



**RPSC AEn-2024  
Main Test Series**

**MECHANICAL  
ENGINEERING**

**Test 16**

Test Mode : • Offline • Online

**Subject : Full Syllabus Test [Paper-II]**

**DETAILED EXPLANATIONS**

**1. Solution:**

**Advantages :**

1. It has smaller size for the given capacity of refrigeration.
2. The coefficient of performance is quite high.

**Disadvantages :**

1. The initial cost is high.
2. The prevention of leakage of the refrigerant is the major problem in vapour compression system.

**2. Solution:**

Dew point temperature (DPT) is the temperature at which the water vapour present in the moist air just begins to condense when the mixture of moist air is cooled at constant pressure.

**3. Solution:**

Since, the heat added during a psychrometric process may be split up into sensible heat and latent heat. The ratio of the sensible heat to the total heat is known as sensible heat factor (SHF) or sensible heat ratio (SHR).

$$\text{SHF} = \frac{SH}{SH + LH}$$

where, SH = sensible heat, and LH = latent heat.

**4. Solution:**

Expansion of working fluid from a region of high pressure across a restriction or very small opening under a steady flow without any heat transfer is referred to as throttling process.

**5. Solution:**

The maximum work output obtained from a certain heat input in a cycle heat engine is called the available energy (A.E) or exergy. The minimum energy that has to be rejected to the sink by the second law is called the unavailable energy (U.E.) or anergy.

**6. Solution:**

If heat rejection is zero, the heat engine will produce net work in a complete cycle by exchanging heat with only one reservoir, thus violating the Kelvin-Planck statement. Such a heat engine is called a PMM2. A PMM2 is impossible.

**7. Solution:**

Thermal boundary layer thickness is defined as the distance away from the surface where temperature difference is 99 % of the temperature difference between the surface and free stream temperature of the fluid.

**8. Solution:**

A radiation shield is a barrier wall of low emissivity placed between two surfaces which reduce the radiation between the bodies.

**9. Solution:**

Condensation : It is define as a process in which vapour phase of a substance changes to liquid phase by releasing its latent heat of vapourisation.

Types of Condensation :

1. Filmwise condensation.
2. Dropwise condensation.

**10. Solution:**

Thermal contact resistance is a thermal resistance to heat flow at the interface between two materials because of surface roughness and void spaces at contact surfaces.

**11. Solution:**

Characteristics of laminar flow are as follows :

1. Flow is irrotational.
2. No slip will occur at the boundary.
3. Each fluid layer flows separately.

**12. Solution:**

**TEL :** Total energy line (TEL) is defined as the line which gives the sum of pressure head, datum head and kinetic head of a flowing fluid in a pipe with respect to some reference line.

**HGL :** Hydraulic gradient line is defined as the line which gives the sum of pressure head and datum head of a flowing fluid with respect to some reference line.

**13. Solution:**

Following are the important characteristic curves for the hydraulic turbine :

1. Main characteristic curves or constant head curves,
2. Operating characteristic curves or constant speed curves, and
3. Constant efficiency curves or iso-efficiency curves.

**14. Solution:**

Net positive suction head (NPSH) is defined as the absolute pressure head at the inlet to the pump minus the vapour pressure head plus the velocity head.

**15. Solution:**

Regeneration is combined to recover increased exhaust heat due to reheating and intercooling, thereby improving overall thermal efficiency.

**16. Solution:**

A nuclear reactor is a device that controls nuclear fission reactions to produce heat energy safely and continuously.

**17. Solution:**

Water-tube boilers can withstand high pressures and temperatures, allow rapid steam generation, and provide better heat transfer and safety.

**18. Solution:**

Equivalence ratio is the ratio of actual fuel-air ratio to stoichiometric fuel-air ratio. It is denoted by  $\phi$ .

$$\phi = \frac{\text{Actual fuel-air ratio}}{\text{Stoichiometric fuel-air ratio}}$$

**19. Solution:**

Major pollutants in exhaust emission are as follows :

1. Carbon monoxide (CO),
2. Hydrocarbons (HC), and
3. Oxides of nitrogen (NO<sub>x</sub>).

**20. Solution:**

**Flash Point :** It is defined as the lowest temperature at which the lubricating oil will flash when a small flame is passed across its surface.

**Fire Point :** Fire point is the lowest temperature at which the oil will burn continuously.

**21. Solution:**

In the equal friction method, the frictional pressure drop per unit length of the duct is maintained constant throughout the duct system. The procedure is to select a suitable velocity in the main duct from sound level considerations. Knowing the air flow rate and velocity in the main duct, the size and friction loss are determined from chart. The remaining ducts are then sized, maintaining the friction loss per unit length at this value for their respective air-flow rates.

This method of sizing ducts, automatically reduces the air velocity in the direction of flow. The method is generally recommended because of its simplicity. Moreover, the use of a calculator, called the ductulator, speeds up the design work.

If an equal friction design has a mixture of short and long runs of duct, the shortest duct will need a considerable amount of dampening. This is a drawback of the equal friction design.

To determine the total friction loss in the duct system, it is necessary to calculate the loss in the duct run that has the highest resistance.

**22. Solution:**

$$\text{Pressure, } p = 2 \text{ bar} = 200 \text{ kPa,}$$

$$\text{Rating of motor} = 100 \text{ W}$$

$$\text{Heat supplied, } Q = 4 \text{ kJ,}$$

$$\text{Duration of heat supply} = 30 \text{ s}$$

Volume increase of the system,

$$\Delta V = 0.06 \text{ m}^3$$

$$\text{Displacement work done of gas} = \int p dV = 200 \times 0.06 = 12 \text{ kJ (positive work)}$$

$$\text{Work done by motor} = 100 \times 30 = 3 \text{ kJ (negative work)}$$

Net work done by the system on the surroundings,

$$W = 12 - 3 = 9 \text{ kJ}$$

As per 1st law of thermodynamics:

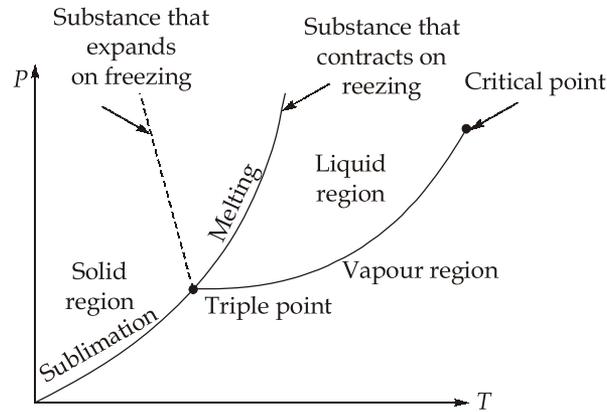
$$Q_s = W + \Delta U$$

$$\Delta U = Q_s - W = 4 - 9 = -5 \text{ kJ}$$

The -ve sign indicates that energy of the system decreases.

**23. Solution:**

P-T diagram for pure substance:



This diagram is often called phase diagram as all three phases are separated from each other by 3 lines.

**Sublimation lines;** Separates solid and vapour region.

**Vaporization line:** Separates the liquid and vapour region.

**Fusion (or melting):** Separates the solid and liquid region.

- The three lines meet at triple point, here all the three phases coexist in equilibrium.
- The slopes of the sublimation and vaporisation curves for all substance are positive.
- The slope of the fusion curve for most substance is positive, but for water, it is negative.

**24. Solution:**

Given:  $m = 0.25 \text{ kg}$ ,  $P_1 = 300 \text{ kPa}$ ,  $T_1 = 90^\circ\text{C} = 363 \text{ K}$ ,  $V_1 = 0.07 \text{ m}^3$ ,  $P_2 = 300 \text{ kPa}$ ,  $V_2 = 0.10 \text{ m}^3$

$$W_{1-2} = -25 \text{ kJ}$$

$$P_1 V_1 = mRT_1$$

$$R = \frac{P_1 V_1}{mT_1} = \frac{300 \times 0.07}{0.25 \times 363} = 0.2314 \text{ kJ/kgK}$$

$$\frac{P_1 V_1}{RT_1} = \frac{P_2 V_2}{RT_2}$$

$$\therefore T_2 = 518.57 \text{ K}$$

Applying energy conservation,

$$\delta Q^o = du + \delta W$$

$$-\delta W = du$$

$$-W_{1-2} = mC_V (T_2 - T_1)$$

$$C_V = \frac{-W_{1-2}}{m(T_2 - T_1)} = -\frac{(-25)}{0.25 \times (518.57 - 363)} \quad \text{Ans.}$$

∴  $C_V = 0.6428 \text{ kJ/kgK}$

$$C_P = C_V + R = 0.6428 + 0.2314 = 0.8742 \text{ kJ/kgK Ans.}$$

Now,

$$(\Delta s)_{2-1} = m \left[ C_P \ln \frac{T_2}{T_1} - R \ln \frac{P_2}{P_1} \right] = m C_P \ln \frac{T_2}{T_1}$$

$$= 0.25 \times 0.8742 \times \ln \left( \frac{518.57}{363} \right)$$

or,  $(\Delta s)_{2-1} = 0.07795 \text{ kJ/K} \quad \text{Ans.}$

25. **Solution:**

**Wein’s displacement law:** As the temperature of a blackbody increases, peak of spectral emissive power shift towards shorter wavelengths. The wavelength at which the peak occurs for a specified temperature is given by Wein’s displacement law as follows:

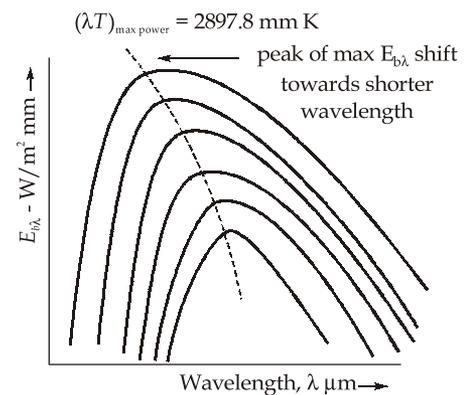
Assume wavelength at which sun has maximum spectral emissive power is  $\lambda_m$ .

From Wein’s displacement law, we know that for blackbody,

$$\lambda_m T = 2898 \mu\text{mK}$$

Surface temperature of sun = 8780 K

⇒ Wavelength for maximum emissive power,  $\lambda_m = 0.33 \mu\text{m}$



26. **Solution:**

**Stability of Floating Body:** For a floating body if ‘G’ is below ‘B’. The body is always stable. But unlike immersed bodies a floating body may still be stable when G is directly above B. Then the stability of a floating body is determined from the position of Meta-centre (M). In case of floating body, the weight of the body is equal to the weight of liquid displaced.

(i) **Stable Equilibrium:** If the point M is above G, the floating body will be in stable equilibrium as shown in **figure (i)**. If a slight angular displacement is given to the floating body in the clockwise direction, the centre of buoyancy shifts from B to B<sub>1</sub> such that the vertical line through B<sub>1</sub> cuts at M. Then the buoyant force F<sub>B</sub> through B<sub>1</sub> and weight W through G constitute a couple acting in the anti-clockwise direction and thus bringing the floating body in the original position.

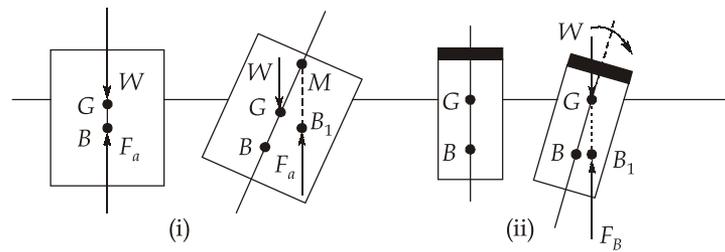


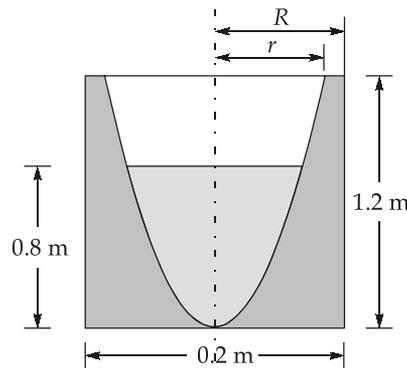
Fig. (i) Stable Equilibrium  $M$  is above  $G$ , (ii) Unstable equilibrium  $M$  is below  $G$ .

**Stability of floating bodies**

- (ii) **Unstable Equilibrium:** If the point  $M$  is below  $G$ , the floating body will be in unstable equilibrium as shown in **figure (ii)**. The disturbing couple is acting in the clockwise direction. The couple due to buoyant force  $F_B$  and  $W$  is also acting in the clockwise direction and thus overturning the floating body.
- (iii) **Neutral Equilibrium:** If the point  $M$  is at the centre of gravity of the body, the floating body will be in neutral equilibrium.

**27. Solution:**

Given:  $D = 0.2 \text{ m}$ ,  $L = 1.2 \text{ m}$



Let the angular speed, when axial depth of water is zero be  $\omega$

$$z = \frac{\omega^2 r^2}{2g}$$

$$\omega^2 r^2 = 2 \times 1.2 \times 9.81$$

$$\omega^2 r^2 = 23.54 \dots (i)$$

Volume of air before rotation = Volume of air after paraboloid

$$\pi R^2 (1.2 - 0.8) = \text{Volume of paraboloid}$$

$$\pi \times 0.1^2 \times 0.4 = \frac{1}{2} (\pi r^2) \times z = \left( \frac{\pi r^2}{2} \right) \times 1.2$$

$$r^2 = 6.67 \times 10^{-3}$$

... (ii)

From equations (i) & (ii), we get

$$\omega^2 \times (6.67 \times 10^{-3}) = 23.54 \text{ or } \omega = 59.40 \text{ rad/s}$$

Also, 
$$\omega = \frac{2\pi N}{60}$$

$$N = \frac{60 \times 59.4}{2\pi} = 567.22 \text{ rpm}$$

## 28. Solution:

(i) **Steady and Unsteady Flow** : When the properties of fluid does not change with respect to time in the given space, then the flow is called steady flow.

If the properties of fluid changes with respect to time then it is called unsteady flow.

(ii) **Uniform and Non-Uniform Flow** : When the properties of fluid does not change with respect to the space then the flow is called uniform flow. When the properties of fluid changes with space then it is called Non-uniform flow.

(iii) **Laminar and Turbulent Flow** : When fluid flows in the form of lamina, it is known as laminar flow. It generally occurs for low velocity and high viscosity i.e. at low Reynold's number. When flow is highly disorderd, it is known as turbulent flow. It occurs for high velocity and low viscosity i.e. at high Reynolds number.

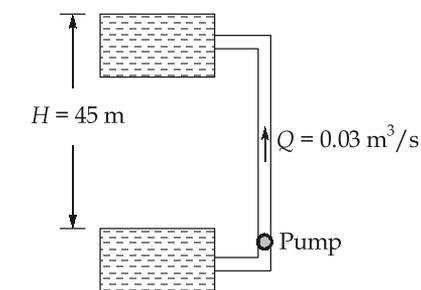
(iv) **Compressible and Incompressible flow** : When the density of fluid does not change with space or time then it is called incompressible flow i.e.  $\frac{D\rho}{Dt} = 0$ .

If the density of fluid changes either with space or time then flow is called compressible flow i.e.  $\frac{D\rho}{Dt} \neq 0$ .

(v) **Rotational and Irrotational flow** : When the fluid particles rotate about their own mass center along the flow, then flow is known as rotational flow. It occurs in viscous flow.

When the fluid particle does not rotate about their own mass center then it is called irrotational flow. It occurs in non-viscous flow.

## 29. Solution:



Layout of the arrangement of tanks

Power of motor,  $P_{\text{motor}} = 20 \text{ kW}$

Ideal power required to pump the water,

$$\begin{aligned}P_{\text{ideal}} &= \rho g Q H \\ &= 10^3 \times 9.81 \times 0.03 \times 45 \\ &= 13.24 \text{ kW}\end{aligned}$$

$\therefore$  Mechanical power converted to thermal energy due to friction,

$$\begin{aligned}P_{\text{friction}} &= P_{\text{motor}} - P_{\text{ideal}} \\ &= 20 - 13.24 = 6.76 \text{ kW}\end{aligned}$$

### 30. Solution:

Once through boilers are the super critical boilers in which only one tube almost about 2 km long is used and there is no steam drum. Such boilers operate above 221.2 bar pressure. There is no latent heat of vapourization involved and the water on heating directly flashes into vapour. Steam is further heated to desired temperature in superheater. Following are the differences between once through boiler and drum boilers:

1. Once through boiler does not require centrifugal pumps and drums where as in drum boilers both pumps and drums are necessary.
2. In once through boilers extremely pure water is required since all the solids present are deposited in tubes or carried along with steam to turbines whereas in drum boilers the limitation of extremely pure water is less severe since there is some blow down of boiler water.
3. The erosion is very less in once through boiler as compared to drum boiler since it uses highly pure water.
4. The once through boilers are easy to operate and can generate peak load compared to drum boilers.
5. Once through boilers have higher thermal efficiency compared to drum boilers.
6. Once through boilers have large heat transfer coefficient compared to drum boilers.

### 31. Solution:

**Advantages of using LPG in S.I. engine:**

1. It is cheaper than gasoline.
2. It is highly knock resistant and does not preignite easily.
3. It gives better manifold distribution and mixes easily with air.
4. Residue and oil contamination is small as it burns clearly.
5. Crank case oil dilution is small.

**Disadvantages:**

1. Much of its advantages are for engines of higher compression ratio.
2. It reduces volumetric efficiency due to its high heat of vaporization.
3. Handling has to be done for pressure of about 18 bar.
4. Response to blending is poor.

**32. Solution:**

Given:  $p = 20 \text{ kPa}$ ;  $\dot{m}_s = 20 \times 10^3 \text{ kg/h} = 5.55 \text{ kg/s}$ ;  $(\Delta T)_w = 10^\circ\text{C}$

Let inlet conditions to the condenser are represented as

$$x_1 = 0.95$$

$$h_1 = h_f + x_1 h_{fg} = 251.4 + 0.95 \times 2358.3 = 2491.785 \text{ kJ/kg}$$

Outlet condition,  $h_2 = h_f = 251.4 \text{ kJ/kg}$

Let mass flow rate of cooling water =  $\dot{m}_w$

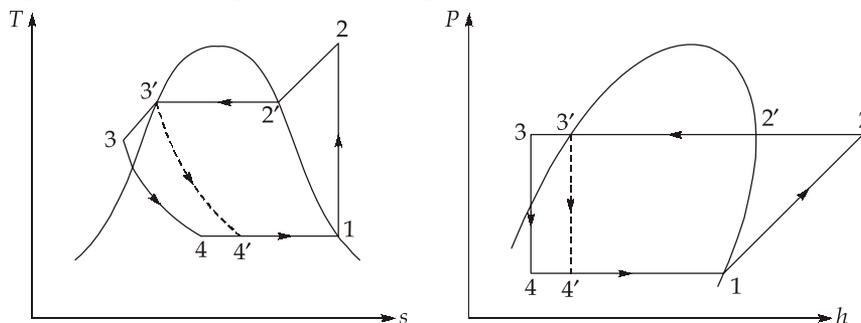
Energy balance in condenser will give,

$$\begin{aligned} \dot{m}_w c_{pw} (\Delta T)_w &= \dot{m}_s (h_1 - h_2) \\ \dot{m}_w \times 4.18 \times 10 &= 5.55 \times (2491.785 - 251.4) \\ \dot{m}_w &= 297.46 \text{ kg/s} \end{aligned}$$

**33. Solution:**

**(i) Effect of subcooling of the liquid in condenser:**

The refrigerant after condensation process is cooled below the saturation temperature ( $T_3$ ) before expansion by throttling. Such a process is called under cooling or subcooling of the refrigerant.



Here, 1 - 2 - 2' - 3' - 4' - 1: Cycle without subcooling.

and, 1 - 2 - 2' - 3 - 3 - 4 - 1: Cycle with subcooling.

The process of subcooling is generally brought about by circulating more quantity of cooling water through the condenser or by using water colder than the main circulating water.

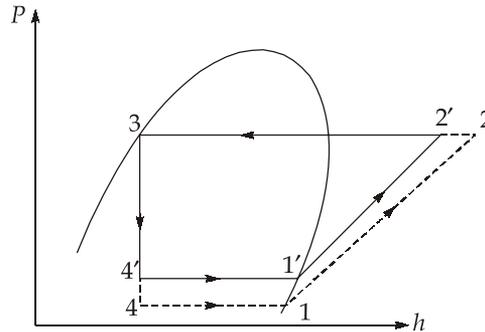
Due to subcooling, refrigeration effect increases while work of compression remains the same. So, the ultimate effect of subcooling is to increase the coefficient of

performance (COP) under the same set of working conditions.

$$\text{COP} = \frac{\text{R.E.}}{W_C} = \frac{(h_1 - h_4)}{h_2 - h_1}$$

∴ As  $(h_1 - h_4)$  increases, COP increases.

(ii) Effect of decrease in evaporator temperature:

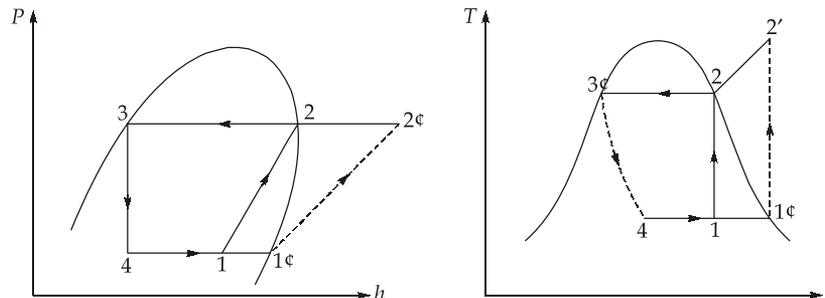


As the suction or evaporator temperature decreases

- (a) refrigeration effect decreases from  $(h_1 - h_4)$  to  $(h_{1'} - h_{4'})$
- (b) the work of compression increases from  $(h_2 - h_1)$  to  $(h_{2'} - h_{1'})$ .

Since, the COP of the system is the ratio of refrigeration effect to the compression work, with decrease in evaporator temperature, the net effect is to decrease the COP of the refrigerating system for the same amount of refrigerant flow, thus increasing refrigeration cost.

(iii) Effect of wet compression:



**Process:** 1 - 2 - 3 - 4: Wet compression of refrigerant.

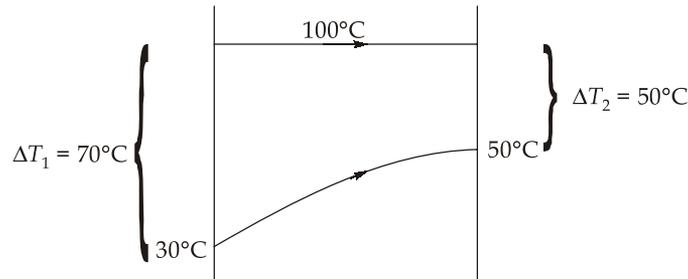
**Process:** 1' - 2' - 3 - 4: Dry compression of refrigerant.

Due to compression of refrigerant in wet region, following effects are observed:

- (a) The presence of liquid refrigerant washes away the lubricating oil hence increasing wear and tear in the compressor.
- (b) Liquid particles obstruct the opening and closing of valves, which may lead to valve damage.
- (c) Loss of refrigeration effect due to incomplete vapourisation of refrigerant.
- (d) The work of compression in wet compression is less than that of in dry compression because of reduced volume handling.

## 34. Solution:

Given:  $d = 1 \text{ cm} = 0.01 \text{ m}$ ,  $t = 0.02 \text{ cm}$ ,  $D = d + 2t = 0.01 + \frac{2 \times 0.02}{100} = 0.0104 \text{ m}$ ,  $\dot{m} = 0.1 \text{ kg/s}$ ,  
 $C_p = 1964 \text{ J/kg-K}$ ,  $\rho_{\text{oil}} = 876 \text{ kg/m}^3$ ,  $k = 0.144 \text{ W/m-K}$ ,  $\mu = 0.210 \text{ N-s/m}^2$ ,  $\text{Pr} = 2870$ .



$$(\Delta T)_{\text{LMTD}} = \frac{\Delta T_1 - \Delta T_2}{\ln\left(\frac{\Delta T_1}{\Delta T_2}\right)} = \frac{70 - 50}{\ln\left(\frac{70}{50}\right)} = 59.44^\circ\text{C}$$

$$\dot{m} = \rho_{\text{oil}} \times A \times V_{\text{oil}}$$

$$\text{or, } V_{\text{oil}} = \frac{0.1 \times 4}{876 \times \pi \times d^2} = \frac{0.1 \times 4}{876 \times \pi \times 0.01^2} = 1.45346 \text{ m/s}$$

$$\text{Re} = \frac{\rho V d}{\mu} = \frac{876 \times 1.45346 \times 0.01}{0.210} = 60.630 < 2000$$

So, flow is laminar.

So, we know that for constant wall temperature.

$$\overline{\text{Nu}} = 3.66$$

$$\frac{\bar{h}d}{k} = 3.66$$

$$\text{or, } \bar{h} = \frac{3.66 \times 0.144}{0.01} = 52.704 \text{ W/m}^2\text{-K}$$

$$Q = \dot{m} \times C_p \times (50 - 30) = \bar{h}A \times (\Delta T)_{\text{LMTD}}$$

$$0.1 \times 1964 \times 20 = 52.704 \times A \times 59.44$$

$$\text{or, } A = 1.25386 \text{ m}^2$$

$$\pi D L = 1.25386$$

$$\text{or, } L = \frac{1.25386}{\pi \times 0.0104} = 38.3765 \text{ m}$$

**Ans.**

**35. Solution:**

Let us consider a rectangular parallelepiped as the control volume in a rectangular Cartesian frame of coordinate axes and as shown below:

1. The point at which the continuity equation has to be derived, is enclosed by an elementary control volume.
2. The influx, afflux and the rate of accumulation of mass is calculated across each surface within the control volume.

Consider a fluid element of length  $dx$ ,  $dy$  and  $dz$  in the direction of  $x$ ,  $y$  and  $z$ . Let  $u$ ,  $v$  and  $w$  are the inlet velocity components in  $x$ ,  $y$  and  $z$  directions respectively.

Mass of fluid entering the face ABCD per second.

$$\begin{aligned} &= \rho \times \text{Velocity in } x\text{-direction} \times \text{Area of ABCD} \\ &= \rho \times u \times (dy \times dz) \end{aligned}$$

Then mass of fluid leaving the face EFGH per second

$$= \rho u dy dz + \frac{\partial}{\partial x}(\rho u dy dz) dx$$

$\therefore$  Gain of mass in  $x$ -direction = Mass through ABCD – Mass through EFGH per second

$$= \rho u dy dz - \rho u dy dz - \frac{\partial}{\partial x}(\rho u dy dz) dx$$

$$= -\frac{\partial}{\partial x}(\rho u dy dz) dx$$

$$= -\frac{\partial}{\partial x}(\rho u) dx dy dz$$

Similarly, the net gain of mass in  $y$ -direction

$$= -\frac{\partial}{\partial y}(\rho v) dx dy dz$$

and in  $z$ -direction

$$= -\frac{\partial}{\partial z}(\rho w) dx dy dz$$

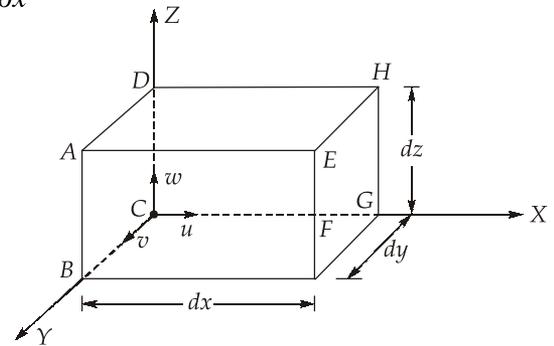
$$\therefore \text{Net gain of masses} = -\left[ \frac{\partial}{\partial x}(\rho u) + \frac{\partial}{\partial y}(\rho v) + \frac{\partial}{\partial z}(\rho w) \right] dx dy dz$$

Since the mass is neither created nor destroyed in the fluid element, the net increase of mass per unit time in the fluid element must be equal to the rate of increase of mass of fluid in the element. But mass of fluid in the element is  $\rho dx dy dz$  and its rate of increase

with time is  $\frac{\partial}{\partial t}(\rho dx dy dz)$  or  $\frac{\partial \rho}{\partial t} dx dy dz$

Equating the two expressions,

$$\text{or, } -\left[ \frac{\partial}{\partial x}(\rho u) + \frac{\partial}{\partial y}(\rho v) + \frac{\partial}{\partial z}(\rho w) \right] dx dy dz = \frac{\partial \rho}{\partial t} dx dy dz$$



or  $\frac{\partial}{\partial t} + \frac{\partial}{\partial x}(\rho u) + \frac{\partial}{\partial y}(\rho v) + \frac{\partial}{\partial z}(\rho w) = 0$  [Cancelling  $dx.dy.dz$  from both sides] ... (i)

Equation (i) is the continuity equation in Cartesian coordinates in its most general form. This equation is applicable to :

- (i) Steady and unsteady flow,
- (ii) Uniform and non-uniform flow, and
- (iii) Compressible and incompressible fluids.

For steady flow,  $\frac{\partial \rho}{\partial t} = 0$  and hence equation (i) becomes as

$$\frac{\partial \rho}{\partial x}(\rho u) + \frac{\partial}{\partial y}(\rho v) + \frac{\partial}{\partial z}(\rho w) = 0$$

If the fluid is incompressible, then  $\rho$  is constant and the above equation becomes as

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z} = 0$$

**36. Solution:**

From the given table,

At 1 : 45°C,

$$x = 0, \quad h_1 = 188.42 \text{ kJ/kg}$$

$$v_1 = 0.00101 \text{ m}^3/\text{kg}$$

$$p_{\text{sat}} = 9.59 \text{ kPa}$$

At state 3, 3 MPa, 600°C

$$h_3 = 3682.34 \text{ kJ/kg}$$

$$s_3 = 7.5084 \text{ kJ/kgK}$$

At state 6, 45°C

$$x = 1, \quad h_6 = 2583.19 \text{ kJ/kg}$$

$$s_6 = 8.1647 \text{ kJ/kgK}$$

$$h_2 = h_1 + w_{\text{pump}} = 188.42 + v_1(p_2 - p_1) = 188.42 + 0.00101 (3000 -$$

9.59)

$$= 191.44 \text{ kJ/kg}$$

For process 3 → 4,  $s_3 = s_4$  (for HP turbine)

Properties at 500 kPa: (state 4) from steam table

$$T_{\text{sat}} = 151.83^\circ\text{C} = 424.98 \text{ K}$$

$$h_l = 640.21 \text{ kJ/kg}, \quad h_v = 2748.7 \text{ kJ/kg}$$

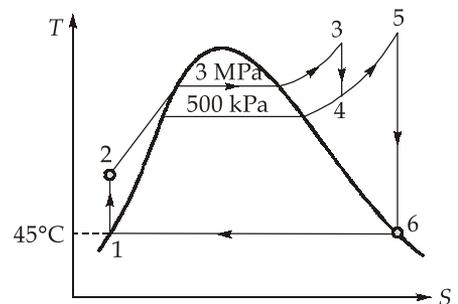
$$s_l = 1.8606 \text{ kJ/kgK}, \quad s_v = 6.8212 \text{ kJ/kgK},$$

$$c_p = 2.41267 \text{ kJ/kgK}$$

3-4 is isentropic

$$s_3 = s_4$$

$$s_3 = s_l + x (s_v - s_l)$$



$$7.5084 = 1.8606 + x (6.8212 - 1.8606)$$

$$x = 1.1385$$

∴ Point 4 is in superheated region

$$\therefore s_3 = s_v + c_{pv} \ln\left(\frac{T_4}{T_{\text{sat}}}\right)$$

$$7.5084 = 6.8212 + 2.4126 \ln\left(\frac{T_4}{424.98}\right)$$

$$T_4 = 565 \text{ K}$$

$$h_4 = h_{4v} + c_p (T_4 - T_{\text{sat}}) = 2748.7 + 2.4126 (565 - 424.98) \\ = 3086.58 \text{ kJ/kg}$$

5-6 isentropic process

$$\therefore s_5 = s_6$$

$$\therefore s_6 = s_{5v} + c_p \ln\left(\frac{T_5}{T_{\text{sat}}}\right)$$

$$8.1647 = 6.8212 + 2.4126 \ln\left(\frac{T_5}{424.98}\right)$$

$$T_5 = 741.6 \text{ K}$$

$$h_5 = h_{5v} + c_p (T_5 - T_{\text{sat}}) = 2748.7 + 2.4126 (741.6 - 424.98) \\ = 3512.75 \text{ kJ/kg}$$

Heat rejected in condenser 10 MW

$$\therefore \dot{m}(h_6 - h_1) = 10 \times 10^3$$

$$\dot{m} = \frac{10 \times 10^3}{(2583.19 - 188.42)} = 4.175 \text{ kg/s}$$

$$\therefore \text{Power output} = \dot{m}[(h_3 - h_4) + (h_5 - h_6)]$$

$$= 4.175 (3682.34 - 3086.58 + 3512.75 - 2583.19)$$

$$\text{Power} = 6368.211 \text{ kW}$$

$$\text{Heat supplied in boiler} = \dot{m}[h_3 - h_2] = 4.175 (3682.34 - 191.44)$$

$$= 14574.50 \text{ kW}$$

$$\text{Heat supplied in boiler} = 14.574 \text{ MW}$$

### 37. Solution:

Given: Bore diameter,  $D = 210 \text{ mm} = 0.21 \text{ m}$ , Stroke length,  $L = 240 \text{ mm} = 0.24 \text{ m}$ , Clearance volume,  $V_c = 1550 \text{ cc} = 1550 \times 10^{-6} \text{ m}^3$ .

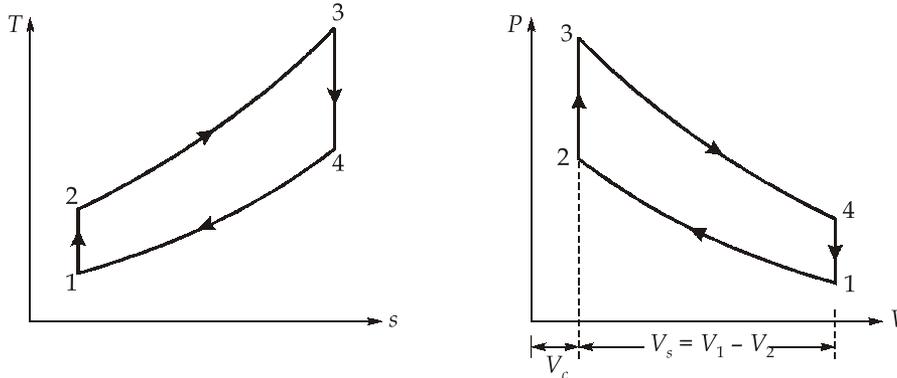
Temperature at the beginning of compression,  $T_1 = 17^\circ\text{C} = 17 + 273 = 290 \text{ K}$

Pressure at the beginning of compression,  $P_1 = 1 \text{ bar} = 100 \text{ kPa}$

Maximum pressure of the cycle,  $P_{\text{max}} = P_3 = 50 \text{ bar} = 5000 \text{ kPa}$

Calorific value of the fuel,  $(CV)_f = 40 \text{ MJ/kg}$

For air:  $C_p = 1.005 \text{ kJ/kgK}$ ,  $C_v = 0.718 \text{ kJ/kgK} \Rightarrow \gamma = \frac{C_p}{C_v} = \frac{1.005}{0.718} = 1.4$



$$\text{Swept volume } V_s = V_1 - V_2 = \frac{\pi}{4} \times D^2 \times L = \frac{\pi}{4} \times 0.21^2 \times 0.24 = 8.3126 \times 10^{-3} \text{ m}^3$$

$$\text{Clearance ratio, } C = \frac{V_c}{V_s} = \frac{1550 \times 10^{-6}}{8.3126 \times 10^{-3}} = 0.18646$$

$$\text{Compression ratio, } r = 1 + \frac{1}{C} = 1 + \frac{1}{0.18646} = 6.363$$

∴ Air standard efficiency of an Otto cycle,

$$\eta_{\text{otto}} = 1 - \frac{1}{(r)^{\gamma-1}} = 1 - \frac{1}{(6.363)^{0.4}} = 0.5229 \text{ or } 52.29\%$$

For Isentropic compression process 1 to 2:

$$\frac{T_2}{T_1} = (r)^{\gamma-1} \Rightarrow T_2 = 290 \times (6.363)^{0.4} = 607.94 \text{ K} \quad \text{Ans.}$$

$$P_2 = P_1 \times (r)^\gamma \Rightarrow P_2 = 100 \times (6.363)^{1.4} = 1333.91 \text{ kPa} \quad \text{Ans.}$$

For constant volume heat addition process 2 to 3:

$$\frac{T_3}{T_2} = \frac{P_3}{P_2} = \frac{50}{13.3391} \Rightarrow T_3 = 2278.79 \text{ K}$$

For isentropic process 3 to 4:

$$\frac{T_3}{T_4} = \left(\frac{V_4}{V_3}\right)^{\gamma-1} \Rightarrow T_4 = \frac{2278.79}{(6.363)^{0.4}} = 1087.02 \text{ K} \quad \text{Ans.}$$

$$P_4 = P_3 \times \left(\frac{1}{r}\right)^\gamma = \frac{50}{(6.363)^{1.4}} = 3.748 \text{ bar} \quad \text{Ans.}$$

Amount of heat supplied during constant volume process,

$$Q_s = C_v(T_3 - T_2) = 0.718 \times (2278.79 - 607.94) = 1199.67 \text{ kJ/kg}$$

∴ Work done during Otto cycle,

$$W = \eta_{\text{otto}} \times Q_s = 0.5229 \times 1199.67 = 627.31 \text{ kJ/kg}$$

$$v_1 = \frac{P_1}{RT_1} = \frac{100}{0.287 \times 290} = 1.2015 \text{ m}^3/\text{kg}$$

$$W = P_m \times v_1 \times \left(1 - \frac{1}{r}\right)$$

$$\Rightarrow P_m = \frac{627.31}{1.2015 \times \left(1 - \frac{1}{6.363}\right)} = 619.464 \text{ kPa}$$

∴ Mean effective pressure,

$$P_m = 6.19 \text{ bar} \quad \text{Ans.}$$

Assuming the relative efficiency to be 50%.

$$\therefore \eta_{\text{relative}} = \frac{\eta_{\text{ith}}}{\eta_{\text{otto}}}$$

$$\Rightarrow \eta_{\text{ith}} = \eta_{\text{otto}} \times \eta_{\text{relative}} = 0.5229 \times 0.5 = 0.2614$$

As, 1 kWh = 3600 kJ

$$\therefore \text{Heat supplied} = \frac{3600}{0.2614} = 13769.36 \text{ kJ/kWh}$$

∴ Indicated specific fuel consumption,

$$isfc = \frac{13769.36}{40000} = 0.344 \text{ kg/indicated kWh}$$

