Test ID:- M16

ZONE TECH

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SOLUTIONS

MECHANICAL ENGINEERING : PAPER-2

Full Length Test -16

Exam Date :- **01 March 2026**

2 Marks

Q.1

Sol. No, they cannot be in thermodynamic equilibrium.

- For thermodynamic equilibrium, a system must satisfy thermal, mechanical, and chemical equilibrium simultaneously.
- Even if pressure is same (mechanical equilibrium), but temperature is different, then thermal equilibrium does not exist.
- Hence, heat transfer will occur if they are allowed to interact.

Therefore, same pressure alone is not sufficient for thermodynamic equilibrium.

Q.2

Sol. PMM-I is impossible because it violates the First Law of Thermodynamics (law of conservation of energy).

- A PMM-I is a machine which produces work without any energy input.
- This means it creates energy from nothing, which is not possible.
- According to First Law:

$$Q = \Delta U + W$$

Energy can neither be created nor destroyed, only converted from one form to another.

Therefore, PMM-I is impossible.

Q.3

Sol. According to clausius, cyclic integral of $\oint \frac{\delta Q}{T}$ is always less than or equal to zero.

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

$$\oint \frac{\delta Q}{T} < 0 \rightarrow \text{Irreversible cycle}$$

$$\oint \frac{\delta Q}{T} = 0 \rightarrow \text{Reversible cycle}$$

$$\oint \frac{\delta Q}{T} > 0 \rightarrow \text{Impossible cycle}$$

Q.4

Sol. According to this theorem the rate of irreversibility is directly proportional to the rate of entropy generation of universe.

$$I \propto (ds)$$
$$I = T_0 (ds)_{\text{universe}}$$
$$(ds)_{\text{universe}} = (ds)_{\text{system}} + (ds)_{\text{surrounding}}$$

Q.5

Sol. Priming of a centrifugal pump is defined as the operation in which the suction pipe, casing of the pump and a portion of the delivery pipe up to the delivery valve is completely filled up from outside source with the liquid to be raised by the pump before starting the pump.

Q.6

Sol. Two important factors affecting boundary layer thickness are:

1. Velocity of flow - Higher velocity → Thinner boundary layer
2. Viscosity of fluid - Higher viscosity → Thicker boundary layer

(You can also write any two of the following in exam):

- Nature of surface (smooth/rough)
- Length of surface in flow direction
- Reynolds number

Q.7

Sol. In laminar flow, the fluid moves in smooth layers and no intermixing of layers occurs. The viscous forces dominate and the fluid does not interact with pipe roughness, so the friction factor depends only on Reynolds number:

$$f = \frac{64}{Re}$$

In turbulent flow, the fluid particles move randomly and eddies strike the pipe wall, so surface roughness affects resistance to flow. Hence, friction factor depends on Reynolds number and relative roughness (k/D).

In short:

- Laminar flow → friction factor depends only on viscosity (Re)
- Turbulent flow → friction factor depends on Re + pipe roughness

Q.8

Sol. The velocity potential lines and streamlines are always perpendicular (orthogonal) to each other, which means:

- There is no flow across streamlines (no fluid crosses a streamline).
- The flow is irrotational and continuous.
- It helps in accurate graphical representation of flow field (flow net), where one family represents equipotential lines and the other represents streamlines.

In short: Orthogonality indicates a physically correct, irrotational flow pattern and ensures unique velocity direction at any point.

Q.9

Sol. The expansion valve (or throttling device) reduces the pressure and temperature of the liquid refrigerant coming from the condenser and controls the flow of refrigerant into the evaporator.

Two main functions:

1. Throttles the high-pressure liquid refrigerant to low pressure.
2. Regulates the quantity of refrigerant entering the evaporator.

Q.10

Sol. Two commonly used working pairs in VARS are:

1. Ammonia – Water (NH_3-H_2O)
2. Lithium Bromide - Water (LiBr-H_2O)

Q.11

Sol. ODP (Ozone Depletion Potential) is a measure of the ability of a refrigerant to destroy the ozone layer compared to a reference substance (usually CFC-11).

Key Point:

One-line revision:

- Refrigerant → Working fluid of refrigeration system
- Primary → Directly used in cycle
- Secondary → Transfers cooling effect
- ODP → Ozone damage potential
- GWP → Global warming impact

Q.12

Sol.
- In a C.I. engine, at high speed the time available for ignition delay is less, so less fuel accumulates before combustion starts, hence knocking reduces.
- In an S.I. engine, at high speed the turbulence and temperature increase, which increases the tendency of end-gas to auto-ignite, hence knocking increases.

Thus, knocking decreases with speed in C.I. engines but increases in S.I. engines.

Q.13

Sol.
- Knocking depends on the auto-ignition of the end-gas ahead of the flame front.
- The pre-flame reaction zone temperature directly affects the reaction rate of the unburnt mixture; higher temperature accelerates chemical reactions, causing early auto-ignition and knock.

Hence, higher pre-flame temperature increases knocking tendency.

Q.14

Sol. A moderator is a material used in a nuclear reactor to slow down fast neutrons produced during fission, so that they can effectively cause further fission reactions.

Example of moderator:

- Graphite
- Heavy water (D_2O)
- Light water (H_2O)

Thus, the moderator helps in sustaining the chain reaction efficiently.

Q.15

Sol.
- Infiltration is the process by which rainwater enters the soil from the ground surface.
- It is important in hydrology because it recharges groundwater, reduces surface runoff and helps in maintaining the water table and base flow of rivers.

Q.16

Sol. **Load Duration Curve:** The load Curve gives the variations of load. But in the Load Duration Curve, all the loads are arranged in descending order of magnitudes from the greatest load on the left and the least loads on the extreme right.

Q.17

Sol. Answer (Exam-Oriented):

Fourier's law is called a phenomenological law because it is based on experimental observation of heat flow behavior, not derived from first principles. It states that heat flows in the direction of negative temperature gradient:

$$q = -kA\frac{dT}{dx}$$

Here, the constant k (thermal conductivity) is obtained experimentally, so the law describes the observed phenomenon rather than explaining its microscopic cause.

Q.18

Sol. The critical radius of insulation depends on geometry:

- For a cylinder:

$$r_c = \frac{k}{h}$$

- For a sphere:

$$r_c = \frac{2k}{h}$$

Since the critical radius of a sphere is twice that of a cylinder, it is greater.

Reason: In a sphere, the heat transfer area increases more rapidly with radius compared to a cylinder, so a larger radius is required before the increase in surface area overcomes the added conduction resistance.

Q.19

Sol. Fin efficiency is maximum when the temperature of the entire fin is nearly equal to the base temperature,

i.e., when:

- Thermal conductivity of fin material is very high, and
- Fin length is small or heat transfer coefficient is low.

In other words, when temperature drop along the fin is negligible, fin efficiency approaches 100%.

Q.20

Sol. Because momentum diffusion and heat diffusion occur at different rates in a fluid.

- Velocity boundary layer develops due to viscosity (momentum diffusion).
- Thermal boundary layer develops due to thermal conductivity (heat diffusion).

Their relative thickness depends on the Prandtl number:

$$\Pr = \frac{\nu}{\alpha}$$

- If Pr > 1 (oils, water): thermal BL is thinner than velocity BL $(\delta_t < \delta)$
- If Pr < 1 (liquid metals): thermal BL is thicker $(\delta_t > \delta)$

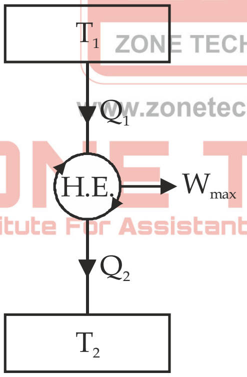
So: Different diffusivities different boundary layer thickness.

5 Marks

Q.21

Sol. Given data:

T_1 = 550°C = (550 +273) K = 823 K,
T_2 = 25° C = (25 +273) K = 298 K,
Q_1 = 1200 kJ/min



For maximum output, $\eta = 1 - \frac{T_2}{T_1}$, also $\eta = \frac{W_{max}}{Q_1}$

$$1 - \frac{T_2}{T_1} = \frac{W_{max}}{Q_1}$$

$$1 - \frac{298}{823} = \frac{W_{max}}{1200}$$

$$1 - 0.3620 = \frac{W_{max}}{1200}$$

$$0.638 = \frac{W_{max}}{1200}$$

or $W_{max} = 0.638 \times 1200 = 765.6 \text{ kJ / min}.$

$$= \frac{765.6}{60} \text{kJ / s} = \mathbf{12.76\ kW}$$

Q.22

Sol. Different stresses developed are:

1. Centrifugal stresses due to high rotational velocity of blade.
2. Bending stresses due to differential pressure on two faces of blades.
3. Transient thermal stresses due to thermal gradient at time of startups.
4. Stresses due creep due large plastic deformation.
5. Dynamic stresses as a result of natural frequency excitation.

These stress can be calculated with help of finite element analysis performing simulation at actual working conditions.

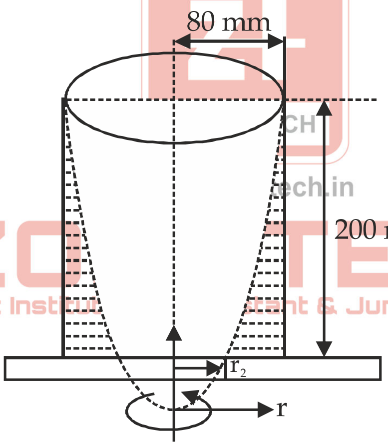
To safeguard blades under above stress they are designed considering above factors, the material selected has high strength at high temperature.

Material with high creep strength is used, such as Nickel based superalloys which incorporate Chromium, Cobalt and Rhenium.

Q.23

Sol. H = 200 mm, r = 80 mm

Let the speed of rotation is Nat which one third bottom of cylinder is exposed



Exposed area of radius r_2

$$\pi r_2^2 = \frac{1}{3}\pi(80)^2$$

$$r_2 = 46.188 \text{ mm}$$

and $r_1 = 80$ mm (open end radius)

we know that the equation for forced vortex flow

$$(z_1 - z_2) = \frac{\omega^2(r_2^2 - r_1^2)}{2g}$$

$$0.2 = \frac{\omega^2(0.08^2 - 0.046188^2)}{2 \times 9.81}$$

$$\omega = 30.326 \text{ rad/s}$$

$$N = 289.6 \text{ rpm}$$

Q.24

Sol.

- When compressibility, turbulence and surface tension forces are neglected and only gravity, pressure and viscous forces are taken into account then the equation of motion is called Navier-Stoke's equation of motion

  i.e. $ma = F_g + F_p + F_v$
- If the flow is assumed to be ideal, viscous forces is zero and only gravity and pressure forces are considered then the equation of motion is called Euler's equation of motion.

  i.e. $ma = F_g + F_p$

Q.25

Sol. Given:

- $L = 600$ m
- $D_1 = 0.25$ m
- $Q = 0.06$ m³/s
- $f = 0.02$
- Two bends: $K_b = 0.35$ each $\Rightarrow$ $K_{b,total} = 0.70$
- Enlargement: $D_2 = 0.35$ m

(1) Velocity in pipe (before enlargement)

$$A_1 = \frac{\pi D_1^2}{4} = \frac{\pi(0.25)^2}{4} = 0.04909\ \text{m}^2$$

$$A_1 = \frac{Q}{A_1} = \frac{0.06}{0.04909} = 1.222\ \text{m/s}$$

Velocity head:

$$\frac{V_1^2}{2g} = \frac{(1.222)^2}{2(9.81)} = \frac{1.493}{19.62} = 0.0761\ \text{m}$$

(2) Major head loss (Darcy-Weisbach)

$$h_f = f\frac{L}{D} = \frac{V_1^2}{2g}$$

$$h_f = 0.02\left(\frac{600}{0.25}\right)(0.0761)$$

$$\frac{600}{0.25} = 2400$$

$h_f = 0.02(2400)(0.0761) = 48(0.0761) = 3.65$ m

Major loss = 3.65 m

(3) Minor loss due to bends

$$h_{bends} = K_{b,total}\frac{V_1^2}{2g} = 0.70(0.0761) = 0.0533\ \text{m}$$

Bend losses = 0.053 m

(4) Minor loss due to sudden enlargement

First find velocity after enlargement:

$$A_2 = \frac{\pi D_2^2}{4} = \frac{\pi(0.35)^2}{4} = 0.0962\ \text{m}^2$$

$$V_2 = \frac{Q}{A_2} = \frac{0.06}{0.0962} = 0.624\ \text{m/s}$$

Loss due to sudden enlargement:

$$h_{se} = \frac{(V_1 - V_2)^2}{2g}$$

$$V_1 - V_2 = 1.222 - 0.624 = 0.598$$

$$h_{se} = \frac{(0.598)^2}{19.62} = \frac{0.3576}{19.62} = 0.0182 \text{ m}$$

Sudden enlargement loss = 0.018 m

Total Head Loss

$$h_{total} = h_f + h_{bends} + h_{se}$$

$$h_{total} = 3.65 + 0.053 + 0.018 = 3.72 \text{ m}$$

Total head loss = 3.72 m of water

(2) Power required

$$P = \rho g Q h_{total}$$

Take $\rho = 1000 \text{ kg/m}^3$

$$P = 1000(9.81)(0.06)(3.72)$$

$$P = 1000 \times 9.81 \times 0.2232$$

$$P = 1000 \times 2.190 \approx 2190 \text{ W}$$

Power required ≈ 2.19 kW

1. Total head loss = 3.72 m
2. Power required = 2.19 kW

Q.26

Sol. **(1) Meaning of Effective Temperature (ET)**

Effective Temperature (ET) is a single temperature index which combines the effects of:

- Dry bulb temperature (DBT)
- Relative humidity (RH)
- Air velocity

It is defined as:

The temperature of still, saturated air which produces the same sensation of comfort as the given actual air condition.

So, different combinations of temperature, humidity and air movement can have the same ET and hence give same comfort feeling.

(2) Why ET is Needed (Limitation of Only DBT)

Human comfort does not depend only on air temperature. It also depends on:

- Humidity → affects evaporation of sweat
- Air velocity → affects convection and evaporation
- Radiation from surroundings

Example:

- 35°C, 20% RH → May feel comfortable
- 30°C, 80% RH → May feel very uncomfortable

Even though DBT is lower in second case, comfort is worse because sweat cannot evaporate.

So:

DBT alone cannot represent comfort. ET is a combined index.

(3) Why ET is a Better Index of Comfort

ET considers:

1. Temperature effect (sensible heat loss)
2. Humidity effect (latent heat loss by sweating)
3. Air motion effect (convection + evaporation)

Hence:

ET gives a much more realistic and correct measure of human comfort than DBT alone.

Key Point:

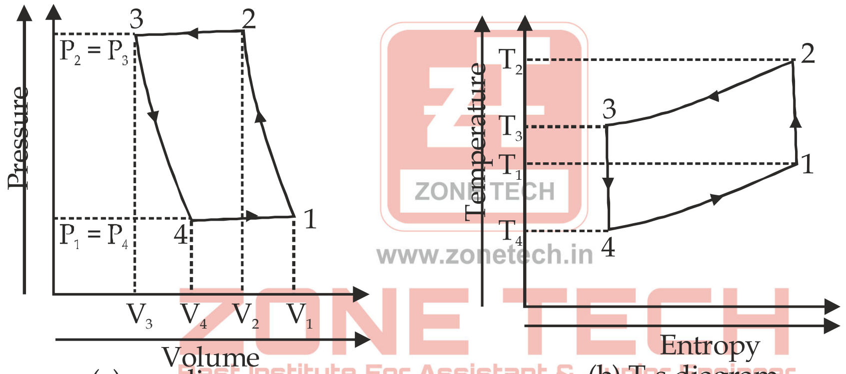
(4) Physical Significance of ET

If two different air conditions have the same ET, then:

- The human body loses heat at the same rate in both conditions
- The comfort sensation will be same, even though DBT, RH, and velocity are different.

Q.27

Sol. The Bell-Coleman cycle is a modification of reversed Carnot cycle. The cycle is shown on p-v and T-s diagrams in Fig. (a) and (b) respectively.



(a) p-v diagram (b) T-s diagram

Process of reversed Brayton cycle are :

Process 1-2 : Isentropic compression (S = constant)

The cold air from the refrigerator is drawn into the compressor cylinder during suction.

Process 2-3 : Constant pressure heat rejection (p= constant).

Heat absorbed by the air is exchange to water (cooling medium), thus it become cooled at constant pressure.

Process 3-4 : Isentropic expansion (S= constant).

Air from the cooler is now drawn into the expander cylinder where it is expanded at constant enthalpy, pressure fall from P_3 to the refrigeration pressure P_4 which is equal to atmospheric pressure.

Process 4-1 : Constant pressure heat addition (p = constant).

Cold air from the expander is now passed to the refrigerator where it is cooled at constant pressure. Heat extracted from the refrigerator is out desired effect known as refrigerant effect.

And, work done per cycle $= \dfrac{\text{RE}}{\text{COP}}$

where,

$$\text{COP} = \frac{1}{\left[(r_P)^{\frac{\gamma-1}{\gamma}} - 1\right]}$$

Q.28

Sol. **(1) Brake Power (BP)**

$$BP = \frac{2\pi NT}{60}$$

Given, N = 1500 rpm, T = 220 N.m

$$BP = \frac{2\pi(1500)(220)}{60} = 2\pi(25)(220) = 1100\pi \approx 3455 \text{ W}$$

$$BP \approx 34.55 \text{ kW}$$

BP = 34.56 kW

(2) BSFC

$$BSFC = \frac{\dot{m}_f}{BP}$$

Fuel rate:

$$\dot{m}_f = 9.0 \text{ kg/h}$$

$$BSFC = \frac{9}{34.56} = 0.260 \text{ kg / kWh}$$

(3) Brake Thermal Efficiency

$$\eta_{bth} = \frac{BP}{\dot{m}_f \times CV}$$

Convert fuel energy rate to kW:

$$Q_{in} = \frac{9 \times 42000}{3600} = \frac{378000}{3600} = 105 \text{ kW}$$

$$\eta_{bth} = \frac{34.56}{105} = 0.329$$

ηbth = 0.329 $\approx$ 32.9%

(4) Mechanical Efficiency

$$\eta_m = \frac{BP}{IP} = \frac{34.56}{60} = 0.576$$

η_m = 57.6%

(5) Air-Fuel Ratio

$$A/F = \frac{\dot{m}_a}{\dot{m}_f} = \frac{180}{9} = 20$$

A/F = 20 : 1

Q.29

Sol. **Air Rate:** Mass of air supplied per second and in gas turbine cycle for combustion of fuel is called as air rate.

Specific Power: Specific power is defined as power output per unit mass of air supplied/sec.

Work Ratio: In gas turbine cycle work is produced in turbine at the same time work is also consumed in compressor. So network output is given as

$$W_{net} = W_T - W_c$$

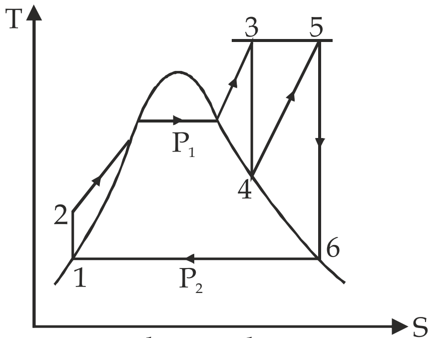
Work ratio is ratio of network to turbine work

$$WR = \frac{W_{net}}{W_T}$$

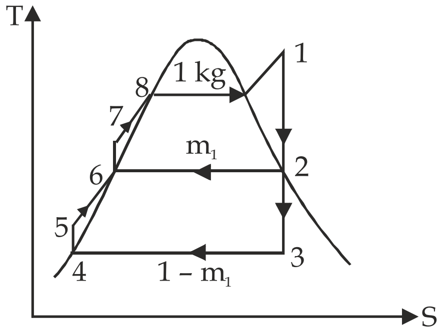
Air rate in significant is deciding the size of the compressor and specific power decides the efficiency of the combustion process. Also it tells complete combustion is taking place or not work ratio is significant in deciding the ratio between compressor work and turbine work and hence efficiency of the cycle.

Q.30

Sol.



reheat cycle



Regenerative cycle

Significance of Reheat: The reheat cycle has been developed to take advantage of the increased efficiency with higher pressure but the chief advantage is in decreasing to a safe value the mixture content in the low-pressure stages of the turbine.

Significance of Regenerative cycle:

- Average temperature of heat addition is increased.
- Heating process in the boiler tends to become reversible.
- less amount of steam is passed through the low pressure stages so blade height will be less resulting is low cost of L.P. turbine.

Q.31

Sol. **(1) Basic Assumptions (Prandtl Boundary Layer Theory)**

For steady, 2-D, incompressible, laminar flow over a flat plate:

- Flow is steady, two-dimensional
- Fluid is incompressible and Newtonian
- Boundary layer thickness is very small compared to plate length $(\delta \ll L)$
- Velocity component u >> v
- Pressure across boundary layer is constant and equal to free stream pressure.

(2) Governing Equations (from Navier-Stokes)

(a) Continuity equation:

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

(b) x-momentum equation:

$$u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} = -\frac{1}{\rho}\frac{\partial p}{\partial x} + v\frac{\partial^2 u}{\partial y^2}$$

(c) y-momentum equation:

$$\frac{\partial p}{\partial y} = 0$$

Since pressure in boundary layer equals free stream pressure and for a flat plate:

$$\frac{dp}{dx} = 0$$

So the boundary layer equation becomes:

$$\boxed{u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} = \nu\frac{\partial^2 u}{\partial y^2}}$$

(3) Boundary Conditions

At plate surface (y = 0):

$$u = 0,\ v = 0$$

At edge of boundary layer ($y \to \infty$):

$$u = U_\infty$$

(4) Blasius Solution (Similarity Solution)

Blasius solved this equation by introducing a similarity variable:

$$\eta = y\sqrt{\frac{U_\infty}{\nu x}}$$

He introduced a stream function:

$$\psi = \sqrt{\nu U_\infty x}\, f(\eta)$$

Which reduces PDE into ODE:

$$\boxed{f''' + \frac{1}{2} f f'' = 0}$$

With boundary conditions:

$$f(0) = 0, \quad f'(0) = 0, \quad f'(\infty) = 1$$

Key Point:

(5) Important Results from Blasius Solution (Very Important for Exams)

1. Boundary layer thickness:

$$\boxed{\delta = \frac{5x}{\sqrt{Re_x}}}$$

2. Wall shear stress:

$$T_w = 0.332\rho U_\infty^2 \frac{1}{\sqrt{Re_x}}$$

3. Local skin friction coefficient:

$$\boxed{C_f = \frac{0.664}{\sqrt{Re_x}}}$$

4. Average skin friction coefficient:

$$\boxed{C_f = \frac{1.328}{\sqrt{Re_L}}}$$

Q.32

Sol. Radiation properties (for a surface):

1. Absorptivity (α)

Fraction of incident radiation absorbed by the surface.

$$\alpha = \frac{E_{abs}}{E_{inc}}$$

2. Reflectivity (ρ)

Fraction of incident radiation reflected by the surface.

$$\rho = \frac{E_{ref}}{E_{inc}}$$

3. Transmissivity (T)

Fraction of incident radiation transmitted through the material.

$$T = \frac{E_{trans}}{E_{inc}}$$

4. Emissivity (ε)

Ratio of radiation emitted by a real surface to that emitted by a black body at the same temperature.

$$\varepsilon = \frac{E}{E_b}$$

Proof of $\alpha + \rho + T = 1$

Let incident radiation on a surface be E_{inc}.

It gets split into three parts:

- absorbed: E_{abs}
- reflected: E_{ref}
- transmitted: E_{trans}

Energy conservation gives:

$$E_{inc} = E_{abs} + E_{ref} + E_{trans}$$

Divide by E_{inc}:

$$1 = \frac{E_{abs}}{E_{inc}} + \frac{E_{ref}}{E_{inc}} + \frac{E_{trans}}{E_{inc}}$$

Using definitions:

$$\boxed{1 = \alpha + \rho + T}$$

Hence proved.

Key Point:

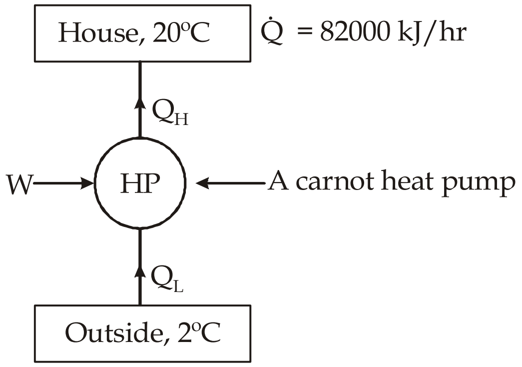
Special Cases (1-line add-on, very scoring)

- Opaque surface: T = 0 $\Rightarrow \alpha + \rho = 1$
- Black body: α = 1, ρ = 0, T = 0
- Perfect reflector: ρ = 1, α = 0, T = 0

20 Marks

Q.33

Sol. Refer to the given figure



Given,

(i) Temperature of the house,

$$T_H = 20^{\circ}C = 293\ K$$

(ii) Temperature outside of the house,

$$T_L = 2^{\circ}C = 275\ K$$

(iii) Rate of heat loss from house,

$$Q_H = 82000\ kJ/hr$$

$(\dot{Q}_H = \dot{Q}$ to maintain house at $20^{\circ}C)$

Power required, $\dot{W} = 8\ kW$

As it is a carnot heat pump

$$COP_{HP} = \frac{T_H}{T_H - T_L} = \frac{293}{293 - 275} = 16.28$$

The amount of heat lost is one day

$$Q_H = \dot{Q}_H \times 24\ hrs$$

$$= 82000 \times 24 = 1968000\ kJ$$

Thus the required work input to this carnot heat pump can be determined from the definition of COP.

$$COP_{HP} = \frac{Q_H}{W}$$

$$\therefore \quad W = \frac{Q_H}{COP_{HP}} = \frac{1968000}{16.28} = 120901\ kJ$$

Thus the length of time, the heat pump ran that day

$$At = \frac{W}{\dot{W}} = \frac{120901}{8} = 15112.63\ s = 4.2\ hrs$$

The total heating cost can be found as

$$cost = W \times price$$

$$= \dot{W} \times \Delta t \times price \qquad \text{(as unit of price is per kWh)}$$

$$= 8 \times 4.2 \times 8 = ₹268.8$$

If the resistance heating were used, the entire heating load for that day would have to be met by electrical energy.

$$\therefore \quad \text{New cost} = Q_H \times \text{price}$$

$$= 1968000 \times \frac{1\,\text{kWh}}{3600\,\text{kJ}} \times 8 = ₹4373.33$$

∴ Clearly economically its much better to use a heat pump than an electrical heater.

Q.34

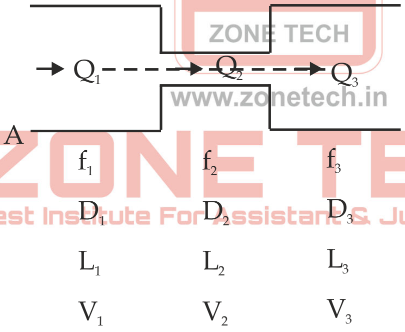
Sol. **Total energy line:-**

- It is a line joining the point representing the value of total head at various cross section of pipe in pipe flow.
- These lines always go down in the direction of flow until or unless some energy supplied externally. Ex:- pump.

Hydraulic gradient line:-

- It is the line joining the point representing the value of piezometric head at the various cross section of pipe in pipe flow.
- These line may go up or down in direction of flow.
- These line always below the total energy line.
- In a uniform diameter pipe hydraulic gradient line always parallel to total energy line and vertical gap between the two line at any section of pipe represent the value of kinetic head.

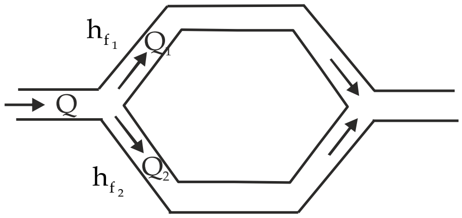
Pipes in Series connection



$$Q_1 = Q_2 = Q_3 = Q \rightarrow \text{Remain constant}$$

$$h_{f_{AB}} = h_{f_1} + h_{f_2} + h_{f_3}$$

Pipes in Parallel connection



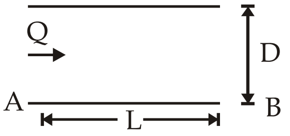
$$Q = Q_1 + Q_2$$

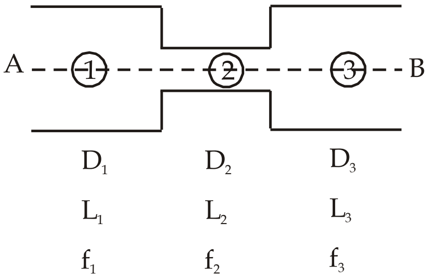
$$h_{f_1} = h_{f_2} \rightarrow \text{Remain constant}$$

- In parallel connection as the ends of pipes are connected between same points therefore the energy loss is same for all parallel pipes.

Equivalent Pipe:- A pipe of uniform diameter is said to be equivalent to a compound pipe when the discharge and head losses are same in both pipes.

For in Series Connection:-

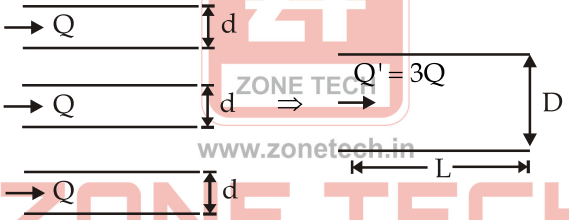




$$\frac{L_{eq}}{D_{eq}^5} = \frac{L_1}{D_1^5} + \frac{L_2}{D_2^5} + \frac{L_3}{D_3^5}$$

This is known as dupuit's equation, in Dupuit's equation minor losses are neglected.

For Parallel Connection:- Discharge is increasing but head loss for each pipe is same.



$$Q' = Q + Q + Q = 3Q$$

Relation between D and d

We know that in parallel connection

$$h_f = h_{f_{eq}} \Rightarrow \frac{fLQ^2}{12d^5} = \frac{fL(3Q)^2}{12D^5}$$

$$D^5 = 9d^5$$

$$D = (3^2)^{1/5} d$$

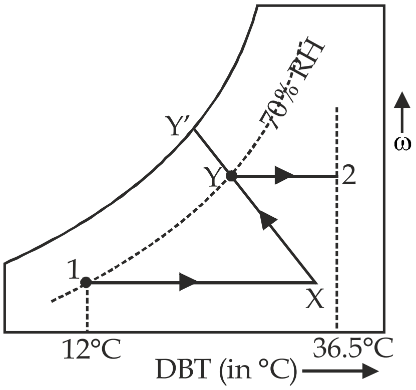
$$D = 1.55d$$

If number of pipe are 'n'

$$D_{eq} = (n)^{2/5} d$$

Q.35

Sol. Plotting the process on psychrometric chart,



At point 1, $\omega_1 = 0.006$ kg w.v/kg

$h_1 = 27$ kJ/kg

St point 2, DBT = 36.5°C; WBT = 21°C

$h_2 = 60.8$ kJ/kg da;

$\omega_2 = 0.0092$ kg w.v/kg d.a.

At point y, $\omega_Y = \omega_2 = 0.0092$ kg w.v / kg d.a.

$h_Y = 42$ kJ/kg d.a.

$T_Y = 18.2°C$

At point x, $h_X = h_Y = 42$ kJ/kg d.a.

$$\omega_X = \omega_1 = 0.006 \text{ kg w.v / kg d.a.}$$

$T_X = 26.8°C$

(a) Temperature to which air is preheated = $T_X = 26.8°C$

(b) Total heating required $= (h_X - h_1) + (h_2 - h_Y) = (42 - 27) + (60.8 - 42)$

$= 33.8$ kJ/kg d.a.

(c) Make up water required in air washer $= \omega_Y - \omega_X = 0.0092 - 0.006$

$$\omega_m = 3.2 \times 10^{-3} \text{ kg w.v / kg d.a.}$$

(d) Humidifying efficiency $= \dfrac{\omega_Y - \omega_X}{\omega_Y' - \omega_X}$

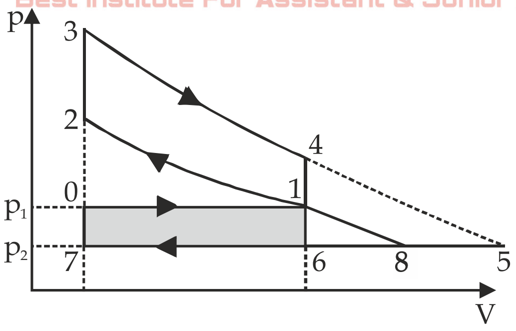
where ω_Y is specific humidity air RH 100% (point y' on chart)

from chart, $\omega_Y = 0.0105$ kg w.v/kg d.a.

$$\eta_H = \frac{3.2 \times 10^{-3}}{0.0105 - 0.006} = 0.7111 = 71.11\%$$

Q.36

Sol. **Supercharging:** The power output of an engine depends upon the amount of air inducted per unit time, the degree of utilization of this air and the thermal efficiency of the engine. The amount of air inducted per unit time can be increased by increasing the density of air at intake. The method of increasing inlet air density, called supercharging, is usually employed to increase the power output of engine.



Above figure shows p-V diagram for an ideal otto cycle super charged engine.

P_1: Supercharging pressure

P_5: Exhaust pressure

Processes:

(i) 0-1-Admission of air at supercharging pressure (which is greater than atmospheric pressure)

(ii) 1-2-Isentropic compression

(iii)2-3- Heat addition at constant volume.

(iv)3-4-Isentropic expansion

4-1-6-Heat rejection at constant volume

(blowdown to atmospheric pressure)

6-7-Driving out exhaust at constant atmospheric pressure

For supercharger

(i) 7-6-8-Admission of air at atmospheric pressure

(ii) 8-1-Isentropic compression to pressure p1.

(iii)1-0-Delivery of supercharged air at a constant pressure p1.

The pressure p_1 represents the super charging pressure and p_5 is exhaust pressure. Area 8-6-7-01-8 represents the work done by the supercharger in supplying air at a pressure p_1 while area 1-2-3-4-1 is the output of the engine. Area 0-1-6-7-0 represents gain in work during the gas exchange process due to supercharging. This a part of supercharger work is recovered. However the area 1-6-8-1 cannot be recovered represents a loss of work. C.I. engine is more suitable for supercharging. This is because, due to supercharging, there is an increase in pressure and temperature of intake air, which reduces ignition delay and hence reduces knocking in C.I. engines.

Q.37

Sol. **(a) Nusselt Number (Nu):** Nusselt number can be defined in several ways:

(i) It is the ratio of heat flow rate by convection process under a unit temperature gradient to the heat flow rate by conduction process under a unit temperature gradient through a stationary thickness of L meters. Thus,

$$Nu = \frac{Q_{conv.}}{Q_{cond.}} = \frac{h}{K/L} = \frac{hL}{K} \qquad ...(i)$$

(ii) It is the ratio of heat transfer rate, Q to the rate at which heat would be conducted within the fluid under a temperature gradient of $\Delta\theta / L$. Thus,

$$Nu = \frac{Q}{(\Delta\theta K)L} = \frac{Q}{\Delta\theta} \times \frac{L}{K} = \frac{hL}{K} \qquad ...(ii)$$

(iii)It is the ratio of characteristic length L to the thickness Ax of a stationary fluid layer conducting the heat at the same rate under the same temperature difference as in the case of convection process. Thus,

$$Q = K\frac{\Delta t}{\Delta x} = h\Delta t$$

or $$\Delta x = \frac{K}{h}$$

∴ $$Nu = \frac{L}{\Delta x} = \frac{L}{K/h} = \frac{hL}{K}$$

The Nusselt number is a convenient measure of the convective heat transfer coefficient. For a given value of the Nusselt number, the convective heat transfer coefficient is directly proportional to thermal conductivity of the fluid and inversely proportional to the significant length parameter.

(b) Prandti Number (Pr): It is the ratio of kinematic viscosity (ν) to thermal diffusivity (α)

$$Pr = \frac{\mu c_p}{K} = \frac{\rho \nu c_p}{K} = \frac{\nu}{(K/\rho c_p)} = \frac{\nu}{\alpha} \qquad ...(i)$$

Kinematic viscosity indicates the impulse transport through molecular friction whereas thermal diffusivity indicates the heat energy transport by conduction process.

- Prandtl number provides a measure of the relative effectiveness of the momentum and energy transport by diffusion.
- Prandtl number is a connecting link between the velocity field and temperature field, and its value strongly influences relative growth of velocity and thermal boundary layers.

(c) Biot Number (Bi): The non-dimensional factor $\frac{hL_c}{K}$ is called the Biot Number.

i.e $$Bi = \frac{hL_c}{K} = \text{Biot Number}$$

It gives an indication of the ratio of internal (conduction) resistance to surface (convection) resistance.

When the value of Bi is small, it indicates that the system has a small internal (conduction) resistance, i.e., relatively small temperature gradient or the existence of practically uniform temperature within the system. The convective resistance then predominates and the transient phenomenon is controlled by the convective heat exchange.

If Bi < 0.1, the lumped heat capacity approach can be used to advantage with simple shape such as plates, cylinder, spheres and cubes.

(d) Thermal Diffusivity: In case of homogeneous (in which properties e.g., specific heat, density, thermal conductivity etc, are same everywhere in the material) and isotropic (in which properties are independent of surface orientation) material, $K_x = K_y = K_z = K$.

$$\frac{\partial^2 t}{\partial x^2} + \frac{\partial^2 t}{\partial y^2} + \frac{\partial^2 t}{\partial z^2} + \frac{q_g}{K} = \frac{\rho c}{K} \cdot \frac{\partial t}{\partial \tau} = \frac{1}{\alpha} \cdot \frac{\partial t}{\partial \tau}$$

Where, $$\alpha = \frac{K}{\rho . c} = \frac{\text{Thermal conductivity}}{\text{Thermal capacity}}$$

The quantity,

$$\alpha = \frac{K}{\rho . c} \text{ is known as thermal diffusivity}$$

- The larger value of a, the faster will the heat diffuse through the material and its temperature will change with time. This will result either due to a high value of thermal conductivity k or a low value of heat capacity (ρ.c.). A low value of heat capacity means the less amount of heat entering the element, would be absorbed and used to raise its temperature and more would be available for onward transmission. Metals and gasses have relatively high value of a and their response to temperature changes is quite rapid. The non-metallic solids and liquids respond slowly to temperature changes because of their relatively small value of thermal diffusivity.
- Thermal diffusivity is an important characteristic quantity for unsteady conduction situation.