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# ESE - 2025

## MAINS EXAMINATION

## QUESTIONS WITH DETAILED SOLUTIONS

## MECHANICAL ENGINEERING

### (Paper-1)

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# MECHANICAL ENGINEERING

# ESE _MAINS_2025_PAPER – I

## Questions with Detailed Solutions

### Subject-wise Weightage

| S.No. | NAME OF THE SUBJECT | MARKS |
|---|---|---|
| 1 | Fluid Mechanics | 64 |
| 2 | Hydraulic Machines | 32 |
| 3 | Thermodynamics | 32 |
| 4 | IC Engines | 66 |
| 5 | Refrigeration and Air conditioning | 92 |
| 6 | Power Plant Engineering | 70 |
| 7 | Heat Transfer | 72 |
| 8 | Renewable Sources of Energy | 52 |

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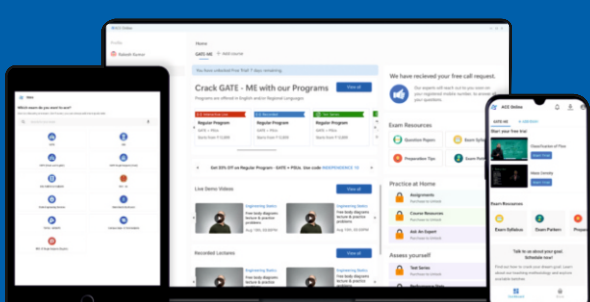

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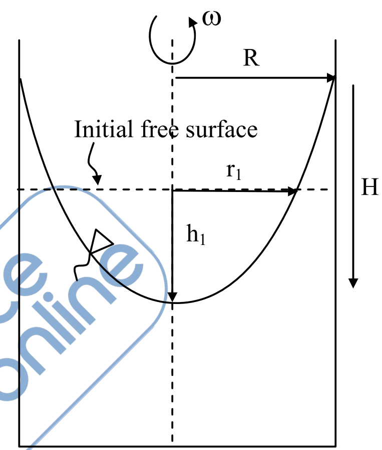
## SECTION – A

**01.(a). Prove that in case of forced vortex, the rise of liquid level at the ends is equal to the fall of liquid level at the axis of rotation. (12 M)**

**Sol:** The amount of volume drop from initial free surface must be equal to the amount of volume rise from the same.




Volume drop $= \frac{1}{2}\pi r_1^2 . h_1$ ............ (1)

Volume rise $= \frac{1}{2}\pi R_1^2 H - \left\{\pi R^2 h_1 - \frac{1}{2}\pi r_1^2 h_1\right\}$

$= \frac{1}{2}\pi R^2 H - \pi R_1^2 h_1 + \frac{1}{2}\pi r_1^2 . h_1$ ............ (2)

(1) = (2)

$\Rightarrow \quad \frac{1}{2}\pi r_1^2 . h_1 = \frac{1}{2}\pi R^2 H - \pi R_1^2 h_1 + \frac{1}{2}\pi r_1^2 h_1$

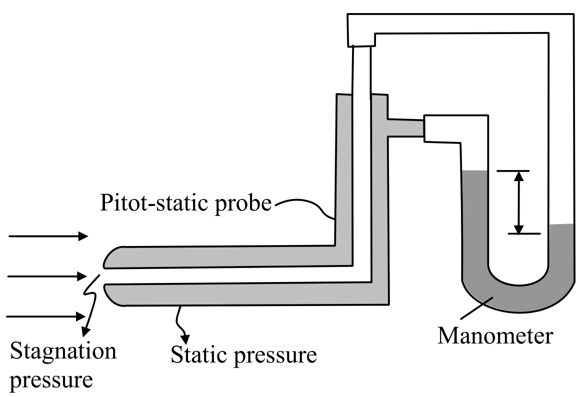
$\Rightarrow \quad h_1 = \frac{H}{2}$

∵ Drop in height is half the height of parabola

∴ The rise and fall of liquid levels are same.

**01.(b). Explain, with the aid of neat sketch, the working principle of a Pitot static tube. Further, explain how the Pitot static tube differs from the Pitot tube. (12 M)**

**Sol:**



Pitot static tube is a combination of Pitot tube and piezometer. The orifice present at the nose of pitot static tube serves to measure the stagnation pressure. The orifices on the periphery of the tube give the value to static pressure. The difference yields the value of dynamic pressure.

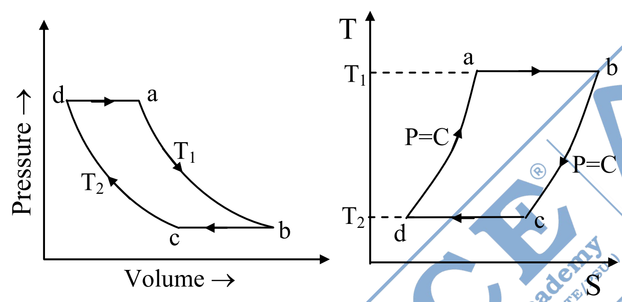
The pitot static can also be integrated with a manometer in case of gas flows or high velocity flows.

The pitot tube only has orifice at the nose, therefore it can only measure stagnation pressure. In such a case a piezometer must also be employed to measure static pressure.

**01.(c). Using an ideal gas as working fluid, show that the thermal efficiency of an Ericsson cycle is identical to the efficiency of a Carnot cycle operating between the same temperature limits.**

**(12 M)**

**Sol: The Ericsson cycle:**




- This cycle consists of two isothermal processes and two constant pressure processes.
- It is made to be thermodynamically reversible by the action of a regenerator during the two constant pressure processes.
- Referring to the PV diagram, hot air to a temperature of $T_1$ is forced in the engine cylinder and expanded isothermally, the heat being supplied by the furnace; this is represented by ab.
- The air is then cooled at constant pressure to $T_2$ by passing it through a regenerator.
- The process is thus made thermodynamically reversible by this graduated method of cooling.
- By this method the air is brought to the condition c.
- It is now compressed isothermally by a separate pump, the heat being rejected to a cold water supply; this operation is represented by cd.
- The air is next heated at constant pressure to $T_1$ by being passed through the regenerator, in the reverse direction, while the pressure is maintained constant; this is represented by da. The cycle is thus completed.

- It should be noticed that the whole of the heat given to the regenerator during the constant pressure operation bc is abstracted from it during the constant pressure operation da. Hence, there is no interchange of heat from an external source during these two operations.

  Heat supplied from an external source = heat supplied during isothermal ab = $RT_1 \ln r_k$

  Heat rejected to an external body = heat rejected during isothermal cd = $RT_2 \ln r_k$

  Hence, work done = $RT_1 \ln r_k - RT_2 \ln r_k$

  The volume ratio $r$ being the same for both strokes.

  $$\text{Efficiency} = \frac{\text{Work done}}{\text{heat supplied}}$$

  $$= \frac{(R \ln r_k)(T_1 - T_2)}{(R \ln r_k)T_1} = \frac{T_1 - T_2}{T_1}$$

  which is the same as the Carnot efficiency.

  **Note:** The Ericsson cycle does not find practical application in piston engines but is approached by a gas turbine employing a large number of stages with heat exchangers, insulators and reheaters.

**01.(d). Distinguish between the following :**

**(i) Thermodynamics and Heat transfer**

**(ii) Free convection and Forced convection**

**(iii) Black body and Gray body** **(12 M)**



**Sol:**

**(i) Differences between thermodynamics and Heat Transfer:**

To understand the difference between thermodynamics and heat transfer, let us consider the cooling of a hot steel bar which is placed in a water bath. Thermodynamics may be used to predict the final equilibrium temperature of the steel bar=water combination; however, it will not help us to find out how long it takes to reach this equilibrium condition or what the temperature of the bar will be after a certain length of time before the equilibrium condition is attained. Heat transfer on the other hand, may be used to predict the temperatures of both the bar and the water as a function of time.

Heat transfer theory combines thermodynamics and rate equations together (to quantify the rate at which heat transfer occurs in terms of the degree of non-equilibrium).

| Thermodynamics | Heat Transfer |
|---|---|
| 1. It deals with the equilibrium states of matter, and precludes the existence of a temperature gradient. | 1. It is inherently a non-equilibrium process (since a temperature gradient must exist for exchange of heat to take place). |
| 2. When a system changes from one equilibrium state to another, thermodynamics helps to determine the quantity of work and heat interactions. It describes how much heat is to be exchanged during a process but does not hint how the same could be achieved. | 2. It helps to predict the distribution of temperature and to determine the rate at which energy is transferred across a surface of interest due to temperature gradients at the surface, and difference of temperature between different surfaces. |

**(ii)**

| Feature | Forced Convection | Natural Convection (Free Convection) |
|---|---|---|
| Driving Force | External means (fan, pump, wind) | Buoyancy forces due to density differences |
| Flow Generation | Mechanically induced | Gravity-induced due to temperature gradients |
| Velocity | Higher flow velocity | Lower flow velocity |
| Heat Transfer Rate | Higher due to increased fluid motion | Lower due to reliance on buoyancy effects |
| Examples | Air conditioning, car radiator, fan cooling | Heating a room, ocean currents, rising steam |
| Governing Equation | Newton's Law of Cooling (forced flow) | Grashof & Rayleigh numbers (buoyancy-driven) |
| Energy Efficiency | Less energy-efficient (requires power input) | More energy-efficient (no external power) |

**(iii)**

| Feature | Black Body | Gray Body |
|---|---|---|
| **Definition** | An idealized body that absorbs all incident radiation | A real body that absorbs a constant fraction of incident radiation |
| **Absorptivity (α)** | $\alpha=1$ (absorbs all radiation) | $0<\alpha<1$ (absorbs partially, same at all wavelengths) |
| **Emissivity (ε)** | $\epsilon=1$ (perfect emitter) | $\epsilon=\alpha<1$ (constant emissivity) |

| | | |
|---|---|---|
| **Spectral Dependence** | Emits and absorbs at all wavelengths equally | Absorbs and emits proportionally at all wavelengths |
| **Example** | Theoretical concept (no perfect black body) | Most real surfaces (e.g., asphalt, metals) |
| **Kirchhoff's Law** | Always satisfies $\epsilon=\alpha=1$ | Satisfies $\epsilon\lambda=\alpha\lambda$ (independent of $\lambda$) |
| **Radiation Behavior** | Follows Planck's Law perfectly | Emits less radiation than a black body at the same temperature |

**01. (e) Explain the effects of the following variables on the volumetric efficiency of an IC engine:**

**(i) Types of fuel**

**(ii) Valve overlap**

**(iii) Inlet valve timing**

**(iv) Exhaust residual**

**(v) Exhaust gas recirculation**

**(vi) Engine speed** **(12 M)**

**Sol:**

| Variable | Positive Effect on Volumetric Efficiency | Negative Effect on Volumetric Efficiency |
|---|---|---|
| **Types of fuel** | Liquid fuels with high latent heat of vaporization cool the intake charge, increasing air density (e.g., gasoline). | Gaseous fuels displace intake air; poor vaporization leads to uneven mixture. |
| **Valve overlap** | Small overlap at high speeds aids scavenging by using exhaust momentum to draw in more air. | Large overlap at low speeds causes backflow of exhaust gases into cylinder. |
| **Inlet valve timing** | Late closing of inlet valve after BDC uses air inertia to fill more charge (good at high speeds). | Too early closing reduces cylinder filling; too early opening can cause backflow. |
| **Exhaust residual** | – | Residual gases increase intake temperature, dilute fresh charge, reduce oxygen availability. |
| **Exhaust gas recirculation (EGR)** | – (primarily used for NOx reduction, not efficiency gain) | Displaces fresh air with exhaust gases, lowering volumetric efficiency and power. |

| | | |
|---|---|---|
| **Engine speed** | Moderate speeds allow optimum filling with good inertia effects. | Very high speeds reduce filling time; very low speeds lose inertia benefits and scavenging effect. |

**02.(a)**

**(i) Enumerate, with the aid of illustrative sketches, the condition of equilibrium of a submerged body. (8 M)**

**Sol:** There are three possible cases in fully submerged body.

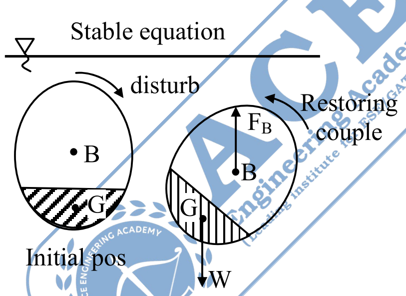
(i). Bottom heavy body {G below B}

(ii). Top heavy body {G above B}

(iii). Homogeneous body {G coincide with B}

In each of the following case we shall give clockwise disturbing moment to each body and observe the couple induced due to weight and Buoyant force at disturbed position.

**(i) Bottom Heavy Body (G below B)**

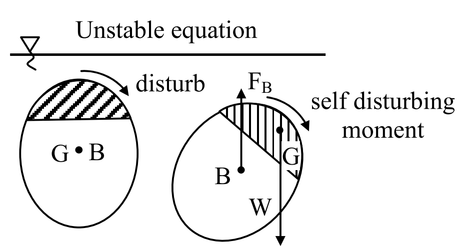



The couple by W and $F_B$ is anticlockwise,

∴ It is restoring couple

∴ The body is in stable equilibrium.

**(ii) Top heavy body {G is above B}**




The couple by W & $F_B$ is also clockwise {in the direction of disturbance}.

∴ Unstable equation.

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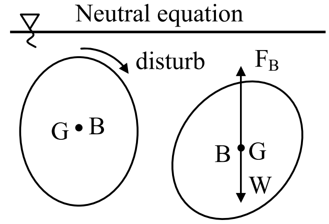
**(iii) Homogeneous body {B & G coincide}**




There is no couple induced by W & $F_B$.

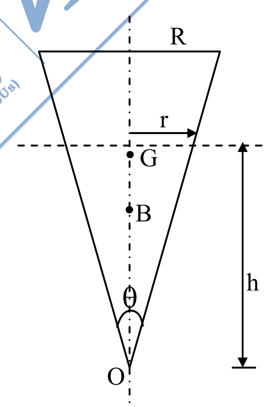
$\therefore$ A new equilibrium position is attained.

$\Rightarrow$ Neutral equation.

**02.(a)**

**(ii) A solid cone of relative density 0·70 floats in water. What should be its minimum apex angle so that it may float its apex downwards in stable equilibrium? (12 M)**

**Sol:** Let the cone be of height H and radius R.




$$OG = \frac{3}{4}H \quad \ldots\ldots\ldots\ldots (1)$$

By equation: $W_{cone} = F_B$

$$\Rightarrow \quad \gamma_c.\frac{\pi}{3}R^2H = \gamma_w.\frac{\pi}{3}r^2.h$$

$$r^2h = S_c.R^2.H$$

$$\Rightarrow \quad S_c = \frac{r^2.h}{R^2.H}$$

By similarity of triangles.

$$\frac{r}{R} = \frac{h}{H}$$

$$\Rightarrow \quad S_c = \frac{h^3}{H^3} \ \& \ S_c = \frac{r^3}{R^3}$$

$$\Rightarrow \quad h = H.S_c^{1/3} \ \& \ r = R.S_c^{1/3} \quad \ldots\ldots\ldots\ldots (2)$$

$$OB = \frac{3}{4}h = \frac{3}{4}H.S_c^{1/3} \quad \ldots\ldots\ldots\ldots\ldots (3)$$

$$BG = OG - OB$$

$$\Rightarrow \quad BG = \frac{3}{4}H - \frac{3}{4}H.S_c^{1/3}$$

$\Rightarrow \quad BG = \frac{3H}{4}\left\{1 - S_c^{1/3}\right\}$ .............. (4)

$I = \frac{\pi}{64}d^4 = \frac{\pi}{4}.r^4 = \frac{\pi}{4}R^4.S_c^{4/3}$ ............... (5)

$V_f = S_c.V_b$

$\Rightarrow \quad V_f = S_c.\frac{\pi}{3}R^2H$ ............... (6)

For stable equilibrium: $\frac{I}{V} > BG$

At minimum: $\frac{I}{V} = BG$

$$\Rightarrow \quad \frac{\frac{\pi}{4}.R^4.S_c^{4/3}}{S_c.\frac{\pi}{3}R^2H} = \frac{3}{4}H\left\{1 - S_c^{1/3}\right\}$$

$$\Rightarrow \quad \frac{R^2}{H^2} = \left\{\frac{1 - S_c^{1/3}}{S_c^{1/3}}\right\}$$

$$\Rightarrow \quad \frac{R^2}{H^2} = \left\{\frac{1}{0.7^{1/3}} - 1\right\}$$

$$\Rightarrow \quad \frac{R}{H} = 0.355 = \tan\left\{\frac{\theta}{2}\right\}$$

$$\Rightarrow \quad \frac{\theta}{2} = 19.56°$$

$$\Rightarrow \quad \theta = 39.12°$$

∴ Minimum apex angle must be 39.12°

**02.(b) Ethylene glycol (1800 kg/hr) is cooled from 100 °C to 60 °C by cooling water that enters the annular space of a single-pass counterflow heat exchanger at 15 °C and has a mass flow rate of 1200 kg/hr. Calculate:**

**(i) the overall heat transfer coefficient if convective heat transfer coefficient of water-side is 8·72 kW/ m$^2$-deg;**

**(ii) the necessary length of copper tubing if it has an internal diameter of 1.25 m;**

**(iii) also the length of the tube required if water flows in the same direction as ethylene glycol.**

**For turbulent flow of fluid inside the tube, the Dittus-Boelter relationship $Nu = 0.023\,(Re)^{0.8}\,(Pr)^{0.4}$ is to be used.**

**The relevant physical properties of ethylene glycol at its bulk temperature of 80 °C are $C_P = 2\cdot64$ kJ/kg-K; $\mu = 11\cdot 72$ kg/hr-m; $k = 0.26 \times 10^{-3}$ kW /m-deg. (20 M)**

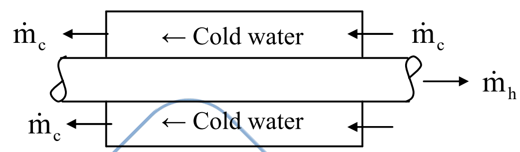
**Sol:**

**(i)** $\dot{m}_h = 1800$ kg/hr = 0.5 kg/sec

$T_{hi} = 100°C$; $T_{ho} = 60°c$ ; $C_h = 2.64$ kJ/kgK

$\dot{m}_c = 1200$ kg/hr = 0.333 kg/sec

$T_{ci} = 15°C$ ; $T_{co} = ?$ $C_c = 4.18$ kJ/kgK




(a) Estimate the outlet temp of cold fluid

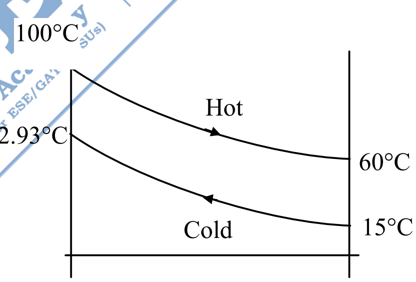
Energy Balance:

$$\dot{m}_h\, c_h\, (T_{hi} - T_{ho}) = \dot{m}_c\, C_c\, (T_{Co} - T_{Ci})$$

$$\therefore Tc_0 = \frac{0.5 \times 2.64 \times (100-60)}{0.333 \times 4.18} + 15$$

$$\dot{Q} = 52.8 \text{ kW}$$

$$T_{co} = 37.93 + 15 = 52.93°C$$




(b) <u>Estimate LMTD:</u>

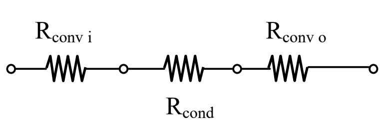
$$\Delta T_1 = 47.06°C$$

$$\Delta T_2 = 45°C$$

$$LMTD = \frac{\Delta T_1 - \Delta T_2}{\ell n\left(\frac{\Delta T_1}{\Delta T_2}\right)} = \frac{47.06 - 45}{0.0447} = 46.02°C$$

(c) $\dot{Q} = U\,A_s\,LMTD$

Estimation of 'U'




$$U_i A_{si} = \frac{1}{R_{total}}$$

$$U_i.A_{si} = \frac{1}{\frac{1}{h_i A_{si}} + \frac{\ln(r_2/r_1)}{2\pi k L} + \frac{1}{h_0\ A_{s0}}}$$

Assuming k⟶ large

$\frac{\ln(r_2/r_1)}{2\pi kL}$ can be neglected

and $U_i = \frac{1}{\frac{1}{h_i}+\frac{1}{h_0}\left(\frac{A_{si}}{A_{so}}\right)}$

As the tube is thin

$A_{si} \cong A_{s0}$

$\Rightarrow U_i = \frac{1}{\frac{(h_i+h_0)}{h_i\ h_0}} \cong \frac{h_i \times h_0}{(h_i+h_0)}$

$h_0 = 8.72$ kW/m$^2$ °C

$\frac{h_i \times d}{k} = 0.023\,(Re)^{0.8}\,(Pr)^{0.4}$

$Re = \frac{4\dot{m}}{\pi d\mu} = \frac{4\times1800}{\pi\times1.25\times11.72} = 156.43$

$Pr = \frac{\mu c_p}{k} = \frac{\frac{11.72}{3600}\times2.64\times10^3}{0.26} = 33.056$

Nu = 0.023 $(156.43)^{0.8} \times (33.056)^{0.4}$

= 0.023 × 56.94 × 4.05

Nu = 5.306 ; $h_i = \frac{5.306\times0.26}{1.25} = 1.1038$

$U = \frac{h_i\times h_0}{h_i+h_0} = \frac{1.1038\times8.72\times10^3}{1.1038+8.72\times10^3} = \frac{9.625\times10^3}{8721.1}$

$U_i = 1.1036$ W/m$^2$

**(ii)** $A_s = \frac{\dot{Q}}{U_i\ LMTD} = \frac{52.8\times10^3}{1.1036\times46.02}$

$A_s = 1039.58$m$^2$

πdL = 1039.58

$\therefore L = \frac{1039.58}{\pi\times1.25}$

L = 264.72 m

**(iii)** $\dot{Q} = U\ A_s)_{PF}\ LMTD)_{PF} = U\ A_s)_{CF}\ LMTD)_{CF}$

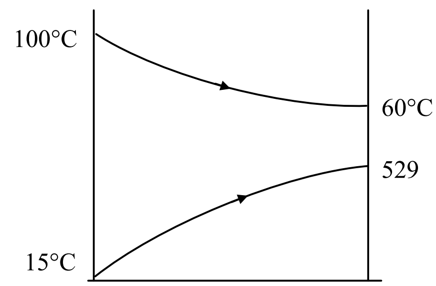
$$\Rightarrow A_s)_{PF} = \frac{As)_{CF} \times LMTD)_{CF}}{LMTD)_{PF}}$$

$$LMTD)_{PF} = \frac{\Delta T_1 - \Delta T_2}{\ln(\Delta T_1/\Delta T_2)}$$

$$LMTD = \frac{85 - 6.17}{\ln(85/6.17)}$$

$$\frac{78.83}{2.622} = 30.06°C$$

$$CF = \frac{264.72 \times 46.02}{30.06} \Rightarrow 405.26\ m$$




**02. (c) A 4-cylinder, 4-stroke SI engine having 70 mm bore and 84 mm stroke runs at 4000 r.p.m. and uses a fuel having 84% carbon and 16% hydrogen by mass. The volumetric efficiency of the engine is 80%. The ambient conditions are 1·0 bar and 27 °C. The depression at the venturi throat is 0·65 bar. Assuming the stoichiometric A/F ratio, calculate the fuel flow rate, the air velocity at the throat and the throat diameter.**
**[Take, $R_{air}$ = 287 J /kg-K; $R_{fuel\ vapour}$ = 98 J /kg-K] (20 M)**

**Sol:** No. of strokes = 4

No. of cylinders = 4 = x

SI Engine

Bore = D = 70 mm

Stroke = L = 84 mm

Speed = N = 4000 rpm

$\eta_{vol}$ = 80%

$P_{atm}$ = 1 bar

$T_{atm}$ = 300 K

dp = 0.65 bar

Stochiometric Air Fuel Ratio

$R_{fuel\ vapor}$ = 98 J/kg.K

$R_{air}$ = 287 J/kg.K

C = 84%

$H_2$ = 16%

Volume flow rate of mixture per second = $\left(\frac{\pi}{4}D^2Lx\times\frac{N}{120}\right)\eta_{vol}$

$$= \frac{\pi}{4}\times 7^2\times 8.4\times 10^{-6}\times 4\times\frac{4000}{120}\times 0.8$$

$\dot{V}_{mix} = 34464.64 \times 10^{-6}$ m$^3$/sec

Stochiometric Air requirement for 1 kg fuel = $\frac{100}{23.3}\left[\frac{8}{3}C + 8H_2\right]$

$$= \frac{100}{23.3}\left[\frac{8}{3}\times 0.84 + 8\times 0.16\right]$$

$$= \frac{100}{23.3}[2.24 + 1.28]$$

= 15.107 kg air/kg fuel

Stochiometric Air Fuel Ratio = 15.107

Specific volume of air = $v_a = \frac{287\times 300}{1\times 10^5} = 0.861$ m$^3$/kg

Specific volume of fuel = $v_f = \frac{98\times 300}{1\times 10^5} = 0.294$ m$^3$/kg

Volume flow rate of air + Volume flow rate of fuel = Volume flow rate of mixture

$\dot{m}_a v_a + \dot{m}_f v_f = \dot{V}_{mix}$

$\frac{\dot{m}_a}{\rho_a} + \frac{\dot{m}_f}{\rho_f} = \dot{V}_{mix}$

$\dot{m}_f = \frac{\dot{m}_a}{15.107}$

$\dot{m}_1 \times 0.861 + \frac{\dot{m}_a}{15.107}\times 0.294 = 0.034467$

$0.88046\dot{m}_a = 0.034467$

$\dot{m}_a = \frac{0.034467}{0.88046} = 0.03915$ kg/sec

$\dot{m}_f = \frac{\dot{m}_a}{15.107} = \frac{0.03915}{15.107} = 0.002592$ kg/sec

dp = $P_1 - P_2$ = 0.65 bar

$P_2$ = 1 – 0.65 = 0.35 bar

$\frac{P_2}{P_1} = \frac{0.35}{1} = 0.35$

Velocity at throat = $\sqrt{2c_p T_1\left(1-\left(\frac{P_2}{P_1}\right)^{\frac{\gamma-1}{\gamma}}\right)}$

$V_2 = \sqrt{2\times1005\times298[1-0.35]^{0.286}} = 727.7$ m/sec

$\rho_a$ at throat = $\frac{P_2}{RT_2}$

$T_2 = T_1\left(\frac{P_2}{P_1}\right)^{\frac{\gamma-1}{\gamma}} = 298\ (0.35)^{0.286} = 220.7$ K

$\rho_2 = \frac{35}{0.287\times220.7} = 0.553$ m$^3$/kg

$A_2 = \frac{\dot{m}_a}{\rho_2 V_2} = \frac{0.03915}{0.553\times727.7} = 9.729\times10^{-5}$ m$^2$

$\frac{\pi}{4}d^2 = 9.729\times10^{-5}$

$d = \sqrt{\frac{4}{\pi}\times9.729\times10^{-5}} = 1.113\times10^{-2}$ m

$= 0.0113$ m $= 1.113$ cm

**03.(a)**

**(i) Let us define a thermal time constant $\tau = \frac{mC_v}{C_q A}$; mass m with an initial uniform temperature $T_0$, and then lower into a water bath with temperature $T_\infty$, and the heat transfer between mass and water has a heat transfer coefficient $C_q$ with surface area A and $C_v$ is specific heat at constant volume. Assume radiation to be negligible. Show, with the help of suitable equations, that for a quick response, thermocouple needs a small thermal time constant $\tau$ while for a house, a large thermal time constant is needed. (10 M)**

**Sol:**

For Bi $\le 0.1$

The rate of decrease in Internal energy$\} = \dot{Q}_{conv}$

$-mc_v\frac{dT}{d\tau} = c_q\ A_s\ (T - T_\infty)$

$$\Rightarrow \quad mc_v \frac{dT}{d\tau} + C_q\, A_s(T - T_\infty) = 0$$

$$\Rightarrow \quad C_1^1 \frac{dT}{d\tau} + \frac{(T - T_\infty)}{\dfrac{1}{C_q A_s}} = 0$$

$$\Rightarrow \quad C_1^1 \frac{dT}{d\tau} + \frac{T - T_\infty}{R} = 0$$

Where $C_1^1 = mC_v$ & $R = \dfrac{1}{C_q.A_s}$

$$\therefore \quad \frac{dT}{d\tau} = \frac{1}{RC_1^1}(T - T_\infty)$$

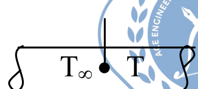
$$\int_{T_0}^{T} \frac{dT}{T - T_\infty} = -\frac{1}{RC_1^1}\int_{\tau=0}^{\tau} d\tau$$

$$\ln\left(\frac{T - T_\infty}{T_0 - T_\infty}\right) = -\frac{1}{RC_1^1}.\tau$$

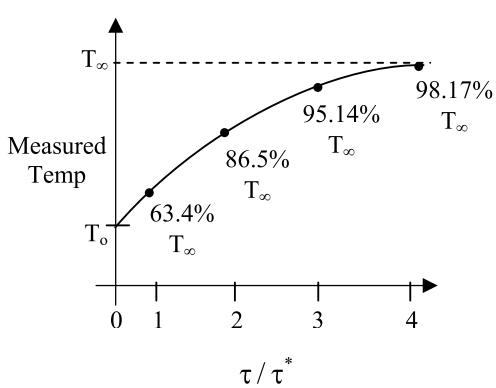
$$\ln\left(\frac{T - T_\infty}{T_0 - T_\infty}\right) = -\frac{1}{\left(\dfrac{mcv}{C_q.A}\right)}.\tau$$

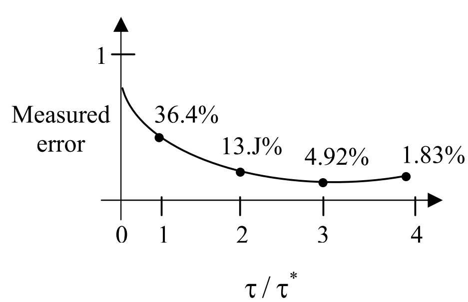
$$\frac{T - T_\infty}{T_0 - T_\infty} = e^{-\tau/\tau^*} \quad \text{where } \tau^* = \frac{mC_v}{Cq.A}$$

For thermocouple, error should be least




Measured error $= (T_0 - T_\infty).e^{-\tau/\tau^*}$

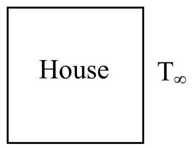



It is observed that at $\tau/\tau^* \geq 4$ the error is less than 1.83%

For House

House should not reach $T_\infty$. i.e., In cold climates the value of $T_\infty < T_{House}$.




In hot climates $T_{House} < T_\infty$. House is always maintained at 24°C DBT for comfort conditions.

Hence, the error between House and $T_\infty$ should be large.

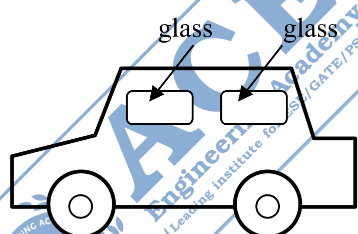
For error to be Large, $\tau/\tau^*$ should be small

Hence $\tau^*$ should be large.

**(ii) On a hot day of summer, a car is left in sunlight with all the windows closed. After some time, it is found that inside of the car is considerably warmer than the air outside. Why?**

**(10 M)**

**Sol:**



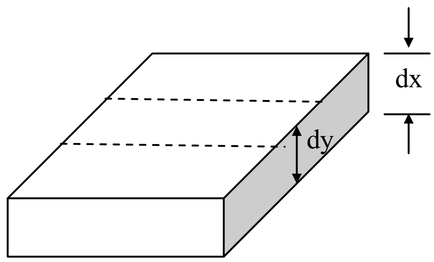

Glass is selective transmitter and allows low wave length light through it and does not allow High wave length infra Red radiation.

Hence, Heat content of inside the car increases. It is green house effect.

**03.(b)**

**(i) Establish a relation for the time taken to form a layer of ice on the surface of a pond. (12 M)**

**Sol:**




$$\frac{dQ}{d\tau} = \frac{KA(\Delta T)}{y}$$

$dQ = (A.\ dy\ .\ \rho).\ h_{fg}$ [$h_{fg}$ = Latent heat of vaporization]

$$\therefore d\tau = \frac{A.dy.\rho.\ h_{fg}.\ y}{k.A\ (\Delta T)}$$

$$\int_{\tau=\tau_1}^{\tau=\tau_2} d\tau = \frac{\rho.\ h_{fg}}{k\Delta T}\int_{\delta_1}^{\delta_2} y\ dy$$

$$\tau_2 - \tau_1 = \frac{\rho.h_{fg}}{k(\Delta T)}.\left[\frac{\delta_2^2 - \delta_1^2}{2}\right]$$

If $\rho = 0$ at $\tau = 0$

then $\tau = \rho h_{fg}\left(\delta^2\right)$



**(ii) Name the various types of insulating materials used in engineering and mention applications for which they are used. (8 M)**

**Sol:** Insulating materials play a crucial role in engineering by preventing or reducing the transfer of heat, electricity, or sound. Based on their purpose, they can be classified into thermal insulators, electrical insulators, acoustic insulators, and cryogenic insulators, each with specific applications in different fields.

Thermal insulating materials are used to reduce the rate of heat transfer, helping to maintain desired temperatures in buildings, industrial equipment, and storage systems. Common examples include fiberglass, which is widely used in building walls, ceilings, and HVAC duct insulation; mineral wool, which finds applications in industrial furnaces and high-temperature piping;

polystyrene foam, used in cold storage rooms, refrigeration units, and packaging; and ceramic fibers, which are ideal for kilns, gas turbines, and other high-temperature furnace applications.

Electrical insulating materials are designed to resist the flow of electric current, ensuring safety and efficiency in electrical systems. Examples include rubber, used for insulating cables and protective gloves for electrical work; mica, employed in high-voltage equipment such as transformers and capacitors; bakelite, used in switchgear, plugs, and sockets; and PVC (polyvinyl chloride), which is common in wire and cable insulation.

Acoustic insulating materials reduce the transmission of sound and are used in noise control applications. Polyurethane foam is often used for soundproofing studios and offices, mineral wool serves in acoustic panels and building walls, and cork is used in floors and walls for vibration and sound damping.

For extremely low-temperature applications, cryogenic insulating materials are used to prevent heat gain. Pearlite is a common choice for cryogenic storage tanks, while vacuum insulation panels are employed in transporting liquid nitrogen and liquefied natural gas (LNG).

In engineering, the selection of insulating material depends on factors such as the temperature range, environmental conditions, mechanical strength, and cost. Choosing the right material ensures efficiency, safety, and durability in the intended application.

**03.(c)**

**(i) A cylinder/piston setup contains 1 L of saturated liquid refrigerant (R-410A) at 40 °C. The piston now moves slowly, expands maintaining constant temperature to a final pressure of 500 kPa in a reversible process. Calculate the work done and heat transfer required to accomplish this process.** **(10 M)**

**State-1**

| Temperature (°C) | Pressure (kPa) | Specific volume, $m^3$/kg | | | Enthalpy, kJ/kg | | | Entropy, kJ/kg-K | | | Internal energy, kJ/kg | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | $v_f$ | $v_{fg}$ | $v_g$ | $h_f$ | $h_{fg}$ | $h_g$ | $s_f$ | $s_{fg}$ | $s_g$ | $u_f$ | $u_{fg}$ | $u_g$ |
| 40 | 2420.7 | 0.001025 | 0.00865 | 0.00967 | 124.09 | 159.04 | 283.13 | 0.4473 | 0.5079 | 0.9552 | 121.61 | 138.11 | 259.72 |

**State-2**

**500 kPa, -13·89 °C**

**v ($m^3$/kg) = 0·06775**

**u (kJ/kg) = 290·32**

**h (kJ /kg) = 324·20**

**s (kJ /kg-K) = 1 ·2398**

**Sol:**

**(i)** Liquid refrigerant saturated = 1 litre = V

$T_{sat} = 40°C$ ; $P_{sat} = 2420.7$ kPa; $v_f = 0.001025\ m^3/kg$

Non-flow process

$v_1 = v_f = 121.61$ kJ/kg

Mass of liquid refrigerant $= \dfrac{V}{v_f}$

$$m_\ell = \frac{1\times10^{-3}}{0.001025} = 0.9756 \text{ kg}$$

Isothermal heating

$$P_1V_1 = P_2V_2$$

$$V_2 = \frac{P_1V_1}{P_2} = \frac{2420.7\times10^{-3}}{500} = 4.8414 \times 10^{-3}\ m^3$$

Isothermal work $= P_1V_1\ell n\dfrac{V_2}{V_1}$

$$dW = 2420.7\times10^{-3}\,\ell n\frac{4.8414\times10^{-3}}{10^{-3}} = 3.804 \text{ kJ}$$

Internal Energy at state (2) $U_2 = 290.32$ kJ/kg

Change in Internal Energy = $dU = m_\ell(U_2 - U_1)$

$= 0.9756\ (290.32 - 121.61) = 164.59$ kJ

$dQ = dU + dW$

$= 164.59 + 3.804 = 168.39$ kJ

**(ii)**

**(1) 1 kg of water at 100 kPa, 120 °C receives 50 kJ /kg in a reversible process by heat transfer. Which thermodynamic process, from the given below, will generate the largest entropy change? Justify your answer:**

**A. Constant temperature**

**B. Constant pressure**

**C. Constant volume** **(6 M)**

**(2) How can you change entropy of a substance going through a reversible process? Keep in mind the second law of thermodynamics.** **(4 M)**

**Sol:**

**(1)** $Q_{1\text{-}2} = mc_{p_w}(t_2 - t_1)$

$50 = 1 \times 4.18\,(t_2 - 120)$

$t_2 = 131.96°C$

$T_1 = 120 + 273 = 393$ K ; $T_2 = 131.96 + 273 = 404.96$ K

A. Constant Temperature Process:

$$\text{Change in entropy, } s_2 - s_1 = \frac{Q_{1-2}}{T} = \frac{50}{393} = 0.1272 \text{ kJ/kg.K}$$

B. Constant Pressure Process:

$$\text{Change in entropy, } s_2 - s_1 = c_p \ell n\left(\frac{T_2}{T_1}\right) = 4.18 \ell n\left(\frac{404.96}{393}\right) = 0.1253 \text{ kJ/kg.K}$$

C. Constant Volume Process:

$$\text{Change in entropy, } s_2 - s_1 = c_p \ell n\left(\frac{T_2}{T_1}\right) = 4.18 \ell n\left(\frac{404.96}{393}\right) = 0.1253 \text{ kJ/kg.K}$$

($\because$ For water, $c_p = c_v$)

The largest entropy change is during isothermal process.

**(2)** The process can be made as a reversible process with very slow movement of the piston inside the cylinder such that the pressure change and temperature change between the successive equilibrium states should be infinitesimally small. The change in entropy can be found zero in a perfect reversible process.

$\therefore$ Constant temperature process will generate the largest entropy change.

**04.(a) A cooling tower cools water from 45 °C to 25 °C. Water enters the tower at a rate of 100000 kg/hr. Air enters the tower is at 20 °C with a relative humidity of 50%; the air leaving is at 40 °C with a relative humidity of 95%. The air enters at the bottom and leaves at the top. The barometric pressure is 92 kPa. Determine—**

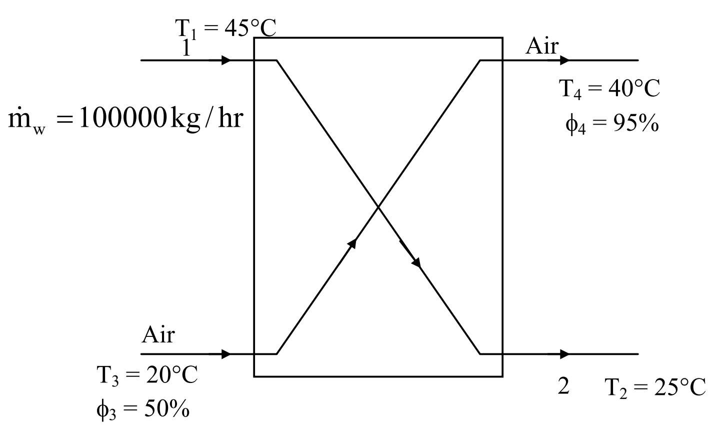
**(i) the required flow rate of atmospheric air in kg/hr;**

**(ii) the amount of water lost by evaporation per hour. (20 M)**

Saturated water—Temperature table

| | | Specific volume, m³/kg | | Internal energy, kJ/kg | | | Enthalpy, kJ/kg | | | Entropy, kJ/kg·K | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Temp., $T$ °C | Sat. press., $P_{sat}$, kPa | Sat. liquid, $v_f$ | Sat. vapor, $v_g$ | Sat. liquid, $u_f$ | Evap., $u_{fg}$ | Sat. vapor, $u_g$ | Sat. liquid, $h_f$ | Evap., $h_{fg}$ | Sat. vapor, $h_g$ | Sat. liquid, $s_f$ | Evap., $s_{fg}$ | Sat. vapor, $s_g$ |
| 0.01 | 0.6117 | 0.001000 | 206.00 | 0.000 | 2374.9 | 2374.9 | 0.001 | 2500.9 | 2500.9 | 0.0000 | 9.1556 | 9.1556 |
| 5 | 0.8725 | 0.001000 | 147.03 | 21.019 | 2360.8 | 2381.8 | 21.020 | 2489.1 | 2510.1 | 0.0763 | 8.9487 | 9.0249 |
| 10 | 1.2281 | 0.001000 | 106.32 | 42.020 | 2346.6 | 2388.7 | 42.022 | 2477.2 | 2519.2 | 0.1511 | 8.7488 | 8.8999 |
| 15 | 1.7057 | 0.001001 | 77.885 | 62.980 | 2332.5 | 2395.5 | 62.982 | 2465.4 | 2528.3 | 0.2245 | 8.5559 | 8.7803 |
| 20 | 2.3392 | 0.001002 | 57.762 | 83.913 | 2318.4 | 2402.3 | 83.915 | 2453.5 | 2537.4 | 0.2965 | 8.3696 | 8.6661 |
| 25 | 3.1698 | 0.001003 | 43.340 | 104.83 | 2304.3 | 2409.1 | 104.83 | 2441.7 | 2546.5 | 0.3672 | 8.1895 | 8.5567 |
| 30 | 4.2469 | 0.001004 | 32.879 | 125.73 | 2290.2 | 2415.9 | 125.74 | 2429.8 | 2555.6 | 0.4368 | 8.0152 | 8.4520 |
| 35 | 5.6291 | 0.001006 | 25.205 | 146.63 | 2276.0 | 2422.7 | 146.64 | 2417.9 | 2564.6 | 0.5051 | 7.8466 | 8.3517 |
| 40 | 7.3851 | 0.001008 | 19.515 | 167.53 | 2261.9 | 2429.4 | 167.53 | 2406.0 | 2573.5 | 0.5724 | 7.6832 | 8.2556 |
| 45 | 9.5953 | 0.001010 | 15.251 | 188.43 | 2247.7 | 2436.1 | 188.44 | 2394.0 | 2582.4 | 0.6386 | 7.5247 | 8.1633 |
| 50 | 12.352 | 0.001012 | 12.026 | 209.33 | 2233.4 | 2442.7 | 209.34 | 2382.0 | 2591.3 | 0.7038 | 7.3710 | 8.0748 |
| 55 | 15.763 | 0.001015 | 9.5639 | 230.24 | 2219.1 | 2449.3 | 230.26 | 2369.8 | 2600.1 | 0.7680 | 7.2218 | 7.9898 |
| 60 | 19.947 | 0.001017 | 7.6670 | 251.16 | 2204.7 | 2455.9 | 251.18 | 2357.7 | 2608.8 | 0.8313 | 7.0769 | 7.9082 |
| 65 | 25.043 | 0.001020 | 6.1935 | 272.09 | 2190.3 | 2462.4 | 272.12 | 2345.4 | 2617.5 | 0.8937 | 6.9360 | 7.8296 |
| 70 | 31.202 | 0.001023 | 5.0396 | 293.04 | 2175.8 | 2468.9 | 293.07 | 2333.0 | 2626.1 | 0.9551 | 6.7989 | 7.7540 |
| 75 | 38.597 | 0.001026 | 4.1291 | 313.99 | 2161.3 | 2475.3 | 314.03 | 2320.6 | 2634.6 | 1.0158 | 6.6655 | 7.6812 |
| 80 | 47.416 | 0.001029 | 3.4053 | 334.97 | 2146.6 | 2481.6 | 335.02 | 2308.0 | 2643.0 | 1.0756 | 6.5355 | 7.6111 |
| 85 | 57.868 | 0.001032 | 2.8261 | 355.96 | 2131.9 | 2487.8 | 356.02 | 2295.3 | 2651.4 | 1.1346 | 6.4089 | 7.5435 |
| 90 | 70.183 | 0.001036 | 2.3593 | 376.97 | 2117.0 | 2494.0 | 377.04 | 2282.5 | 2659.6 | 1.1929 | 6.2853 | 7.4782 |
| 95 | 84.609 | 0.001040 | 1.9808 | 398.00 | 2102.0 | 2500.1 | 398.09 | 2269.6 | 2667.6 | 1.2504 | 6.1647 | 7.4151 |
| 100 | 101.42 | 0.001043 | 1.6720 | 419.06 | 2087.0 | 2506.0 | 419.17 | 2256.4 | 2675.6 | 1.3072 | 6.0470 | 7.3542 |
| 105 | 120.90 | 0.001047 | 1.4186 | 440.15 | 2071.8 | 2511.9 | 440.28 | 2243.1 | 2683.4 | 1.3634 | 5.9319 | 7.2952 |
| 110 | 143.38 | 0.001052 | 1.2094 | 461.27 | 2056.4 | 2517.7 | 461.42 | 2229.7 | 2691.1 | 1.4188 | 5.8193 | 7.2382 |
| 115 | 169.18 | 0.001056 | 1.0360 | 482.42 | 2040.9 | 2523.3 | 482.59 | 2216.0 | 2698.6 | 1.4737 | 5.7092 | 7.1829 |
| 120 | 198.67 | 0.001060 | 0.89133 | 503.60 | 2025.3 | 2528.9 | 503.81 | 2202.1 | 2706.0 | 1.5279 | 5.6013 | 7.1292 |
| 125 | 232.23 | 0.001065 | 0.77012 | 524.83 | 2009.5 | 2534.3 | 525.07 | 2188.1 | 2713.1 | 1.5816 | 5.4956 | 7.0771 |
| 130 | 270.28 | 0.001070 | 0.66808 | 546.10 | 1993.4 | 2539.5 | 546.38 | 2173.7 | 2720.1 | 1.6346 | 5.3919 | 7.0265 |
| 135 | 313.22 | 0.001075 | 0.58179 | 567.41 | 1977.3 | 2544.7 | 567.75 | 2159.1 | 2726.9 | 1.6872 | 5.2901 | 6.9773 |
| 140 | 361.53 | 0.001080 | 0.50850 | 588.77 | 1960.9 | 2549.6 | 589.16 | 2144.3 | 2733.5 | 1.7392 | 5.1901 | 6.9294 |
| 145 | 415.68 | 0.001085 | 0.44600 | 610.19 | 1944.2 | 2554.4 | 610.64 | 2129.2 | 2739.8 | 1.7908 | 5.0919 | 6.8827 |

**Sol:**



$P_{atm}$ = 92 kPa; $T_{sat}$ = 20°C; $P_{sat}$ = 2.3392 kPa

$$\phi_3 = \frac{Pv_3}{P_{sat}}$$

$$0.50 = \frac{Pv_3}{2.3392}$$

$Pv_3$ = 1.1696 kPa

$$\omega_3 = 0.622\frac{Pv_3}{P_{atm} - Pv_3} = \frac{0.622 \times 1.1696}{92 - 1.1696} = 0.008\frac{\text{kgvap}}{\text{kgd.a}}$$

$T_{sat}$ = 40°C; $P_{sat}$ = 7.3851 kPa

$$\phi_4 = 0.95 = \frac{Pv_4}{P_{sat}} = \frac{Pv_4}{7.3851}$$

$Pv_4$ = 7.0158

$$\omega_4 = 0.622\frac{Pv_4}{P_{atm}.Pv_4} = 0.622 \times \frac{7.0158}{92 - 7.0158} = 0.05134\frac{\text{kgvap}}{\text{kg.d.a}}$$

$h_3 = c_{pa}(T_3 - 0) + w_3[2500 + 1.88(T_3 - 0)] = 1.005\ (20 - 0) + 0.008\ [2500 + 1.88 \times 20]$

20.1 + 20.3 = 40.4 kJ/kg

$h_4 = c_{pa}(T_4 - 0) + \omega_4\ [2500 + 1.88(T_4 - 0)]$

40.2 + 132.21 = 172.41 kJ/kg

Heat gained by air = Heat cost by water

$$\dot{m}_a(h_4 - h_3) = \dot{m}_w c_{pw}(T_1 - T_2)$$

$$\dot{m}_a(172.41 - 40.4) = \frac{100000}{3600} \times 4.187(45 - 25)$$

$$\dot{m}_a = \frac{100000}{3600} \times \frac{4.187(45-25)}{(172.41 - 40.4)} = \frac{2326.11}{132.01} = 17.621 \text{ kg/sec}$$

$$= 17.621 \times 3600 = 63434.55 \text{ kg/hr}$$

Water vapor carried away air = $\dot{m}_a(\omega_4 - \omega_3) = 63434.55\ (0.05134 - 0.008) = 2749.25$ kg/hr

**04.(b) For the velocity profile of laminar boundary layer**

$$\frac{u}{U_\alpha} = \sin\left(\frac{\pi}{2}, \frac{y}{\delta}\right)$$

**find the expressions for-**

**(i) boundary layer thickness;**

**(ii) shear stress;**

**(iii) average coefficient of drag.** **(20 M)**

**Sol:** $\dfrac{u}{U_\infty} = \sin\left\{\dfrac{\pi}{2}\dfrac{y}{\delta}\right\}$

$\Rightarrow \quad u = U_\infty.\sin\left\{\dfrac{\pi}{2}\dfrac{y}{\delta}\right\}$

$$\tau_w = \mu.\left.\frac{du}{dy}\right|_{y=0} = \mu.\frac{d}{dy}\left\{U_\infty.\sin\left(\frac{\pi}{2}.\frac{y}{\delta}\right)\right\}_{y=0}$$

$$\Rightarrow \quad \tau_2 = \frac{\pi\mu U_\infty}{2\delta} \qquad \text{.........} (1)$$

$$\theta = \int_0^\delta \frac{u}{U_\infty}\left(1-\frac{u}{U_\infty}\right).dy = \int_0^\delta \frac{u}{U_\infty}.dy - \int_0^\delta\left(\frac{u}{U_\infty}\right)^2.dy$$

$$\Rightarrow \quad \theta = \int_0^\delta \sin\left(\frac{\pi}{2}.\frac{y}{\delta}\right).dy - \int_0^\delta \sin^2\left(\frac{\pi}{2}.\frac{y}{\delta}\right)dy$$

$$\Rightarrow \quad \theta = \frac{2\delta}{\pi} - \frac{\delta}{2}$$

$$\Rightarrow \quad \theta = \delta\left\{\frac{2}{\pi} - \frac{1}{2}\right\} \qquad \text{.........} (2)$$

By Karman Momentum Integral equation:

$$\frac{\tau_w}{\rho U_\infty^2} = \frac{\partial\theta}{\partial x}$$

$$\Rightarrow \quad \frac{\pi\mu U_\infty}{2\delta\rho U_\infty^2} = \left\{\frac{2}{\pi} - \frac{1}{2}\right\}.\frac{d\delta}{dx}$$

$$\Rightarrow \quad \int_0^\delta \delta.d\delta = \frac{\pi}{2\left\{\frac{2}{\pi} - \frac{1}{2}\right\}}.\frac{\mu}{\rho U_\infty}\int_0^x dx$$

$$\Rightarrow \quad \frac{\delta^2}{2} = \frac{\pi}{2\left(\frac{2}{\pi} - \frac{1}{2}\right)}.\frac{\mu x^2}{\rho U_\infty.x}$$

$$\Rightarrow \quad \delta^2 = \frac{\pi}{\left(\frac{2}{\pi} - \frac{1}{2}\right)}.\frac{x^2}{Re_x}$$

$$\Rightarrow \quad \delta = \frac{4.795x}{\sqrt{Re_x}} \qquad \text{..........} \text{ Ans (i)}$$

$$\tau_w = \frac{\pi\mu.U_\infty}{2\delta} = \frac{\pi\mu.U_\infty}{2\left\{\frac{4.795.x}{\sqrt{Re_x}}\right\}}$$

$$= 0.3276.\frac{\mu.U_\infty.\sqrt{Re_x}}{x}.\frac{\sqrt{Re_x}}{\sqrt{Re_x}}$$

$$= \frac{0.3276}{\sqrt{Re_x}}.\frac{\mu U_\infty\left\{\frac{\rho U_\infty.x}{\mu}\right\}}{x}$$

$$\tau_w = \frac{0.3276}{\sqrt{Re_x}}.\rho U_\infty^2 \qquad \text{……… Ans: (ii)}$$

$$F_D = B\int_0^L \tau_w.dx = B\int_0^L \frac{0.3276}{\sqrt{Re_x}}.\rho U_\infty^2$$

$$F_D = \frac{0.655}{\sqrt{Re_L}}.B.L.\rho U_\infty^2 \qquad \text{………… Ans. (iii)}$$

**04. (c)**

**(i) A 4-cylinder, 4-stroke engine has cylinder dia 10.0 cm and stroke length 10.0 cm. The engine is connected to an eddy current dynamometer, and 80·0 kW of power is dissipated by the dynamometer. Assuming engine mechanical efficiency as 85% at 4500 r.p.m. and the dynamometer efficiency as 95%, calculate-**

**(1) the frictional power lost;**

**(2) the brake mean effective pressure;**

**(3) the engine torque at 1500 r.p.m.;**

**(4) the engine specific volume. (10 M)**

**Sol:** Given data:

No. of cylinders = x = 4

No. of strokes = 4

D = 10 cm

L = 10 cm

Power = 80 kW

$\eta_{\text{mech engine}} = 0.85$

$\eta_{\text{dynamo}} = 0.95$

$$\text{Engine Power} = \frac{\text{Power delivered}}{\eta_{\text{Mech Engine}} \times \eta_{\text{dynamo}}} = \frac{80}{0.85 \times 0.95} = 99.07 \text{ kW}$$

Speed = N = 4500 rpm

(i) Frictional Power lost = 99.07 – 80 = 19.07 kW

$$bp = \frac{P_{mb} LANx}{120}$$

(ii) $$P_{mb} = \frac{120 \times bp}{LANx} = \frac{120 \times 80}{0.1 \times \frac{\pi}{4} \times 0.1^2 \times 4500 \times 4} = 679.4 \text{ kPa}$$

$P \propto N$

$$\frac{P_1}{N_1} = \frac{P_2}{N_2}$$

$$P_2 = \frac{1500}{4500} \times 50 = \frac{80}{3} \text{kW}$$

$$P_2 = \frac{2\pi NT}{60000}$$

(iii) $$T = \frac{60000 P_2}{2\pi N} = \frac{60000 \times \frac{80}{3}}{2 \times 3.14 \times 1500} = 169.85 \text{ Nm}$$

(iv) $$\text{Engine specific volume} = \frac{\text{Total swept volume (or) displacement volume}}{\text{Brake power}}$$

$$= \frac{\frac{\pi}{4} D^2 Lx}{B.P} = \frac{\frac{\pi}{4} \times (0.1)^2 \times 0.1 \times 4}{80}$$

$= 3.93 \times 10^{-5}$ m$^3$/kW

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**04. (c)**

**(ii)** **A single-cylinder SI engine is operated with gasoline of calorific value 44 MJ /kg and density 780 kg/m$^3$. During each combustion cycle when the flame reaches up to a height of 2 cm, combustion reaction stops due to closeness of the wall and dampens out all fluid motion while conducts heat anyway. The boundary layer of unburnt charge is formed in the combustion chamber of 4 cm dia and fuel is distributed equally throughout the combustion chamber having unburnt charge layer of approximately 0·1 mm thickness. Find the fraction of the unburnt fuel and resulting heat loss. (10 M)**

**Sol:** Volume of fuel $(V_f) = \frac{\pi}{4}D^2L = \frac{\pi}{4}\times 4^2 \times 2 = 25.13\text{ cm}^3 = 25.13\times10^{-6}\text{ m}^3$

Unburnt fuel $(V_{u_f}) = \left[\left(2\times\frac{\pi}{4}D^2\right) + \pi DL\right]t$

$$= \left[\left(2\times\frac{\pi}{4}\times4^2\right) + (\pi+4\times2)\right]\times0.1\times10^{-1}$$

$$= 0.5026\text{ cm}^3 = 0.5026\times10^{-6}\text{ m}^3$$

Fraction of Unburnt fuel $= \frac{V_{u_f}}{V_f} = \frac{0.5026}{25.13} = 0.02$

Resulting heat loss $= m_{u_f}\times CV = V_{u_f}\times\rho\times CV$

$$= 0.5026\times10^{-6}\times780\times44000$$

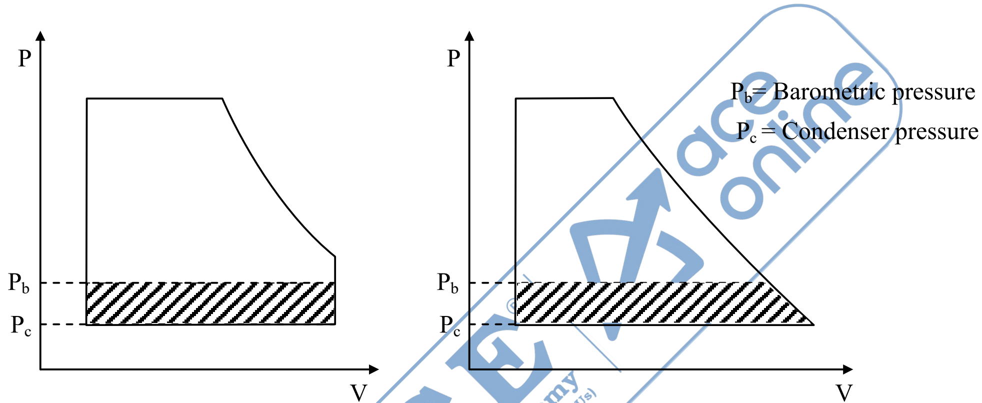
$$= 17.24\text{ KJ}$$

## SECTION – B

**05.(a) Enumerate the advantages of using steam condenser in a steam power plant. Explain the significance of vacuum efficiency and condenser efficiency. (12 M)**

**Sol: Advantages of using steam condenser in a steam power plant:**

1. Improvement in the efficiency of the plant due to increased available enthalpy drop.
2. Reduction in steam consumption per kW/hour. Increase in vacuum from 71 to 73.5 cm of Hg gives about 45% reduction in steam consumption.




*(a) Steam Engine* *(b) Steam Turbine*

**Note:** The hatched areas in above figure a & b represent the increase in work done by a steam engine and a steam turbine by exhausting the steam into a condenser.

3. The condensed steam called condensate collected in the hot well may be pumped back to the boiler as a feed water. Recovery of condensate reduces the make up water that must be added to the system from 100% when non-condensing to 1.5% when condensing. For steam power plants where sufficient quantity of good quality boiler feed water is not available recovery of condensate is very important. For marine practice where sea water is treated before being used in the boiler, recovery is a necessity.
4. To prevent the deposit in boiler piping, the feed water if not available in pure form has to be treated first in the water softening plant. The recovered condensate reduces the capital and running cost of the water softening plant.
5. Provision for the supply of hot water to the boiler results in fuel economy and safety from thermal stresses.

**Significance of Vacuum efficiency and condenser efficiency in steam power plant:**

1. **Vacuum efficiency:** Vacuum efficiency measures how close to the condenser's vacuum is to the maximum possible vacuum for the available cooling water temperature.

$$\eta_{vac} = \frac{\text{Actual vacuum}}{\text{Ideal vacuum}}$$

Ideal vacuum = vacuum corresponding to the saturation temperature of the cooling water outlet.

Actual vacuum = measured in the condenser during operation

**Significance:** A higher vacuum means the steam turbine exhaust pressure is lower, which increases the expansion ratio and therefore the turbine's outlet work.

Poor vacuum efficiency means air leaking or non-condensable gases are reducing the vacuum, forcing the turbine to exhaust ensures better plant thermal efficiency without burning more fuel.

2. **Condenser efficiency:** Condenser efficiency tells you how well the condenser is cooling the exhaust steam relative to the coding water's capacity.

$$\eta_{cond} = \frac{\text{Rise in coding water temperature}}{\text{Temperature difference between steam and inlet cooling water}}$$

**Significance:** High condenser efficiency means the condenser transfers heat effectively from steam to cooling water.

Low condenser efficiency can come from fouled tubes, low cooling water flow, or air pockets, all of which leads to higher turbine exhaust pressure and lower efficiency.

A good condenser ensures the steam is condensed quickly and vacuum is maintained.

**05.(b) Derive an expression for acceleration head impressed on the flow in case of a reciprocating pump. Assume that the piston has simple harmonic motion. (12 M)**

**Sol:** Consider pressure change due to inertia force in suction pipe as $(\Delta P_s)$

$$(\Delta P_s) = \frac{\text{Inertia force in suction pipe}}{\text{area of suction pipe}} = \frac{m_s a_s}{A_s} = \frac{\rho(A_s.L_s).a_s}{A_s}$$

$$= \rho L_s.a_s$$

Hence, acceleration head in suction pipe is given by

$$H_{as} = \frac{\Delta P_s}{\rho g} = \frac{\rho L_s a_s}{\rho g}$$

$$H_{as} = \frac{L_s.a_s}{g} \quad \text{………… (1)}$$

Now for S.H.M of piston,

$V_p = r\omega \sin\omega t$

By continuity equation, $A_pV_p = A_sV_s$

$$\therefore \quad V_s = \frac{dv_s}{dt} = \frac{A_p}{A_s}.r\omega \sin\omega t$$

$$\text{Now,} \quad a_s = \frac{dv_s}{dt} = \frac{A_p}{A_s}.r\omega.\cos\omega t.\omega$$

Substitute in eq.(1)

$$H_{as} = \frac{L_s}{g}.\frac{A_p}{A_s}.r\omega^2.\cos\theta$$

Similarly acceleration head in delivery pipe is given by

$$H_{ad} = \frac{L_d}{g} \times \frac{A_p}{A_d}.r\omega^2 \cos\theta$$

**05.(c) What is the need of mine ventilation? Explain, with a sketch, the working of mine air conditioning system. Also mention the various heat sources in mines. (12 M)**

**Sol: Mine Air Conditioning and Ventilation:**

Air conditioning and ventilation of mines requires very special expertise. The description presented here is only a brief overview of the topic.

Mine ventilation is required to supply oxygen to underground facilities, to remove dangerous substances like hydrocarbon methane ($CH_4$), radon, strata gases, dust, blasting fumes, diesel emission, etc., and also to remove heat, and help control humidity. Use of ventilation is limited by the wet bulb temperature which should not exceed the prescribed range which is considered satisfactory between 25.5 to 29°C. Accordingly, ventilation can be done to a depth of 2500 m at the most. Below this depth, air temperatures in the intake shaft reach very high values, and air conditioning becomes absolutely necessary.

'Stope' in the mine is a production site where ore is actually mined. Actual cooling load is calculated at the average stope temperature, which is lower than the acceptable temperature for ventilation.

Heat enter the mines from wall rocks.

Other loads are from electric motors, lights, substation losses, calorific value of diesel burnt, and occupancy. Another important source of heat entering mine is due to adiabatic compression of air descending the shaft.

Finally, heat enters from ground water.

Wall rock heat flow is the main source of heat in deep rock mines. Note that the temperature at the earth's core is estimated about 5700°C. Heat flux from core to mine's internal surface may be as high as 50 W/m$^2$ which corresponds to thermal conductivity k = 5.5 W/mK, and thermal diffusivity $\alpha$ = 0.008 m$^3$/h of surrounding earth.

For estimation of wall rock heat flow, one may refer to ASHRAE Handbook Application, 2003.

Note that air descending a shaft increases in pressure.

This may be referred to as 'adiabatic compression'. As a result, temperature of descending air increases. Load due to this adiabatic compression is given by

$$Q = Q_v \rho E \Delta L$$

where the load Q is in W, $Q_v$ is air flow in shaft in m$^3$/s, $\rho$ is air density about 1.12 kg/m$^3$, E is energy added per unit distance of elevation about 0.01 kJ/kg m, and $\Delta L$ is the change in elevation.

For example, load of adiabatic compression of 150 m$^3$/s of air at $\rho$ = 1.12, flowing down 1500 m deep shaft is

$$\dot{Q} = (150)(1.12)(0.01)(1500) = 2520 \text{ W}$$

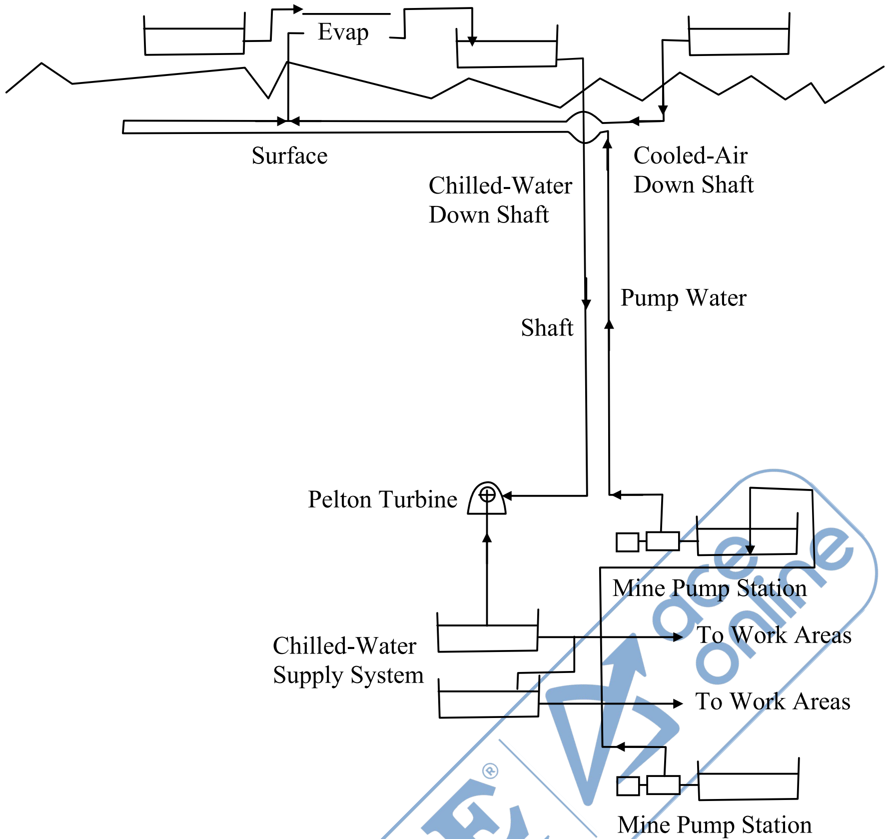
Groundwater load is an important factor. For example, if 1.5 L/s of water at 53°C leaks into shaft sump which is at 29°C, the load is

$$\dot{Q} = \left(15\frac{L}{2}\right)\left(1\frac{kg}{L}\right)\left(4.1868\frac{kJ}{kgK}\right)(53-29)K = 151 \text{ kW}$$

For mine air conditioning, we may have a surface plant or an underground plant. Underground plants do the same job as surface plants. They have the advantage of being closer to work areas. As a result, they given better efficiency and utilization.

But heat rejection is limited by the temperature of mine exhaust air which is used for cooling in condenser. Maintenance is also more difficult. Building spray chambers is more costly.

Mine A/C plant may either cool air or supply chilled water Figure shows a combination system. It can cool air chill water also.




Such a surface plant provides a higher fraction of cooling capacity to cool intake air in bulk in summer. In winter, a higher fraction of cooling capacity is used to chill air conditioning water. This water is delivered underground.

Figure shows that chilled water from chilled water reservoir is taken to the following:

**(i)** **Air Washer:** From air washer, cooled-air is sent down shaft.

**(ii)** **Underground Chilled Water Supply System:** Chilled water first goes to pelton turbine which produces power from the 'head' of water corresponding to depth below ground level. After doing work in turbine, water is available for chilled-water fan-coil unit (FCU), and other services. A mine pump station returns the water to surface. This return water plus return water from air washer together enter the evaporator/chiller of the refrigeration plant. The plant uses centrifugal or screw compressor. Most common refrigerant is HCFC22. Ammonia is also commonly used in surface plants. Other method being developed includes air cycle refrigeration. Air is compressed on the surface. It is sent underground to a turbine where it turns a generator and exits at –40°C.

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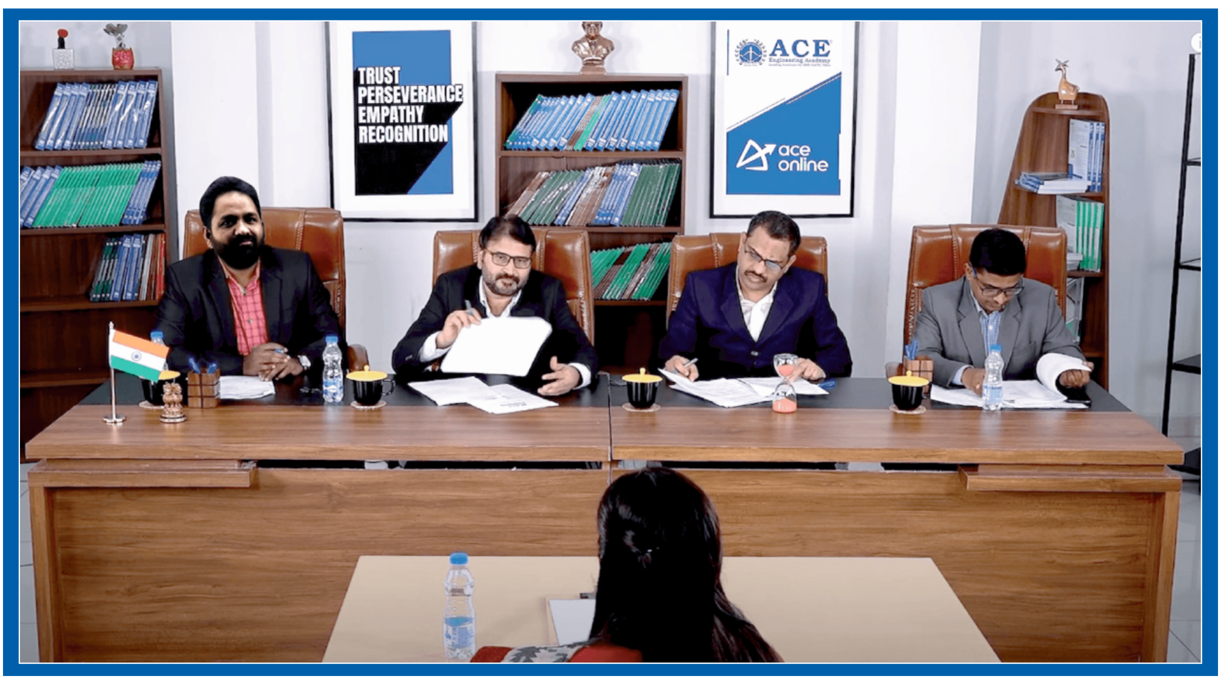


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**05.(d) Briefly discuss the impact of the following variables on the performance of a concentrating solar collector:**

**(i) Fluid inlet temperature**

**(ii) Mass flow rate of fluid**

**(iii) Concentration ratio**

**(iv) Type of absorber surface** **(12 M)**

**Sol: Impact of Variables on Solar Collector Performance**

**(i) Fluid Inlet Temperature**

- Higher inlet temperature can reduce the temperature difference between the absorber and the fluid, lowering the heat transfer rate and efficiency.
- Very low inlet temperature increases losses due to larger temperature difference with the environment.

**(ii) Mass Flow Rate of Fluid**

- Increasing mass flow rate improves heat removal rate, potentially increasing instantaneous power output.
- However, too high a flow rate may reduce fluid residence time, decreasing overall temperature rise and efficiency.

**(iii) Concentration Ratio**

- Higher concentration ratio means more solar energy is focused on the absorber, raising operating temperature and efficiency.
- Excessively high ratios can increase thermal losses, reducing collector performance if not managed properly.

**(iv) Type of Absorber Surface**

- Black, selective surfaces absorb more solar energy and minimize radiative losses, boosting performance.
- Non-selective or shiny surfaces reflect more radiation, decreasing efficiency of the collector.

**05.(e) (i) Mention any four advantages of a high-pressure boiler.** **(4 M)**

**Sol:**

**(i) Advantages of High Pressure Boiler :**

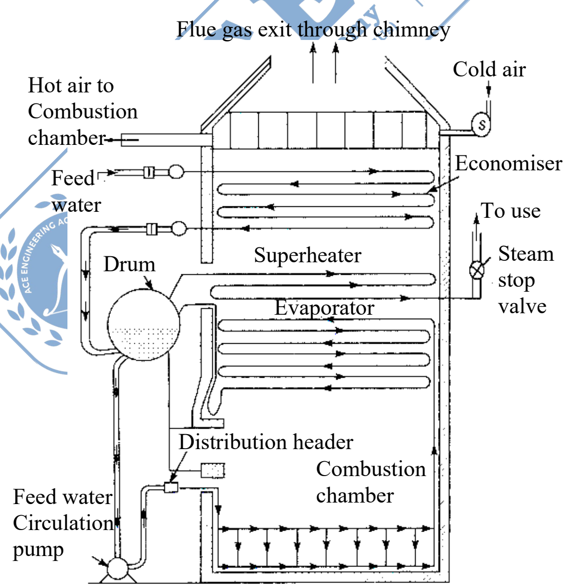
- Smaller bore and therefore lighter tubes makes the unit more compact and space requirement are minimized

- Reduction in the number of drums.
- Boiler capable of meeting rapid changes of load.
- All parts are heated uniformly which eliminated the danger of overheating and setting up thermal stress
- Due to uniform temperature of parts the differential expansions are minimized and this reduces the leakage of gas and air.
- There is complete elimination of high head which is needed for natural circulation.
- Due to high circulation velocity tendency from scales is eliminated to a large extent.

**(ii) Briefly explain, with the aid of an illustrative sketch, the working principle of LaMont boiler. (8 M)**

**Sol:**

**(ii)** The La Mont boiler is a high-pressure, water-tube type boiler. It works on a forced-circulation principle**.** The water circulation is maintained by a centrifugal pump. The below fig shows the schematic of a La Mont boiler.




**La Mont Boiler**

- The feed water is circulated through the water walls and drums continuously and prevents the tubes from being overheated.
- The feed water first passes through the economizer. Most of the sensible heat is supplied to the feed water in the economizer. Then water enters the boiler drum. A water circulation pump draws water from the drum and delivers to the tubes of the evaporating section, where water is heated in

a large number of small-diameter tubes and a mixture of steam and water is formed. This mixture is stored in the drum. The convective super heater draws wet steam from the drum and heats the steam for its superheating. The superheated steam is supplied to a prime mover. The La Mont boiler generates approximately 50 tonnes of steam per hour at a pressure of 13 bar and a temperature of 500°C.

**Advantages of a La Mont Boiler**

1. With the use of small diameter tubes, the high heat-transfer rate is maintained.
2. The multiple-tube circuit gives flexibility for suitable location of heat transfer equipments.
3. With forced circulation of water through the tubes, a high evaporation rate is achieved.

**06.(a) In a vapour compression refrigeration cycle based ice plant of 20 TR capacity using $NH_3$ as refrigerant, the following data are used for the calculations:**

**The temperatures of water entering and leaving the condenser are 20 °C and 27 °C, and the temperature of brine in the evaporator is –15 °C. Before entering the expansion valve, ammonia is cooled to 20 °C and ammonia enters the compressor dry saturated.**

**Calculate:**

**(i) the compressor power required;**

**(ii) the flow rate of cooling water circulated in the condenser;**

**(iii) the COP of the plant for 1 TR capacity.**

**Show the cycle on t-s and p-h diagrams. Use the properties given in the table:**

| Saturation Temperature (°C) | Entropy, kJ/kg-K | | Enthalpy, kJ/kg | | Sp. Heat, kJ/kg-K | |
|---|---|---|---|---|---|---|
| | Liquid | Vapour | Liquid | Vapour | Liquid | Vapour |
| –15 | 0.4572 | 5.5490 | 112.34 | 1426.54 | 4.396 | 2.303 |
| 25 | 1.1242 | 5.0391 | 298.90 | 1465.84 | 4.606 | 2.805 |

**(20 M)**

**Sol:** Capacity = 20 TR

$= 20 \times 3.597 = 70.34$ kW

$h_2 = 1426.54$ kJ/kg

$s_2 = 5.5490$ kJ/kg.K

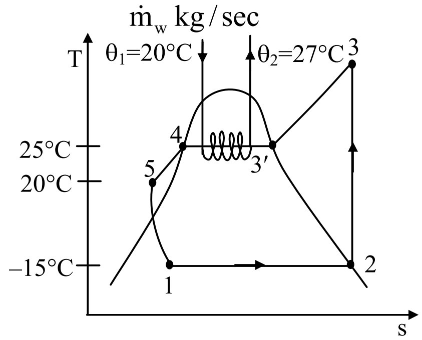
$h_4 = 112.34$ kJ/kg

$c_{p_{\ell_4}} = 4.606 \dfrac{kJ}{kg.K}$

$c_{p_{v_{3'}}} = 2.805 \text{ kJ/kg.K}$

$s'_3 = 5.0391 \text{ kJ/kg.K}$

$h'_3 = 1465.84 \dfrac{kJ}{kg}$




$s_2 = s_3 = c_{p_{v_{3'}}} \ell n \dfrac{T_3}{T_{3'}} + s'_3$

$5.5490 = 5.0391 + 2.805 \ell n \dfrac{T_3}{298}$

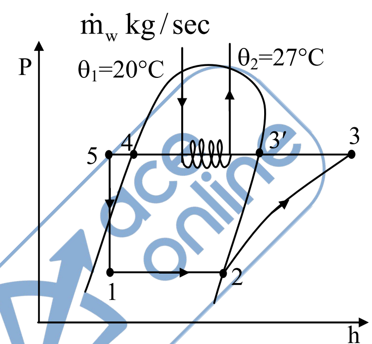
$\ell n \dfrac{T_3}{298} = \dfrac{5.5490 - 5.0391}{2.805} = 0.1818$

$T_3 = 298\ e^{0.1818} = 357.4K$

$h_3 = h_{3'} + c_{p_{v_{3'}}} (T_3 - T_{3'})$

$= 1465.84 + 2.805\ (357.4 - 298)$

$= 1465.84 + 166.617 = 1632.46 \text{ kJ/kg}$




$h_5 = h_4 - c_{p_{\ell_4}} (T_4 - T_5)$

$= 112.34 - 4.606\ (25 - 20)$

$= 89.31 \text{ kJ/kg} = h_1$

$\dot{m}_r (kg/sec)(h_2 - h_1)\dfrac{kJ}{kg} = NRE\ kW$

$\dot{m}_r = \dfrac{70.34}{1426.54 - 89.31} = 0.0526 \dfrac{kg}{sec}$

Heat gained by condensing water = Heat lost by refrigerant

$\dot{m}_w (c_{pw})(\theta_2 - \theta_1) = \dot{m}_r \left(\dfrac{kg}{sec}\right)(h_3 - h_5)\dfrac{kJ}{kg}$

$\dot{m}_w = \dfrac{\dot{m}_r (h_3 - h_5)}{c_{pw}(\theta_2 - \theta_1)} = \dfrac{0.0526(1632.46 - 89.31)}{4.187 \times (27 - 20)} = 2.769 \text{ kg/sec}$

Compressor Power $= \dot{m}_r \left(\dfrac{kg}{sec}\right)(h_3 - h_2)\dfrac{kJ}{kg}$

$= 0.0526\ (1632.46 - 1426.54) = 10.832 \text{ kW}$

$(COP)_{\text{perTon of Ref}} = \dfrac{NRE\ kW}{Power} = \dfrac{70.34}{10.832} = 6.491$

**06.(b) For a hot and humid summer condition, an air-conditioning system needs to be designed for meeting an industrial demand and the following data are used:**

**Outside conditions: 32 °C DBT and 65% RH**

**Required inlet air conditions: 25 °C DBT and 60% RH**

**Amount of free air circulated is 250 m$^3$/min, coil dew point temperature is 13 °C. The required condition is achieved by cooling and dehumidification initially and then by heating. Calculate the following:**

**(i). The cooling capacity of the cooling coil and its by-pass factor**

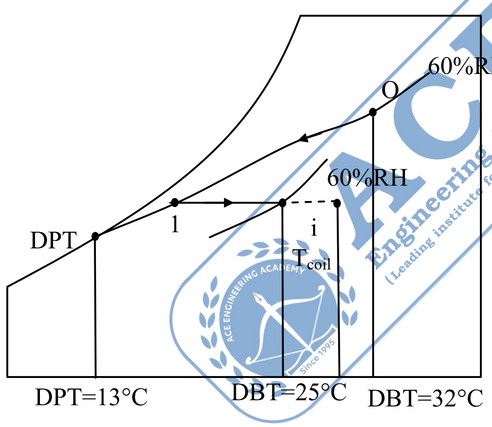
**(ii). The heating capacity of the heating coil in kW and surface temperature of the heating coil if the by-pass factor is 0.3**

**(iii). The mass of water vapour removed per hour**

**Show the psychrometric processes involved on Psychrometric Chart.**

**[Psychrometric Chart is given at the end] (20 M)**

**Sol:**




On psychrometric chart mark point "O" outside condition at 32°C and 65% RH

From chart $h_0 = 83\dfrac{kJ}{kgda}$ $v_0 = 0.89\dfrac{m^3}{kgda}$ $\omega_0 = 0.0195$ kgvap/kgda

Mark point "i" on psychrometric chart at 25°C and 60% RH

From chart $h_I = 5.7$ kJ/kgda $v_i = 0.86$ m$^3$/kgda $\omega_I = 0.012$ kg vap/kgda

From point (i) drop a horizontal on to line joining "O" to DPT which intersect at point (1) from chart

$h_1 = 48$ kJ/kg.da $v_1 = 0.845$ m$^3$/kgda $\omega_1 = 0.012$ kg vap/kgda

DPT from chart

$h_{DPT} = 37$ kJ/kg $T_{DPT} = 13°C$

Volume flow rate of free air = $\dot{V} = 250\dfrac{m^3}{min}$

Mass flow rate of outside air = $\dot{m}_o = \dfrac{\dot{V}}{v_o} = \dfrac{250}{0.89} = 280.9$ kg/min

Cooling capacity of coil (kW) = $\dot{m}_o\left(\dfrac{kg}{sec}\right)(h_0 - h_1)$

$$= \frac{280.9}{60}(83-48) = 163.86 \text{ kW}$$

$$(BPF)_{\text{cooling coil}} = \frac{h_1 - h_{DPT}}{h_0 - h_{DPT}} = \frac{48-37}{83-37} = \frac{11}{46} = 0.24$$

Heating capacity of coil = $\dot{m}_0\left(\dfrac{kg}{sec}\right)(h_i - h_1)\dfrac{kJ}{kg.da}$

$$= \frac{280.9}{60}(57-48)$$

$$= 42.135 \text{ kW}$$

$$(BPF)_{\text{Heating coil}} = \frac{T_{coil} - T_i}{T_{coil} - T_1}$$

$$0.3 = \frac{T_c - 25}{T_c - 18}$$

$0.3T_c - 5.4 = T_c - 25$

$0.7\ T_c = 25.54 - 19.6$

$T_c = \dfrac{19.6}{0.7} = 28°C$

Temperature of heating coil = 28°C

Mass of water vapor removed per hour = $\dot{m}_o\left(\dfrac{kg}{hr}\right)(\omega_0 - \omega_1)$

$$= 250 \times 60\ (0.0195 - 0.012)$$

$$= 112.5 \text{ kg/hr}$$

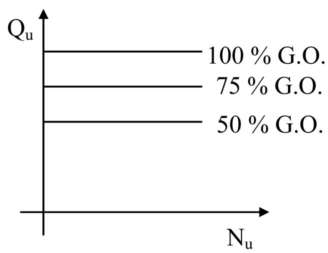
**06.(c)**

**(i) Draw and explain in detail each of the constant head characteristics of Pelton, Francis and Kaplan turbines. (10 M)**

**Sol:**

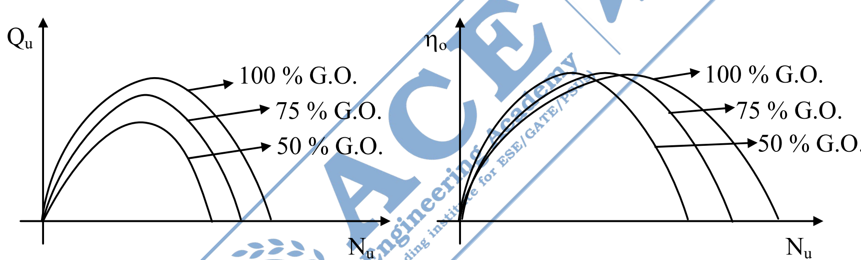
**(i)**

- The constant head characteristics are called main characteristics of a turbine.
- Main characteristics of a turbine are obtained by keeping head constant and speed is varied by changing the load on the turbine.
- Main characteristics are useful during the selection of the turbine.
- Discharge-Speed characteristic of Pelton turbine




Discharge of Pelton turbine only depends upon gate opening (G.O) and it is independent upon speed of the turbine.

- Power and efficiency characteristics of Pelton turbine:

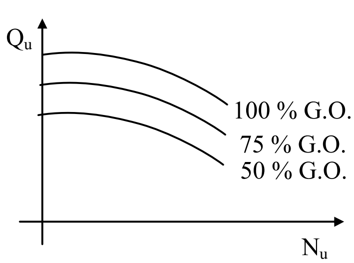



Power developed by the Pelton turbine initially increase with speed, it becomes maximum when $u = \frac{V}{2}$ and then decreases to zero at runaway speed.

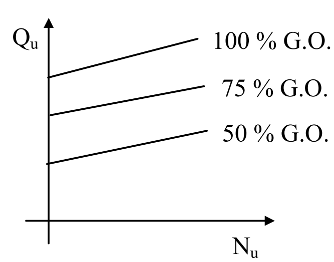
Efficiency curve also follows similar trend because efficiency is proportional to power output.

- Main characteristics for Reaction turbines.

Francis Turbine



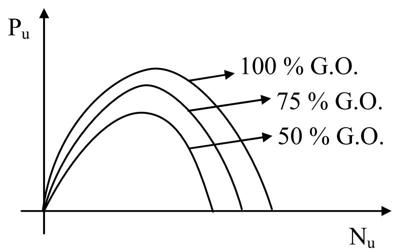

Kaplan Turbine

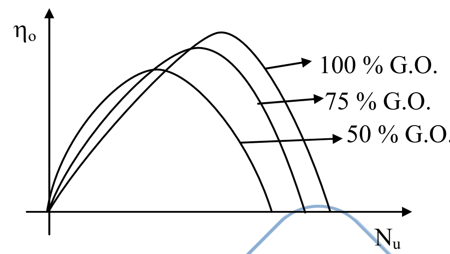


For Francis turbine discharge decrease with speed because at higher speed centrifugal forces oppose the flow of incoming water.

For Kaplan turbine discharge increases with speed because centrifugal force have no impact axial flow.

$P_u$ and $\eta_o$ characteristics for Francis & Kaplan turbine is nearby same.




**(ii) A Francis turbine was installed in a power plant system. For first few years of operation, it gave noise or vibration frequency around 15 Hz. But after 10 years of operation, the noise/frequency coming out of it is around 100 Hz. Can you explain the different causes of this increase in noise or vibration and suggest the remedies for it? Can you also suggest the places where the errors are located? (6 M)**

**Sol:** **Causes:** Vibrations can come from variety of causes like

- Wear and tear of components can cause mass imbalance.
- Damaged bearings can create noise.
- Cavitation can generate high frequency noise.

**Remedies:**

- Regular inspection and replacement of damaged parts.
- Proper alignment and tightening of loose parts.

**(iii) Describe the significance of specific speed in turbine sizing, if any. (4 M)**

**Sol:** A significant point about the specific speed is that it is independent of the dimensions or size, both of the actual turbine and of the specific turbine. It therefore means that all turbines of the same geometrical shape, working under the same value of $K_u$ and $\psi$, and thus having the same efficiency, will have the same specific speed, no matter what their sizes be and what powers they develop under what heads. As such it may be stated that $N_s$ represents the specific speed of the actual turbine, as well as of the specific turbine. Therefore, the following general definition for the specific speed may be given.

The specific speed of any turbine is the speed in r.p.m. of a turbine geometrically similar to the actual turbine but of such a size that under corresponding conditions it will develop 1 kilowatt power when working under unit head (i.e., 1 metre)

**07.(a) Compare running costs of winter heating system of a conference hall for which 50000 kJ/hr of heating is required using the following three methods of heating:**

**(i) Vapour compression cycle based heating**

**(ii) Direct heating using fuel**

**(iii) Electric heating**

**Take the following data for calculation:**

**COP of VCRC system = 3.0**

**Fuel charges for light diesel oil = ₹. 64/L**

**Specific gravity of oil = 0.87**

**Heating value of fuel = 42 MJ/kg**

**Combustion efficiency = 0.80**

**Electricity charges = ₹. 8.5/unit**

**Now-a-days in winter season, which is the most common system being used and why? (20 M)**

**Sol:** Heat to be supplied = 50000 kJ/hr

**(i) VCRC**

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

$= 1 + 3 = 4$

$$\text{Work input} = \frac{Q}{(COP)_{HP}} = \frac{50000}{4} = 12500 \text{ kJ/hr}$$

$$\text{Power} = \frac{12500}{3600} = 3.472 \text{ kW}$$

For 1 hour operation electricity consumed = 3.472 kWhr

Cost = 3.472 × 8.5 = 29.51

**(ii) Direct heating using fuel**

$\dot{Q}_s = 50000$ kJ/hr

$$\dot{V}_f \times \left(\frac{m^3}{sec}\right) \times \rho_f \left(\frac{kg}{m^3}\right) \times (HV)_{fuel} \times \eta_{comb} = \frac{50000}{3600} = \dot{Q}_s$$

$$\dot{V}_f \times 870 \times 42000 \times 0.8 = \frac{50000}{3600}$$

$$\dot{V}_f = \frac{50000}{3600 \times 870 \times 42000 \times 0.8} = 4.7512 \times 10^{-7}\ m^3/sec$$

$$= 4.7512 \times 10^{-4}\ litres/sec$$

Consumption per hour = $4.7512 \times 10^{-4} \times 3600 = 1.7104$ litres

Cost (Rs) = $1.7104 \times 64 = 109.47$

**(iii) Electric Heating**

Heat to be supplied = $\dot{Q}_s = \frac{50000}{3600} = 13.88\,kW$

For one hour operation electricity consumption = 13.88 kWhr

Cost (Rs) = $13.888 \times 8.5 = 117.98$

Cheapest option is VCRC system and most followed option is the VCRC.

**07.(b) Air enters a turbojet engine at $10 \times 10^4$ kg/hr at 25°C and 1.03 bar, and is compressed adiabatically to 192 °C and four times the pressure. Products of combustion enter the turbine at 815 °C and leave the compressor at 650 °C to enter the nozzle. Calculate the isentropic efficiency of the compressor, the power required to drive the compressor, the exit speed of gases, and the thrust developed when flying at 900 km/hr. Assume that isentropic efficiency of turbine is same as that of compressor and the nozzle efficiency is 90%. Assume for air $\gamma_a = 1.4$, $C_p = 1.005$kJ / kg- K and for gases assume $\gamma_g = 1.3$ and R = 1.147 kJ / kg-K.**

**(20 M)**

**Sol:** Mass of air $(\dot{m}_a) = 10 \times 10^4$ kg/hr $= \frac{10 \times 10^4}{3600} = 27.78$ kg/s

Air entering temperature $(T_1) = 25 + 273 = 298$ K

Air entering pressure $(P_1) = 1.03$ bar

Temperature after adiabatic compression $(T_3^1) = 192 + 273 = 465$ K

Compression pressure ratio $\left(\frac{P_3}{P_2}\right) = 4$

Temperature of gas at inlet to turbine $(T_4) = 815 + 273 = 1088$ K

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MEGA MOCK TEST
Selected in Public Health, MA & UD Dept. Govt. of TG.

RANK 3 EE
Devarakonda Sathwik
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AND MANY MORE...

**500+ SELECTIONS**

**CE : 434 | EE : 61 | ME : 20**

Gas temperature at exit of turbine $(T_5') = 650 + 273 = 923$ K

Flight speed $(V_a) = V_1 = 900$ km/hr $= 900 \times \frac{5}{18} = 250$ m/s

Turbine efficiency = Compressor efficiency

Nozzle efficiency $(\eta_N) = 0.9$

**For air**

$\gamma_a = 1.4$

$c_{pa} = 1.005$ kJ/kg.K

**For gas**

$\gamma_g = 1.3$

$c_{pg} = 1.147$ kJ/kg.K

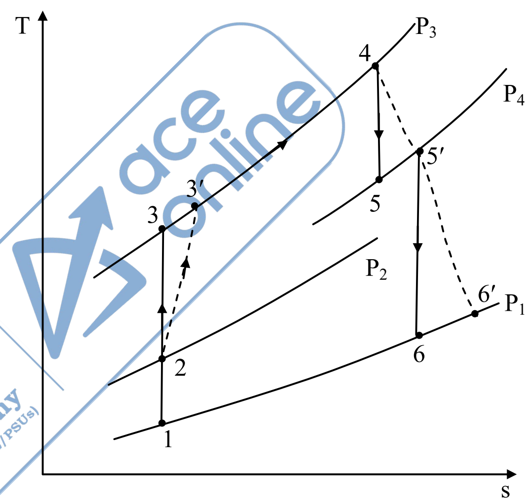
**To find:**

Isentropic efficiency of compressor $(\eta_c)$

Power required to drive the compressor $(P_c)$

Exhaust gas temperature $(V_s)$

Thrust developed $(F_{th})$




**Assumptions:**

1. Diffusion is ideal
2. Turbine work is equal to compression work
3. Mass of fuel is ignored.

<u>1 – 2 Isentropic (Ideal) diffusion</u>

$$\frac{V_1^2}{2} + h_1 = \frac{V_2^2}{2} + h_2$$

$$\frac{V_1^2}{2} + c_p T_1 = c_p T_2$$

$$T_2 = \frac{V_1^2}{2c_p} + T_1 = \frac{250^2}{2 \times 1.005 \times 10^3} + 298 = 329.09 \text{ K}$$

$V_2 \approx 0$

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

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

$$P_2 = P_1\left(\frac{T_2}{T_1}\right)^{\frac{\gamma_a}{\gamma_a - 1}} = 1.03\left(\frac{329.09}{298}\right)^{\frac{1.4}{0.4}} = 1.457 \text{ bar}$$

2 – 3 Isentropic Compression

$$\frac{T_3}{T_2} = \left(\frac{P_3}{P_2}\right)^{\frac{\gamma-1}{\gamma}} \Rightarrow T_3 = T_2\left(\frac{P_3}{P_2}\right)^{\frac{\gamma_a-1}{\gamma_a}}$$

$$T_3 = 329.09(4)^{\frac{0.4}{1.4}} = 489.02\ K$$

Since this temperature ($T_3$) is more than given temperature. This problem has to be solved by ignoring the flight velocity to find the compressor exit temperature.

For 1-3 Process (Isentropic compression)

$$\frac{T_3}{T_1} = \left(\frac{P_3}{P_1}\right)^{\frac{\gamma_a-1}{\gamma_a}}$$

$$T_3 = T_1(4)^{\frac{\gamma_a-1}{\gamma_a}} = 298(4)^{\frac{0.4}{1.4}} = 442.82\ K$$

$$T_3' = 465K\ \ (\text{given})$$

Compression efficiency

$$\eta_c = \frac{T_3 - T_1}{T_3' - T_1}\times 100 = \frac{442.82 - 298}{465 - 298}\times 100 = 86.72\%$$

Compressor power ($P_c$) = $\dot{m}_a c_{pa}(T_3' - T_1)$ = (27.78)(1.005)(465 – 298) = 4662.45 kW

4 – 5 Isentropic expansion in turbine:

Turbine efficiency $(\eta_T) = \frac{T_4 - T_5'}{T_4 - T_5}\times 100$

$$86.72 = \frac{1088 - 923}{1088 - T_5}\times 100$$

$$1088 - T_5 = \frac{1088 - 923}{86.72}\times 100 = 190.26$$

$$T_5 = 1088 - 190.26 = 897.73\ K$$

$$\frac{T_4}{T_5} = \left(\frac{P_4}{P_5}\right)^{\frac{\gamma_g-1}{\gamma_g}}$$

$$\frac{1088}{897.73} = \left(\frac{4.12}{P_5}\right)^{\frac{1.3-1}{1.3}}$$

$$\left(\frac{1088}{897.73}\right)^{\frac{1.3}{0.3}} = \frac{4.12}{P_5}$$

$$2.3 = \frac{4.12}{P_5}$$

$$P_5 = \frac{4.12}{2.3} = 1.79 \text{ bar}$$

$P_4 = P_3 = 4P_1 = 4(1.03) = 4.12$ bar

$$(c_v)_g = \frac{R_g}{r_g - 1} = \frac{1.147}{0.3} = 3.82$$

$c_{pg} = \gamma_g c_{vg} = 1.3(3.82) = 4.97$ kJ/kg.K

5′ - 6 Isentropic expansion in nozzle

$$\frac{T_5'}{T_6} = \left(\frac{P_5'}{P_6}\right)^{\frac{\gamma_g - 1}{\gamma_g}}$$

$$\frac{923}{T_6} = \left(\frac{1.79}{1.03}\right)^{\frac{1.3-1}{1.3}}$$

$$T_6 = \frac{923}{1.136} = 812.5 \text{ K}$$

$$\eta_N = \frac{T_5' - T_6'}{T_5' - T_6}$$

$$0.9 = \frac{T_5' - T_6'}{923 - 812.5}$$

$$(T_5' - T_6') = 0.9\ (923 - 812.5)$$

$$= 99.45°C$$

$P_6 = P_1$

exhaust gas temperature

$$V_6 = V_5 = 44.72\sqrt{h_5' - h_6'}$$

$$= 44.72\sqrt{c_{pg}(T_5' - T_6')}$$

$$= 44.72\sqrt{4.97(99.45)}$$

$$= 994.25 \text{ m/s}$$

Thrust developed $(F_{th}) = (\dot{m}_a + \dot{m}_f)(V_g - V_a)$

$$= \dot{m}_a(V_g - V_a) \qquad [\because\ m_f = 0]$$

$$= 27.78\ (994.25 - 250) = 20675.35 \text{ N} = 20.675 \text{ kN}$$

## Hearty Congratulations

# To our students CIVIL ENGINEERING
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LALAM RAMU NAIDU
Roll No. 8601102319
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Selected in: MES


SUNIL SHARMA
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& many more..

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**07.(c)**

**(i)** **A small rural village having 40 houses with 5 members each is located remotely. Design a solar photovoltaic system to meet the daily energy needs, considering 24 × 7 energy requirements. Assume the following data for solar panel:**

**Peak power = 80W**

**Voltage at peak power = 17.6V**

**Current at peak power = 4.55A**

**Operating factor = 0.8**

**Mismatch factor = 0.85**

**Sunshine hours = 5hr / day**

**State clearly, if any assumptions are made.** **(10 M)**

**Sol:** **Given data:**

A solar photovoltaic (PV) system for a rural village with 40 houses, each having 5 members, to meet 24×7 energy needs. The provided panel specs are:

Peak Power: 80 W

Voltage at Peak Power: 17.6 V

Current at Peak Power: 4.55 A

Operating Factor: 0.8

Mismatch Factor: 0.85

Sunshine Hours: 5hr/day

**Assumptions**

- Each house consumes 0.5 kWh/day (not given in question)
- Sunshine hours available are 5 hr/day.
- System losses and local climatic conditions (dust, shading) are encompassed within operating and mismatch factors.

**Estimate the Daily Energy Requirement**

- Assume each house needs basic lighting and appliance operation for 24hrs.
- Let's assume a modest average load of 0.5kWh/day/house
- Total daily energy for 40 houses: 0.5 kWh/house × 40 =20 kWh/day

**Calculate Actual Output of One Panel Per Day**

- Effective Power Output per Panel = Peak Power × Operating Factor × Mismatch Factor

$$= 80\ \text{W} \times 0.8 \times 0.85 = 54.4\ \text{W}$$

- Daily Energy Output per Panel = Effective Power Output × Sunshine Hours

$$= 54.4\ \text{W} \times 5\ \text{hr} = 272\ \text{Wh} = 0.272\ \text{kWh/day}$$

**Number of Panels Required**

For the village's total demand:

$$\text{Number of Panels} = \frac{\text{Total daily demand}}{\text{Daily output per panel}} = \frac{20\,\text{kWh}}{0.272\,\text{kWh}} \approx 74\ \text{panels}$$

**(ii) What are the important factors affecting the solar cell performance? Discuss in brief. (10 M)**

**Sol: Factors Affecting Solar Cell Performance**

- Quality and type of solar cell (monocrystalline, polycrystalline)
- Temperature: Higher temperatures reduce cell efficiency
- Shade and orientation: Panels must be shade-free and correctly angled
- Dirt/dust accumulation: Regular cleaning needed
- System losses: Wiring, inverter, and battery inefficiencies
- Mismatch, aging, and light-induced degradation effects

**08.(a)**

**(i) A blast furnace gas has the following volumetric compositions :**

**$CO_2$ = 10%**

**CO = 30%**

**$H_2$ = 1.5%**

**$N_2$ = 58.5%**

**Determine the theoretical volume of air required for the complete combustion of 1 $m^3$ of the gas. Also determine the percentage composition of dry flue gases by volume. Consider that air contains 21% of $O_2$ and 79% of $N_2$ by volume. (14 M)**

**Sol:** Volumetric composition of gas

$CO_2$ = 10%; CO = 30%;

$H_2$ = 1.5%; $N_2$ = 58.5%


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AIR 10 ME Ashutosh kumar
AIR 10 ME Jetti Ganateja
AIR 10 ME Pitchika Kumar Vasu
AIR 10 CE Adnan Quasain
& mamy more....

Theoretical volume of air required for complete combustion $= \frac{100}{21}[0.5CO + 0.5H_2]$

$= \frac{100}{21}[0.5 \times 0.3 + 0.5 \times 0.015]$

$= 0.75\,m^3 \frac{\text{air}}{m^3 \text{of gas}}$

**$CO_2$**

Volume of $CO_2$ in fuel = 0.1 $m^3$

Volume of $CO_2$ in exhaust due to conversion of CO is = 0.3 $m^3$

$2CO + O_2 \rightarrow 2CO_2$

$CO + \frac{1}{2}O_2 \rightarrow 1CO_2$

Volume of $CO_2$ in exhaust = $CO_2$ in fuel + $CO_2$ flue to CO in fuel

$V_{CO_2} = 0.1 + 0.3 = 0.4\ m^3$

Volume of $N_2$ in exhaust = Volume of $N_2$ in fuel + Volume of $N_2$ in air supplied

= 0.585 + (0.79)(0.75)

= 1.1775 $m^3$

Total volume of exhaust gases = Volume of $CO_2$ + Volume of $N_2$

= 0.4 + 1.1775

= 1.5775 $m^3$

% of $CO_2$ in dry exhaust gases $= \frac{(\text{Vol})_{CO_2}}{\text{Total volume}} \times 100$

$= \frac{0.4}{1.5775} \times 100$

= 25.36 %

% of $N_2$ in dry exhaust gases $= \frac{(\text{Vol})N_2}{\text{Total volume}} \times 100 = \frac{1.1775}{1.5775} \times 100 = 74.64\%$

**(ii) How does ash in the coal affect power plant economics? (06 M)**

**Sol:** Ash content in coal has a significant and detrimental impact on the performance of thermal power plant. High ash content leads to many problems that reduce efficiency, decrease capacity of plant, and increase in maintenance and operating costs.

The main effects are:

1. **Reduced efficiency and capacity:**

- Ash is an inert material that does not contribute to the heat generated during combustion. Higher ash content means a lower useful heat value per kg of coal, requiring more coal to be burned to produce the same amount of heat energy.
- High ash content can lead to increased slagging and fouling on boiler heating surfaces. This accumulation of ash deposits acts as an insulator, hindering the transfer of heat from the hot flue gas to the boiler tubes. As a result the amount of heat transfer to steam generator decreases.

2. **Increased wear and maintenance:**

- Ash particles, especially these with high silica content, are highly abrasive. They cause erosion and wear on various plant components.
- The accelerated wear and tear on equipment necessitate more frequent inspections, repairs and components replacements leading to higher maintenance cost and reduced plant availability.

3. **Operational and Handling challenges:**

- High ash content results in a much larger volume of ash that must be handled and disposed off. This requires extensive infrastructure for collection, storage and transportation.
- Improper handling can lead to environmental pollution of air, water and soil.

**08.(b)**

**(i) What is the need of alternative fuels for transportation? Compare the utility of bio-diesel and bio-alcohol in Indian context. (10 M)**

**Sol: Need for Alternative Fuels for Transportation**

- Reduce Import Dependence: India relies heavily on imported crude oil for transportation. By switching to alternative fuels like bio-diesel and bio-alcohol, import bills can be reduced, improving energy security and economic stability.
- Environmental Benefits: Alternative fuels, including bio-diesel and bio-alcohol, result in lower emissions of greenhouse gases, sulphur, carbon monoxide, and particulates compared to fossil fuels. This supports India's climate goals and cleaner air.
- Rural Development & Economic Benefits: Biofuel production offers new income sources for farmers by utilizing non-food crops, agricultural residue, and wasteland for feedstock. It stimulates rural economies and creates jobs.


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AIR 10 E&T RAJVARDHAN SHARMA
AIR 10 ME AKSHAY VIDHATE
TOTAL 36 SELECTIONS IN TOP 10
CE: 09 | ME: 10 | EE: 08 | E&T: 09

- Waste Utilization: Bio-diesel can be made from used cooking oil and non-edible vegetable oils, reducing environmental impact and supporting waste-to-wealth initiatives.

Utility of Bio-diesel and Bio-alcohol in Indian Context

| Criteria | Bio-diesel | Bio-alcohol (Ethanol/Methanol) |
|---|---|---|
| Feedstock | Non-edible oils, used cooking oil, animal fat | Sugarcane, grains, biomass |
| Blending Policy | 5% biodiesel in diesel planned by 2030 | 20% ethanol in petrol targeted by 2025–26 |
| Benefits | Lower $CO_2$, SOx, PM emissions, rural jobs | Lower GHG emissions, supports sugar industry |
| Current Status | Emerging, limited blending rate | E10 and E20 blending targets under progress |
| Challenges | Feedstock availability, cost, infrastructure | Seasonal supply, local production capacity |

**08.(b)**

**(ii) A wind turbine is operating at wind speed of 7.0 m/s to pump water at a rate of 5.0 $m^3$/hr with a lift of 6.0 m. Calculate the radius of the rotor and the tip speed ratio.**

**Assume:**

**Water density = 1000kg /$m^3$**

**Water pump efficiency = 45%**

**Efficiency of rotor to pump = 80%**

**Power coefficient = 0.25**

**Air density = 1.2 kg / $m^3$**

**Angular velocity of the rotor = 60 r.p.m.** **(10 M)**

**Sol: Wind Turbine:**

Given data:

Wind speed = V = 7.0 m/s

Water pumped = Q = 5 $m^3$/hr = $\frac{5}{3600}$ = 0.00139 $m^3$/sec

Lift = 6.0 m

$u_{pump} = 0.45$

$u_{Rotor} = 0.8$

Power coefficient = $c_p = 0.25$

Air density = $\rho_{air} = 1.2\ kg/m^3$

Rotor angular velocity = N = 60 rpm

**Water Power:**

$$P_{water} = \frac{\text{Flow rate} \times g \times \text{lift} \times \text{density}}{u_p \times u_R} = \frac{0.00139 \times 9.81 \times 6 \times 1000}{0.45 \times 0.8} = 227\ W$$

Wind Power Available:

$$P_{wind} = \frac{1}{2}\rho A V^3 \times c_p$$

$$A = \pi r^2$$

$$P_{wind} = \frac{1}{2} \times 1.2 \times \pi r^2 \times (7)^3 \times 0.25 = 57.45\pi r^2$$

$$P_{water} = P_{wind}$$

$$227 = 51.45\ r^2$$

$$r = 1.19\ m$$

$$\text{Tip-speed ratio} = TSR = \frac{Rw}{V} = \frac{1.19 \times \frac{60 \times 2\pi}{60}}{7} = 1.07$$

**08.(c) Gas at 8 bar and 300 °C expands to 4 bar in an impulse turbine stage. The nozzle angle is 65 ° with reference to the exit direction. The rotor blades have equal inlet and outlet angles, and the stage operates with optimum blade speed ratio. Assuming that the isentropic efficiency of the nozzle is 0.9 and velocity at entry to the stage is negligible, deduce the blade angle used and the mass flow required for this stage to produce 75 kW.**

**[Given, $C_p$ = 1.15kJ / kg – K, γ = 1.333] (20 M)**

**Sol:** Pressure of gas at inlet of nozzle ($P_1$) = 8 bar

Temperature of gas at inlet of nozzle ($T_1$) = 300°C = 573 K

Pressure of gas at exit of nozzle ($P_2$) = 4 bar

Nozzle angle (α) = 65°

Identical blade angles (θ = ϕ)

Turbine operates at optimum blade speed ratio $(\rho_{opt}) = \dfrac{\cos\alpha}{2}$

Isentropic efficiency of nozzle ($\eta_N$) = 0.9

**To find**

Blade angles ($\theta = \phi$)

Mass flow rate of gas ($\dot{m}_g$)

Stage power (P) = 75 kW

$c_{pg}$ = 1.15 kJ/kg.K

$\gamma_g$ = 1.333

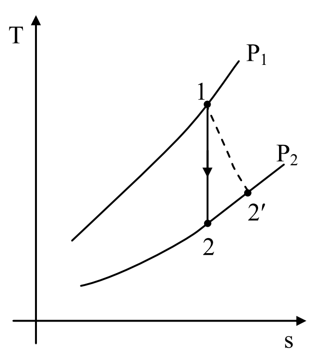
**Assumptions:**

1. Gas is treated as perfect gas.
2. Friction effect is ignored for deciding the optimum blade speed of turbine.
3. Gas enters smoothly to the turbine blade.

1 – 2 Isentropic expansion in nozzle:

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

$$\frac{573}{T_2} = \left(\frac{8}{4}\right)^{\frac{0.333}{1.333}}$$




$$T_2 = \frac{573}{1.189} = 481.89\text{ K}$$

Nozzle efficiency $(\eta_N) = \dfrac{T_1 - T_2'}{T_1 - T_2}$

$$0.9 = \frac{T_1 - T_2'}{573 - 481.89}$$

$$T_1 - T_2' = 81.99\,\text{K}$$

Gas velocity at inlet of turbine or exit of nozzle

$$(V_1) = 44.72\sqrt{c_{pg}(T_1 - T_2')}$$

$$= 44.72\sqrt{1.15(81.99)} = 434.25\text{ m/s}$$

Optimum blade speed ratio, $\rho_{opt} = \dfrac{u}{V_1} = \dfrac{\cos\alpha}{2}$

$$u = \frac{V_1}{2}\cos\alpha = \frac{434.25}{2}\cos(65°) = 91.76 \text{ m/s}$$

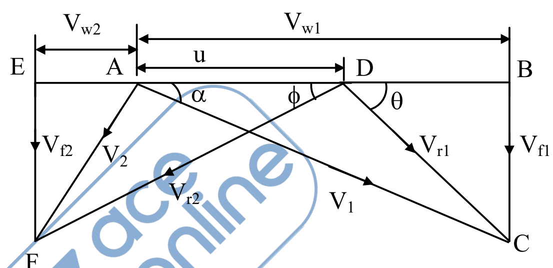
**From Δle ABC**

$$\cos\alpha = \frac{V_{w1}}{V_1} \quad \Rightarrow \quad V_{w1} = 434.25 \cos 65° = 183.52 \text{ m/s}$$

$$BD = V_{w1} - u = 183.52 - 91.76 = 91.76 \text{ m/s}$$

$$\sin\alpha = \frac{V_{f1}}{V_1} \quad \Rightarrow \quad V_{f1} = V_1 \sin\alpha = 434.25 \sin(65°) = 393.56 \text{ m/s}$$

**From Δle DBC**




$$\tan\theta = \frac{V_{f1}}{BD} \quad \Rightarrow \theta = \tan^{-1}\left(\frac{V_{f1}}{BD}\right)$$

$$\theta = \tan^{-1}\left(\frac{393.56}{91.76}\right) = 76°52'$$

$\theta = \phi = 76°52'$

$V_{r1}^2 = V_{f1}^2 + BD^2$

$V_{r1} = \sqrt{(393.56)^2 + (91.76)^2}$

$V_{r1} = 404.11$ m/s

$V_{r2} = V_{r1}$ ………….. If there is no friction on blade surface.

$V_{r2} = V_{r1} = 404.11$ m/s

**From the Δle DEF**

$$\cos\theta = \frac{u + V_{w2}}{V_{r2}}$$

$$\cos(76°52') = \frac{91.76 + V_{w2}}{404.11}$$

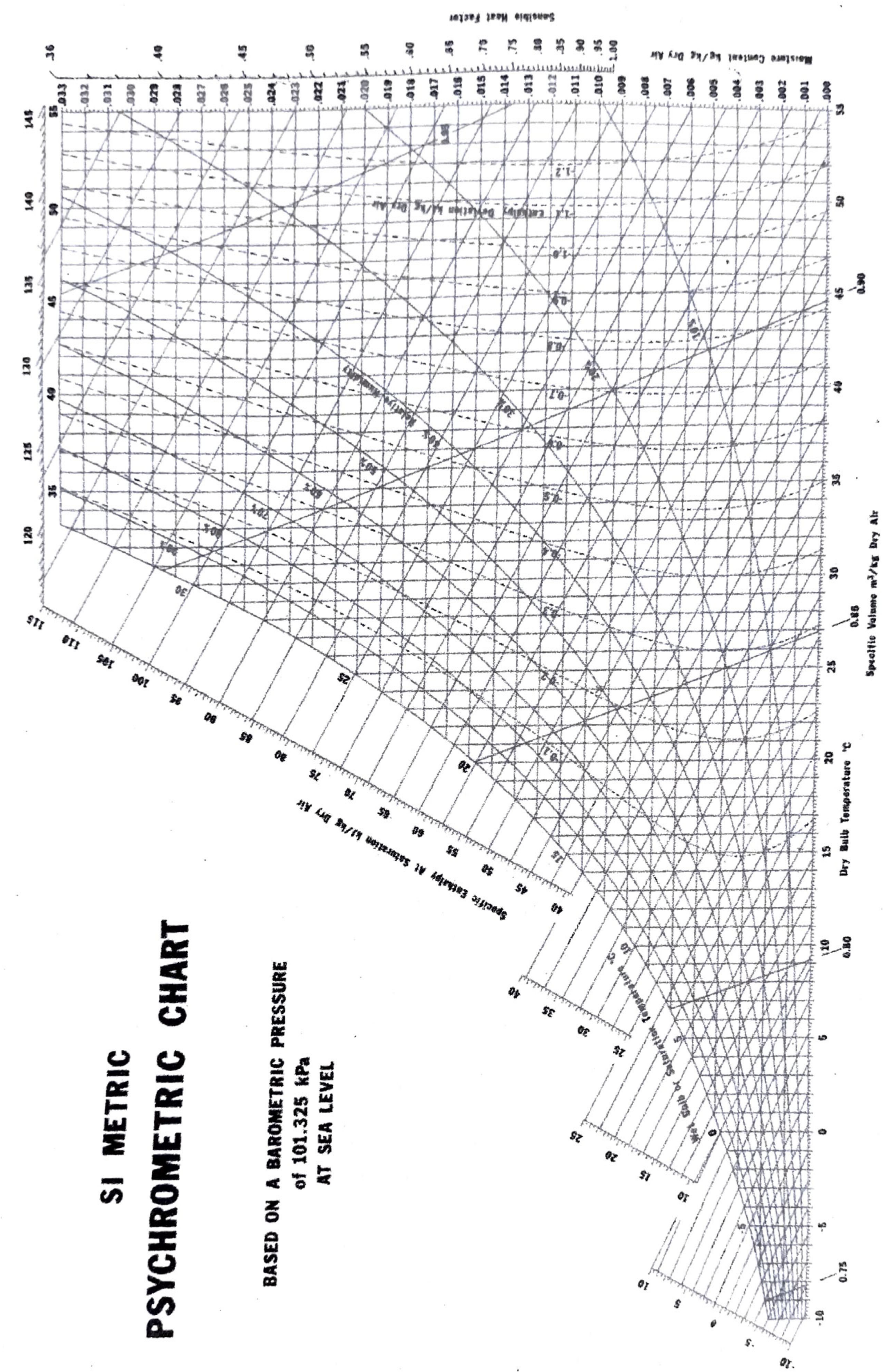
$V_{w2} = 0$

Power developed by turbine

$(P) = \dot{m}_g (V_{w1} + V_{w2})u$

$75000 = \dot{m}_g (183.52 + 0)(91.76)$

$$\dot{m}_g = \frac{75000}{183.52 \times 91.76} = 4.45 \text{ kg/s}$$


SI METRIC
PSYCHROMETRIC CHART
BASED ON A BAROMETRIC PRESSURE
of 101.325 kPa
AT SEA LEVEL
Sensible Heat Factor
Moisture Content kg/kg Dry Air
Specific Volume m³/kg Dry Air
Dry Bulb Temperature °C
Specific Enthalpy At Saturation kJ/kg Dry Air
Wet Bulb or Saturation Temperature °C
Enthalpy Deviation kJ/kg Dry Air
Relative Humidity