} = \frac{V_2}{T_2}$$

2. **Work done by the gas :**

$$W_{1-2} = \int_1^3 dW = \int_1^2 PdV$$

$$W_{1-2} = P(V_2 - V_1)$$
$$= mR\,(T_2 - T_1) \qquad (\because\ PV = mRT)$$

3. **Change in internal energy :**

$$dU = U_2 - U_1$$
$$= m\,C_2\,(T_2 - T_1) \qquad \text{(By Joule's law)}$$

4. **Heat supplied to the gas :**
By first law of thermodynamics,

$$dQ = dU + dW$$

$$\int_1^2 dQ = \int_1^2 dW + \int_1^2 dU$$

$$Q_{1-2} = m\,R(T_2 - T_1) + mC_1\,(T_2 - T_1)$$
$$Q_{1-2} = m(T_2 - T_1)\,(R + C_1)$$
$$Q_{1-2} = m\,C_P\,(T_2 - T_1) \qquad (\because\ C_P - C_1 = R)$$

Thus, the heat supplied to the gas is utilized in two wave, (a) in increasing internal energy of gas and (b) for doing some external work.

5. **Change in enthalpy :**

$$dH = m\,C_P\,(T_2 - T_1)$$

6. **Change in entropy :**

$$S_{1-2} = \int_1^2 dS = \int_1^2 \frac{dQ}{1}$$

$$= \int_1^2 \frac{mC_2}{1}\,dT$$

$$= m\,C_P \int_1^2 \frac{dT}{T}$$

$$= m\,C_P[\log_e (T)]_1^2$$

$$= m\,C_P - \log_e\left(\frac{T_2}{T_1}\right)$$

5. (c) **Temperature Entropy Diagram for Steam Generation**

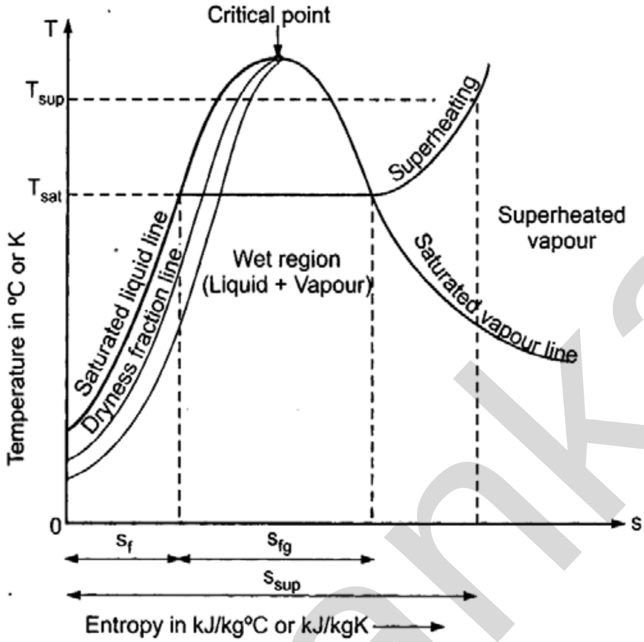


Fig. (a) : Temperature entropy diagram.

- Critical point is the point, at which, latent heat becomes zero.
- The pressure and temperature corresponding to critical point are 221.2 bar and 374.15 °C. The saturated liquid line and saturated vapour curve meet at critical point.
- The region below the curve joining saturated liquid and vapour line is called as wet region or two phase region.
- The saturated vapour line is also called as dry saturated steam line.
- The temperature entropy diagram can be read in the following manner. Refer to the Figure (b).
- In the following figure, point K represents the critical point, where latent heat becomes zero.
- The line AK acts as boundary between liquid and wet steam and is saturated liquid line.
- The line KC acts as boundary between wet steam and superheated steam and is saturated vapour (steam) line.
- The line HI represents the phase transformation of water into steam at constant temperature i.e. saturation temperature.
- Out of BC, EF and HI, the HI represents maximum value of pressure.

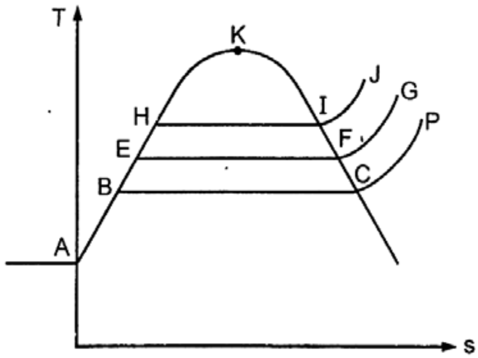


Fig. (b) : Example of temperature entropy diagram.

6. (a) Performance of a Refrigerator

- "It is a thermodynamic system, which absorbs heat from low temperature body (space to be cooled) and transfers it to high temperature body (atmosphere)".

$$(COP)_R = \frac{Output}{Input} = \frac{Q_1}{W_R}$$

$$= \frac{Q_1}{Q_2 - Q_1}$$

In term of temperature, COP is given as,

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

- A simple flow diagram for refrigerator is given below :

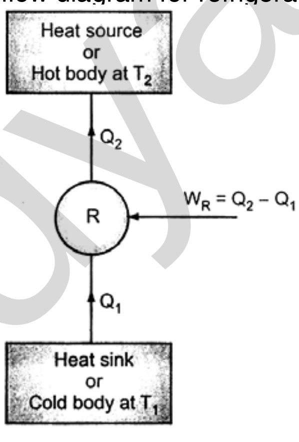


Fig. : Refrigerator.

Coefficient of Performance

- The index of performance of heat pump and refrigerator is expressed in terms of coefficient of performance.
- Coefficient of performance is defined as, "the ratio of energy effect (output) desired to the energy input required". In simple words, it is the ratio of output to input.

- We have, $(COP)_P = \dfrac{Q_2}{Q_2 - Q_1}$ and $(COP)_R = \dfrac{Q_1}{Q_2 - Q_1}$

$$(COP)_R + 1 = \frac{Q_1}{Q_2 - Q_1} + 1$$
$$= \frac{Q_1 + Q_2 - Q_1}{Q_2 - Q_1} = \frac{Q_2}{Q_2 - Q_1}$$
$$= (COP)_P$$
$$(COP)_R + 1 = (COP)_P$$

6. (b) Given data : $T_2 = 800 + 273 = 1073$ K
$T_1 = 30 + 273 = 303$ K

Procedure : Efficiency of Carnot engine is :

$$\eta_E = \frac{T_2 - T_1}{T_2} = \frac{1073 - 303}{1073} = 0.7176 = 71.76\%$$

We have to calculate the amount of heat rejected i.e. 'Q_1' for 1 kW work done.

$$W_E = Q_2 - Q_1 = 1 \text{ kW}$$

Also, efficiency is given by

$$\eta_E = \frac{Q_2 - Q_1}{Q_2}$$

$$\therefore \quad 0.7176 = \frac{1}{Q_2}$$

$$\therefore \quad Q_2 = \frac{1}{0.7176} = 1.393 \text{ kW}$$

But, $W_E = Q_2 - Q_1 = 1$

$$\therefore \quad 1.393 - Q_1 = 1$$
$$Q_1 = 0.393 \text{ kW}$$

6. (c) Bourdon's Pressure Gauge

Function :

- To indicate the steam pressure of boiler.

Construction :

- It is normally mounted in the front top of the boiler.
- It consists of an elliptical elastic tube (spring tube) bent into an arc of an circle, called as an bourdon tube.
- One end of this tube is connected through hollow block and other end is closed. This hollow block connects the Bourdon tube to the steam space.
- The closed end of spring tube is connected to the pinion and gear arrangements through a link.
- A pointer is mounted on the spindle pinion, which moves on the graduated scale, as pinion moves.

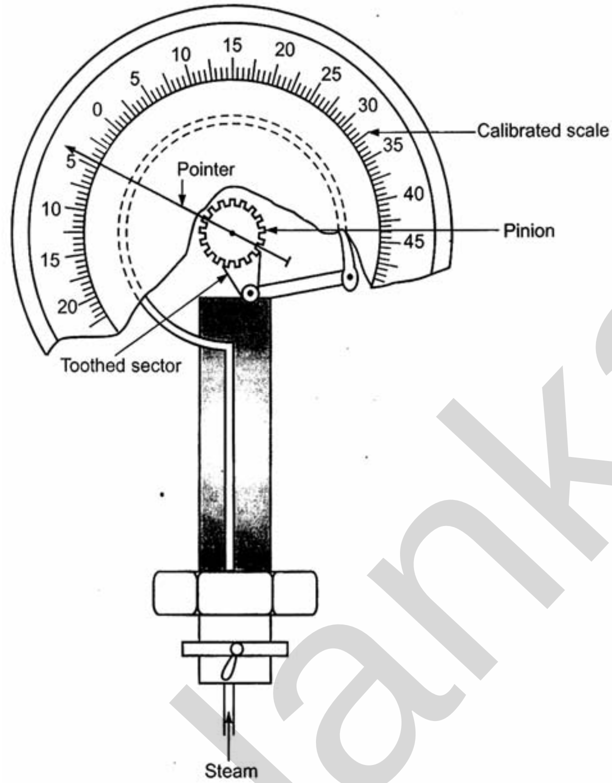


Fig. : Bourdon pressure gauge.

Working :

- When the steam under pressure flows into the tube, the Bourdon's tube tends to straighten.
- As the one end of tube is fixed to the block, the free end moves and the link connected to it moves the pinion and gear arrangement.
- It causes the pointer to move on graduated scale, which directly gives the gauge pressure.

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