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India's Best Institute for IES, GATE & PSUs

Detailed Solutions

# ESE-2022 Mains Test Series

# Mechanical Engineering Test No : 7

**Section A :** IC Engine + Power Plant

**Section B :** Renewable Sources of Energy-1 + Industrial & Maintenance Engg.-1
Production Engg. & Material Science-2

## Section : A

**1. (a)**

**(i)**

$$\text{Stoichiometric air fuel ratio} = \frac{0.86 \times \frac{32}{12} + 0.13 \times \frac{16}{2}}{0.23} = 14.49$$

$$\text{So, actual A/F} = \left(1 + \frac{120}{100}\right) \times 14.49 = 31.878$$

Now, molecular weight of air = 0.23 × 32 + 0.77 × 28 = 28.92 kg/kmol

Let $x$ kmol of air be supplied per kg of fuel.

The combustion reaction per kg of fuel can be written as

$$\frac{0.86}{12}C + \frac{0.13}{2}H_2 + x[0.21O_2 + 0.79N_2] \rightarrow aCO_2 + bH_2O + cO_2 + dN_2$$

From carbon balance, $a = \frac{0.86}{12} = 0.07167$

From hydrogen balance, $b = \frac{0.13}{2} = 0.065$

From oxygen balance, $0.21x = a + \frac{b}{2} + c$ ...(i) and number of kmol of air per kg of fuel,

$$\Rightarrow \quad x = \frac{31.878}{28.92}$$

$$\Rightarrow \quad x = 1.102$$

From equation (i),

$$0.21\,(1.102) = 0.07167 + \frac{0.065}{2} + c$$

$$c = 0.1273$$

From nitrogen balance, $0.79x = d$

$$\Rightarrow \quad 0.79(1.102) = d$$

$$\Rightarrow \quad d = 0.8705$$

Now, volumetric composition of dry exhaust gas is given by

| Constituent | Kmol | Volume (%) |
|---|---|---|
| $CO_2$ | 0.07167 | 6.70 |
| $O_2$ | 0.1273 | 11.90 |
| $N_2$ | 0.8705 | 81.40 |

**(ii)**

Given: $bp$ = 100 kW, $\eta_m$ = 82% = 0.82, $\eta_{ith}$ = 35% = 0.35, $\eta_v$ = 75% = 0.75, $CV$ = 42 MJ/kg

Now, $$ip = \frac{bp}{\eta_m} = \frac{100}{0.82} = 121.95 \text{ kW}$$

$$\eta_{ith} = \frac{ip}{\dot{m}_f \times CV}$$

$$\Rightarrow \quad \dot{m}_f = \frac{121.95}{0.35 \times 42000} = 8.2959 \times 10^{-3} \text{ kg/s}$$

So, $$\dot{m}_a = \dot{m}_f (\text{actual A/F})$$

$$= (8.2959 \times 10^{-3})(31.878)$$

$$= 0.2644 \text{ kg/s}$$

Now, $$\rho_a = \frac{\dot{m}_a}{\dot{V}_a}$$

$$1.3 = \frac{0.2644}{\dot{V}_a}$$

$$\dot{V}_a = 0.2034 \text{ m}^3/\text{s}$$

Now, $$\dot{V}_s = \frac{\dot{V}_a}{\eta_v} = \frac{0.2034}{0.75} = 0.2712 \text{ m}^3/\text{s}$$

Also, $\dot{V}_s = \left(\frac{\pi}{4}D^2L\frac{N}{2\times 60}\times K\right)$

$$0.2712 = \left(\frac{\pi}{4}D^2(1.2D)\frac{1500}{2\times 60}\times 4\right)$$

$\Rightarrow$ $D^3 = 5.7558 \times 10^{-3}$

$$D = 0.1792 \text{ m} = 179.2 \text{ mm}$$

and $L = 1.2D = 1.2(179.2) = 215 \text{ mm}$

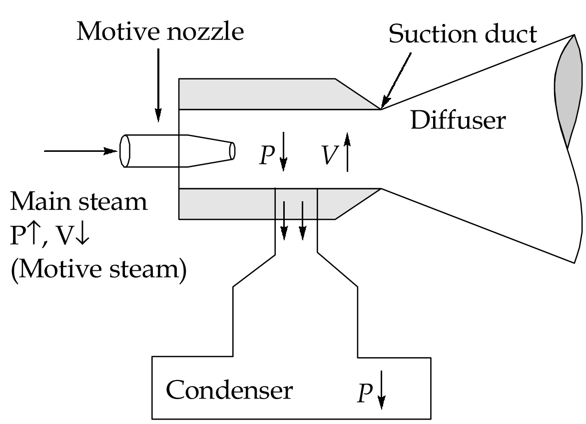
**1. (b)**

In a steam power plant, it is important to remove non-condensable gases that get accumulated in condenser. Non-condensable gas mostly include air that leaks through joints into condenser due to negative pressure. It also include gases formed due to decomposition of water into oxygen and hydrogen by thermal action and by chemical reaction between water and materials of construction.

**Due to the presence of non-condensable gases, following effects are observed :**

1. Condenser pressure increases ($\eta_{cycle}\downarrow$).
2. Blanket heat transfer surfaces.
3. Problem of chemical reactions like corrosion.

**Working**




- It uses main steam at a reduced pressure that enters a driving flow nozzle in first stage ejector, from which it exits with high velocity and reduced pressure.
- This reduced pressure draws non condensable gases from condenser and it results in momentum exchange, gases are carried away by steam jet.
- The combined flow of steam and gases is now compressed in diffuser (P↑) of the first stage of ejector and discharge into a small intercondenser, where steam

is condensed. Cooling is here done by main condensate or part of feed water heating system ($\eta_{cycle}\uparrow$).

- The non-condensable gases and remaining steam are then passed to second stage of ejector where they are compressed and passed to an after condenser (known as vent condenser).
- The steam, if any, gets condensed and non-condensable gases (air) at higher pressure then atmospheric pressure is vented out.

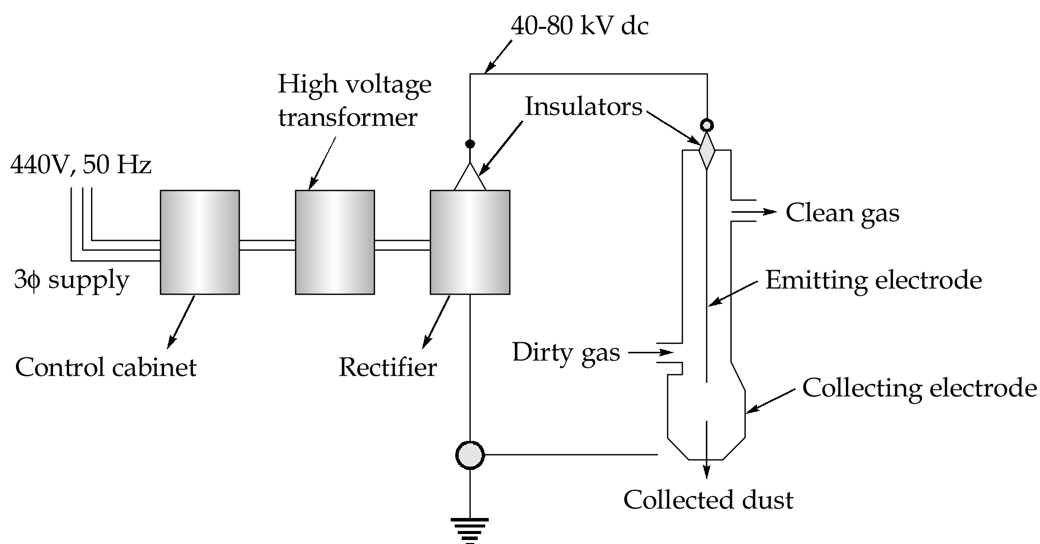
**Application of Air Ejectors :**

1. **Steam Jet Air Ejector :** It is one of the types of air ejector which is used in the steam like near the condenser to remove the non condensable gases and some vapour entering into main condenser by an air ejector and it is cooled by the main condensate and released in the ejector condenser.
2. **Fresh Water Generator :** The next main application of the air ejector in marine field is in fresh water generator as it is used to remove the air and non condensable in the evaporator chamber so as to maintain the vacuum inside the chamber. Thus the efficiency of the generation increases at low temperature of the sea water.
3. **Self Priming of Centrifugal Pumps :** It is also employed in priming of the centrifugal pumps by the air ejector, which removes the air inside the casing of the pump by the suction effect created by the air ejector thus by flooding casing with the liquid so that it helps in stating of the pump.

**1. (c)**

The principal components of an electrostatic precipitator (ESP) are two sets of electrodes insulated from each other. The first set is composed of rows of electrically grounded vertical parallel plates, called the collection electrodes, between which the dust-laden gas flows. The second set of electrodes consists of wires, called the discharge or emitting electrodes that are centrally located between each pair of parallel plates. The wires carry a unidirectional negatively charged high-voltage (between 20 and 100 kV) from an external dc source. The applied high voltage generates a unidirectional, non-uniform electrical field whose magnitude is greatest near the discharge electrodes. When that voltage is high enough, a blue luminous glow, called a corona, is produced around them. Electrical forces in the corona accelerate the free electrons present in the gas so that they ionize the gas molecules, thus forming more electrons and ions. The new electrons create again more free electrons and ions, which result in a chain reaction.

The positive ions travel to the negatively charged wire electrodes. The electrons follow the electrical field toward the grounded electrodes, but their velocity decreases as they move away from the corona region around the wire electrodes toward the grounded plates. Gas molecules capture the low velocity electrons and become negative ions. As these ions move to the collecting electrode, they collide with the fly ash particles in the gas stream and give them negative charge. The negatively charged fly ash particles are driven to the collecting plate by the force which is proportional to the product of this charge and the strength of the electric field.




**Basic elements of an electrostatic precipitator**

The particles to the plates and makes removal more difficult. This can be rectified either by operating at high gas temperatures (before APH) or by superimposing a high voltage pulse on the base voltage to enhance ESP performance during operation under high-resistivity conditions.

Collected particulate matter must be removed from the collecting plates on a regular schedule to ensure efficient collector operation. Removal is usually accomplished by a mechanical hammer scrapping system. The vibration knocks the particulate matter off the collecting plates and into a hopper at the bottom of the precipitator.

**1. (d)**

Given : Four stroke SI engine, $d$ = 300 mm = 0.3 m; $L$ = 500 mm = 0.5 m; $D_{eff}$ = 1.5 m;

$R_{eff}$ = 0.75 m; $t$ = 35 min; $N$ = 9000; $N_E$ = 3600; $W_{net}$ = 100 kg = 100 × 9.81 = 981 N

$P_{in}$ = 6 bar; $V_{gas}$ = 7.5 m$^3$ ; $CV$ = 20 MJ/m$^3$ at NTP

$$P_{gas} = P_{atm} + P_{gauge}$$

$$= 760 + \frac{150}{13.6} = 771.03 \text{ mm of Hg}$$

$$T_a = 27°C = 300 \text{ K}$$

$$(\Delta T)_w = 50°C$$

$$m_w = 180 \text{ kg}$$

Now,

Volume of gas at NTP, $(V_g)_{NTP} = 7.5 \times \frac{293}{300} \times \frac{771.03}{760} = 7.431 \text{ m}^3$

$$\text{Now, heat supplied} = \frac{7.431 \times 20000}{35} = 4246.28 \text{ kJ/min}$$

and $$ip = \frac{P_{in} LAN_E}{60000} = \frac{6 \times 10^5 \times 0.5 \times \frac{\pi}{4} \times (0.3)^2 \times \frac{3600}{35}}{60000} = 36.35 \text{ kW}$$

and $$bp = \left(W_{net} \times \frac{D_{eff}}{2}\right)\left(\frac{2\pi N}{60}\right) = \frac{W_{net}\pi(D_{eff})N}{60}$$

$$bp = \frac{981 \times \pi \times 1.5 \times \frac{9000}{35}}{60} = 19812.23 \text{ W} = 19.812 \text{ kW}$$

Now, heat supplied equivalent of *bp*

$$= 19.812 \times 60 = 1188.73 \text{ kJ/min}$$

$$\text{Heat loss in cooling medium} = m_w \times c_{p_w} (\Delta T)_w$$

$$= \frac{180 \times 4.18 \times 50}{35} = 1074.85 \text{ kJ/min}$$

and heat lost in exhaust, radiation etc

$$= 4246.28 - 1188.73 - 1074.85$$

$$= 1982.7 \text{ kJ/min}$$

Now, $$\eta_{ith} = \frac{ip \times 60}{\text{Heat supplied}} = \frac{36.35 \times 60}{4246.28}$$

$$= 0.5136 = 51.36\%$$

$$\eta_{bth} = \frac{bp \times 60}{\text{Heat supplied}} = \frac{19.812 \times 60}{4246.28}$$

$$= 0.2799 = 27.99\%$$

| S.No. | Equivalent heat | (kJ/min) | % |
|---|---|---|---|
| 1. | Heat input/supplied by fuel | 4246.28 | 100 |
| 2. | Heat equivalent of bp | 488.73 | 27.99 |
| 3. | Heat lost to cooling medium | 1074.85 | 25.31 |
| 4. | Heat lost in exhaust | 1982.7 | 46.70 |

**1. (e)**

**Scavenging :** Process of replacing the exhaust gases with the fresh charge is known as scavenging. The process of scavenging includes both the intake and exhaust processes.

**Scavenging parameters:**

- Delivery ratio, also known as scavenging ratio
- Scavenging efficiency
- Trapping efficiency
- Charging efficiency
- Purity

**(a) Scavenging ratio :** It is the ratio of mass flow rate of the fresh charge supplied to the engine to the mass flow rate of the fresh charge supplied during the scavenging process.

i.e. $$R_{sc} = \frac{\dot{m}_{\text{supplied}}}{\dot{m}_{\text{reference}}}$$

**(b) Scavenging efficiency :** It is the ratio of mass of fresh charge retained in the cylinder to the ideal mass retained during the scavenging.

i.e. $$\eta_{sc} = \frac{\dot{m}_{\text{retained}}}{\dot{m}_{\text{cylinder}}}$$

For perfect mixing, $$\eta_{sc} = 1 - e^{-R_{sc}}$$

**(c) Trapping efficiency :** It is the ratio of mass of fresh charge retained in the cylinder to the mass of the fresh charge supplied.

i.e. $$\eta_T = \frac{\dot{m}_{\text{retained}}}{\dot{m}_{\text{supplied}}}$$

**(d) Purity :** It is the ratio of mass of fresh charge trapped to the mass of trapped cylinder charge. It indicates degree of dilution of fresh charge with burned gases.

**2. (a)**

**(i)**

The flow of water and steam within the boiler circuit is called circulation. Adequate circulation must be provided to carry away the heat from the furnace. Circulation ratio (CR) is defined as:

$$\text{Circulation Ratio} = \frac{\text{Flow rate of saturated water in downcomers}}{\text{Flow rate of steam released from the drum}}$$

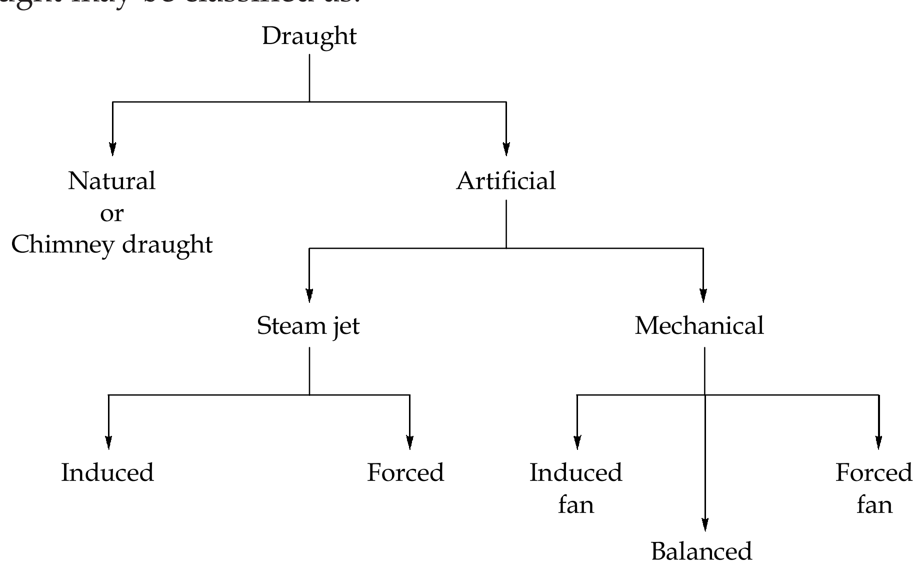
It refers to the amount of saturated water to be circulated through the downcomer-riser circuit per kg of steam released from the drum.

FD fans are larger in the size because FD fans should have high blade speed so as to rotate at high speeds and handle large volume flow of air. Therefore, centrifugal fans with backward-curved blading are normally used for FD fans.

**(ii)**

A small pressure difference which causes the flow of gas to take place is termed as draught. The function of draught, in case of a boiler, is to force air to the fire and to carry away the gaseous products of combustion.

The draught may be classified as:




1. In a natural draught, the draught is obtained by the use of a chimney.
2. The artificial draught may be a mechanical draught or steam jet draught. In the mechanical draught system, the draught is produced by a fan. Steam jet draught may be forced or induced type depending upon where the steam jet to produce draught is located.

**Advantages of balanced draught system:**

1. Balanced draught is a combination of forced and induced draught.
2. It is better in control and more economical than natural draught.
3. It is maintained at a slightly negative gauge pressure to ensure that any leakage would be inward.
4. Modern boilers are mostly designed with balanced draught firing.

**The factors affecting the amount of draught to be produced in a boiler are:**

1. The average gas temperature $T_g$; Higher the $T_g$, higher the draught produced.
2. The ambient temperature ($T_a$)
3. The mass flow of flue gases through the chimney in a plant
4. Velocity of flue gases flowing through the chimney

**2. (b)**

By air-standard cycle analysis, it can be understood that how efficiency can be improved by increasing the compression ratio. However this analysis cannot bring out the effect of air-fuel ratio on the thermal efficiency because the working medium is assumed to be air.

The presence of fuel in cylinder is taken into account and accordingly the working medium will be a mixture of fuel and air. By fuel-air cycle analysis it will be possible to bring out effect of fuel-air ratio on thermal efficiency and also to study how the peak pressures and temperatures vary with respect to fuel-air ratio during the cycle.

**The various factors affecting the analysis of fuel-air cycle are:**

(1) Actual composition of the cylinder gases.

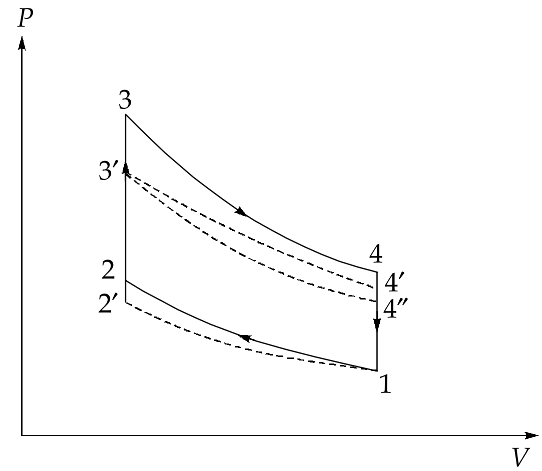
(2) Variation in specific heats with temperature.

(3) Effect of dissociation.

(4) Variation in the number of molecules.

**Effect of variable specific heats:**

Almost all gases show an increase in specific heat with temperature. Since the difference between $c_p$ and $c_v$ is constant (i.e. $R$), the value of $\gamma$ decreases with increase in temperature. Thus, if the variation of specific heats is taken into the account during the compression stroke, the final temperature and pressure would be lower than the case when constant values of specific heats are used.




Cycle 1 - 2 - 3 - 4 : With constant specific heat

Cycle 1 - 2′ - 3 - 4′ : With variable specific heat

Cycle 1 - 2 - 3′ - 4″ : With constant specific heat from point 3′.

The efficiency of diesel cycle is given by

$$\eta = 1-\left(\frac{1}{r}\right)^{\gamma-1}\left[\frac{1}{\gamma}\left(\frac{r_c^{\gamma}-1}{r_c-1}\right)\right]$$

where, $r$ = compression ratio, $r_c$ = cut off ratio

Now,
$$1-\eta = \left(\frac{1}{r}\right)^{\gamma-1}\left(\frac{1}{\gamma}\right)\left(\frac{r_c^{\gamma}-1}{r_c-1}\right)$$

Taking log both sides, we get

$$\ln(1-\eta) = -(\gamma-1)\ln(r)+\ln\left(r_c^{\gamma}-1\right)-\ln\left(r_c-1\right)-\ln\gamma$$

Differentiating with respect to $\gamma$, keeping $r$ and $r_c$ as constant,

$$-\left(\frac{1}{1-\eta}\right)\frac{d\eta}{d\gamma} = -\ln r+\frac{r_c^{\gamma}\ln r_c}{r_c^{\gamma}-1}-\frac{1}{\gamma}$$

$$\frac{d\eta}{\eta} = \frac{1-\eta}{\eta}d\gamma\left[\ln r-\frac{r_c^{\gamma}\ln r_c}{r_c^{\gamma}-1}+\frac{1}{\gamma}\right]$$

We know,

$$\frac{R}{c_v} = \gamma-1$$

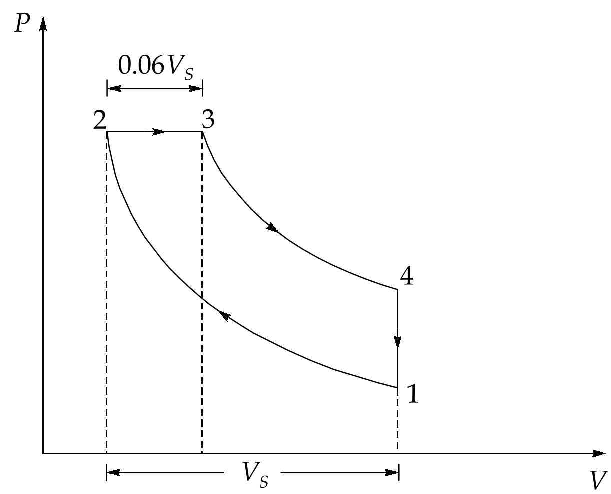
Differentiating,

$$\Rightarrow \quad \frac{-R}{c_v^2}dc_v = d\gamma$$

$$\Rightarrow \quad d\gamma = \frac{-R}{c_v}\left(\frac{dc_v}{c_v}\right) = -(\gamma-1)\frac{dc_v}{c_v}$$

Substituting the value of $d\gamma$ in equation (i), we get

$$\frac{d\eta}{\eta} = \left(\frac{1-\eta}{\eta}\right)(\gamma-1)\left[\ln r - \frac{r_c^{\gamma}\ln r_c}{r_c^{\gamma}-1} + \frac{1}{\gamma}\right]\frac{dc_v}{c_v} \quad \text{...(ii)}$$




We have, $r = \frac{V_1}{V_2} = 18$

$\Rightarrow$ $V_1 = 18V_2$

and $V_S = V_1 - V_2 = 17V_2,$

$V_3 - V_2 = 0.06V_S = 0.06(17V_2)$

$\Rightarrow$ $V_3 = 2.02V_2$

So, $r_c = \frac{V_3}{V_2} = 2.02$

and $c_p = c_v + R = 0.717 + 0.287 = 1.004$ kg/kgK

and $\gamma = \frac{c_p}{c_v} = \frac{1.004}{0.717} = 1.4$

So,
$$\eta = 1 - \left(\frac{1}{r}\right)^{\gamma-1}\left(\frac{1}{\gamma}\right)\left(\frac{r_c^{\gamma}-1}{r_c-1}\right)$$

$$= 1 - \left(\frac{1}{18}\right)^{0.4}\left(\frac{1}{1.4}\right)\left(\frac{2.02^{1.4}-1}{2.02-1}\right) = 0.6306$$

and from equation (ii),

$$\frac{d\eta}{\eta} = \left(\frac{1-0.6306}{0.6306}\right)(0.4)\left((\ln(18) - \frac{(2.02)^{1.4}\ln 2.02}{(2.02)^{1.4}-1} + \frac{1}{1.4}\right)(0.02)$$

$$\Rightarrow \quad \frac{d\eta}{\eta} = -0.01163$$

$$\Rightarrow \quad \frac{d\eta}{\eta}\times 100 = -1.163\%$$

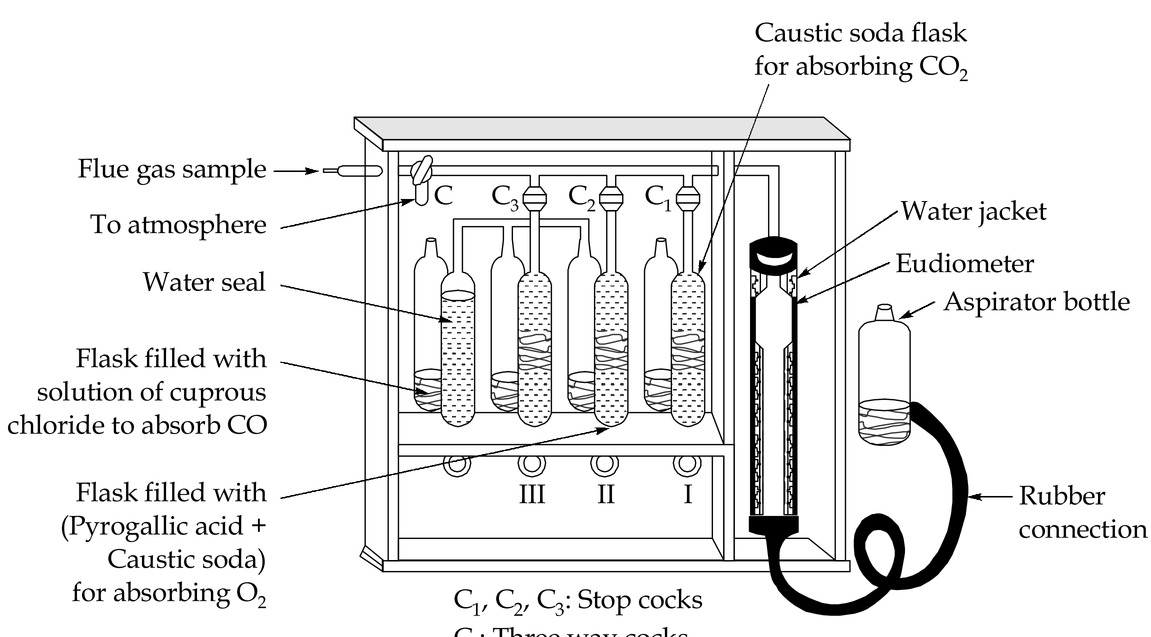
Therefore, the efficiency decreases by 1.163% if the value of specific heat at constant volume increases by 2%.

**2. (c)**

**Proximate analysis :** It is the one in which the composition of the individual constituent elements such as C, $H_2$, S, $N_2$ etc are not determined rather only fraction of moisture, volatile matter, ash, carbon, etc, are determined. Thus, proximate analysis is not exact and gives only some idea about the fuel composition.

**Ultimate analysis :** In this analysis composition of the individual elements such as C, $H_2$, S, $N_2$ and ash etc present in the fuel are determined on mass basis. Thus it gives relative amounts of chemical elements constituting the fuel.

**Orsat analyzer :** It is also called as Orsat apparatus and is used for carrying out volumetric analysis of dry products of combustion. Schematic of apparatus is shown in figure below.




*Orsat analyzer*

It has three flasks containing different chemicals for absorption of $CO_2$, $O_2$ and CO respectively and a graduated eudiometer tube connected to an aspirator bottle filled with water.

Flask I is filled with NaOH or KOH solution (about one part of KOH and 2 parts of water by mass). This 33% KOH solution shall be capable of absorbing about fifteen to twenty times its own volume of $CO_2$. Flask II is filled with alkaline solution pyrogallic acid and above KOH solution. Here 5 gm of pyrogallic acid powder is dissolved in 100 cc of KOH solution as in Flask I. It is capable of absorbing twice its own volume of $O_2$. Flask III is filled with a solution of cuprous chloride which can absorb CO equal to its volume. Cuprous chloride solution is obtained by mixing 5 mg of copper oxide in 100 cc of commercial HCl till it becomes colourless. Each flask has a value over it and $C_1$, $C_2$, $C_3$ valves are put over flasks I, II and III. All the air or any other residual gas is removed from eudiometer by lifting the aspirator bottle and opening main valve. The flue gas for analysis is taken by opening the main valve (three way valve) while valves $C_1$, $C_2$ and $C_3$ are closed. 100 cc of flue gas may be taken into eudiometer tube by lowering aspirator bottle until the level is zero and subsequently forced into flask for absorbing different constituents. Aspirator bottle is lifted so as to inject flue gas into flask I with only valve $C_1$ in open state where $CO_2$ present shall be absorbed. Aspirator bottle is again lowered and reading of eudiometer tube taken. Difference in readings of eudiometer tube initially and after $CO_2$ absorption shall give percentage of $CO_2$ by volume. Similar steps may be repeated for getting $O_2$ and CO percentage by volume for which respective flask valve shall be opened and gas passed into flask. Thus Orsat analyzer directly gives percentage by volume of constituents. In case of other constituents to be estimated the additional flasks with suitable chemical may be used. The remaining volume in eudiometer after absorption of all constituents except $N_2$ shall give percentage volume of $N_2$ in flue gas.

As in combustion of hydrocarbon fuel moisture is present in flue gases but in Orsat analysis only dry flue gases are taken into account which means moisture will be condensed and separated out. Therefore the percentage by volume of constituents estimated shall be on higher side as in actual products moisture is there but in dry flue gas it is absent. Orsat analyzer does not give exact analysis.

**3. (a)**

Given : $K = 4$, 4 stroke, $D = 50$ mm = 0.05 m, $L = 75$ mm = 0.075, $N = 2500$ rpm, $a = 0.30$ m,

$W_{net} = 150$ N, $\dot{V}_f = 5.5$ litre/hour , $s = 0.75$, $CV = 42000$ kJ/kg

$W_{234} = 108$ N, $W_{134} = 101$ N, $W_{124} = 103$ N, $W_{123} = 110$ N

**(i)**

$$bp = T\omega = (W_{net} \times a)\left(\frac{2\pi N}{60}\right)$$

$$= (150 \times 0.3)\left(\frac{2\pi \times 2500}{60}\right) = 11.78 \text{ kW}$$

**(ii)**

$$P_{bmep} \times \dot{V}_s = bp$$

$$\Rightarrow \quad P_{bmep} \times \left[\frac{\pi}{4} D^2 L \frac{N}{2 \times 60} \times K\right] = bp$$

$$\Rightarrow \quad P_{bmep} \times \left[\frac{\pi}{4} \times (0.05)^2 (0.075) \frac{2500}{2 \times 60} \times 4\right] = 11.78$$

$$\Rightarrow \quad P_{bmep} = 960 \text{ kPa}$$

**(iii)**

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

$$= \frac{11.78}{\left\{\frac{5.5 \times 10^{-3} \times 0.75 \times 1000}{3600}\right\} \times 42000}$$

$$= \frac{11.78}{(1.146 \times 10^{-3}) \times 42000} = 0.24478$$

$$= 24.47\%$$

**(iv)**

$$bsfc = \frac{\dot{m}_f}{bp} = \frac{1.146 \times 10^{-3} \times 3600}{11.78}$$

$$= 0.350 \text{ kg/kWh}$$

**(v)** Morse test

We know, $$ip_{1234} - FP = bp_{1234} \quad \text{...(i)}$$

when cylinder (i) is not firing,

$$ip_{234} - FP = bp_{234} \quad \text{...(ii)}$$

when cylinder (ii) is not firing,

$$ip_{134} - FP = bp_{134} \quad \text{...(iii)}$$

when cylinder (iii) is not firing,

$$ip_{124} - FP = bp_{124} \quad ...(iv)$$

when cylinder (iv) is not firing,

$$ip_{123} - FP = bp_{123} \quad ...(v)$$

Now, from equation (i) – equation (ii), we get

$$ip_1 = bp_{1234} - bp_{234} \quad ...(vi)$$

Similarly, equation (i) – equation (iii), we get

$$ip_2 = bp_{1234} - bp_{134} \quad ...(vii)$$

equation (i) – equation (iv), we get

$$ip_3 = bp_{1234} - bp_{124} \quad ...(viii)$$

equation (i) – equation (v), we get

$$ip_4 = bp_{1234} - bp_{123} \quad ...(ix)$$

Now, sum of equation (vi), (vii), (viii) and (ix) gives

$$ip_{1234} = 4bp_{1234} - (bp_{234} + bp_{134} + bp_{124} + bp_{123}) \quad ...(x)$$

Now,
$$bp_{234} = (W_{234} \times a)\left(\frac{2\pi N}{60}\right) \times \frac{1}{1000}$$

$$= (108 \times 0.3)\left(\frac{2 \times \pi \times 2500}{60}\right) \times \frac{1}{1000} = 8.482 \text{ kW}$$

Similarly,
$$bp_{134} = (W_{134} \times a)\left(\frac{2\pi N}{60}\right) \times \frac{1}{1000}$$

$$= (101 \times 0.3)\left(\frac{2\pi \times 2500}{60}\right) \times \frac{1}{1000} = 7.9325 \text{ kW}$$

$$bp_{124} = (W_{124} \times a)\left(\frac{2\pi N}{60}\right) \times \frac{1}{1000}$$

$$= (103 \times 0.3)\left(\frac{2\pi \times 2500}{60}\right) \times \frac{1}{1000} = 8.089 \text{ kW}$$

and
$$bp_{123} = (W_{123} \times a)\left(\frac{2\pi N}{60}\right) \times \frac{1}{1000}$$

$$= (110 \times 0.3)\left(\frac{2\pi \times 2500}{60}\right) \times \frac{1}{1000} = 8.6393 \text{ kW}$$

Putting values in equation (x), we get

$$ip_{1234} = 4(11.78) - (8.482 + 7.9325 + 8.089 + 8.6393)$$

$$\Rightarrow \quad ip_{1234} = 13.9772 \text{ kW}$$

**(vi)**

$$\eta_m = \frac{bp}{ip} = \frac{11.78}{13.9772}$$

$$= 0.8420 = 84.20\%$$

**(vii)**

$$P_{imep} \times \dot{V}_S = ip$$

$$P_{imep} \times \left[\frac{\pi}{4} D^2 L \times \frac{N}{2 \times 60} \times K\right] = ip$$

$$P_{imep} \times \left[\frac{\pi}{4}(0.05)^2 (0.075) \times \left(\frac{2500}{2 \times 60}\right) \times 4\right] = 13.9772$$

$$P_{imep} = 1139.136 \text{ kPa}$$

**3. (b)**

**(i)**

The modern high pressure boilers employed for power generation are of steam capacities 30 to 650 tonne/h and above with a pressure upto 160 bar and maximum steam temperature of about 540°C.

Various types of high pressure boilers are

1. La Mont boiler
2. Benson boiler
3. Loffler boiler
4. Babcock and Wilcox boiler

Following are the unique features of high pressure boilers:

1. **Method of water circulation:** In all modern high pressure boiler plants, the water circulation is maintained with the help of pump which forces the water through the boiler plant. The use of natural circulation is limited to sub-critical boilers due to its limitations.
2. **Type of tubing:** In most of the high pressure boilers, the water circulated through the tubes and their external surfaces are exposed to the flue gases. In most of the cases, several sets of the tubings are used. This type of arrangement helps to reduce the pressure loss, and gives better control over the quality of the steam.
3. **Improved method of heating:** The following improved method of heating may be used to increase the heat transfer.

(a) The saving of heat by evaporation of water above critical pressure of the steam.

(b) The heating of water can be made by mixing the superheated steam.

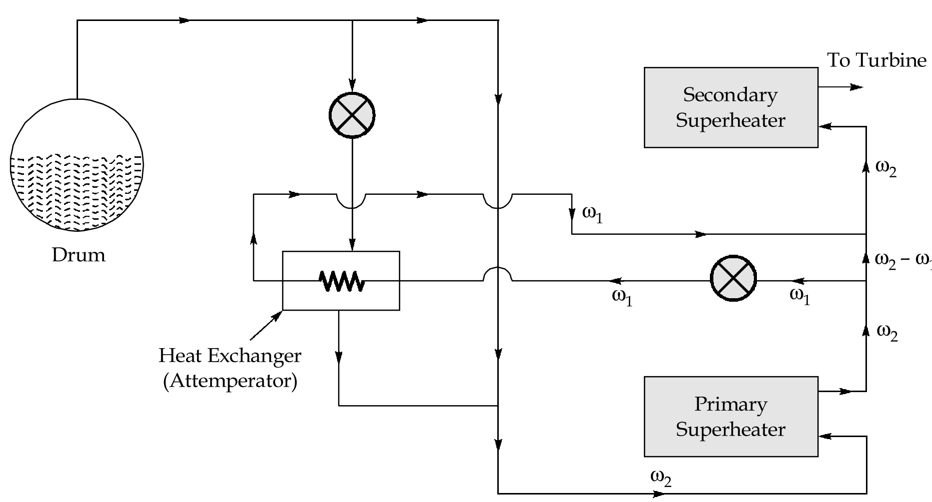
(c) The overall heat transfer coefficient can be increased by increasing the water velocity inside the tube and increasing the gas velocity above sonic velocity.

4. **Higher steam pressure and temperature:** The steam is generated at a pressure between 80 bar to 300 bar and temperature of 450°C to 585°C with two superheater in series. The use of such steam is very useful for power generation. It increases thermal efficiency of the plant and reduces the moisture content in low pressure stages of expansion in the turbine.

5. **Compactness:** The high rate of heat transfer inside the boiler reduces the overall size of the boiler and the boiler becomes compact.

**(ii)**

Temperature control by Attemperation: Control of steam temperature by attemperation means that the steam temperature is reduced by removing energy from the steam. In a tubular type, a portion of steam ($\omega_1$) taken out through tubes from a point between the primary and secondary superheaters by an automatic valve directed to a shell and tube heat exchanger where boiled water from the drum may be circulated. The steam gives up some of its energy to that water and re-mixes with the primary steam ($\omega_2$) before entering the secondary superheater.




**Control of Steam Temperature by Attemperation**

**3. (c)**

Given : $T_1$ = 25°C = 298 K; $\eta_{SC}$ = 0.8; $\eta_{ST}$ = 0.9; $\in_{HE}$ = 0.75; $\eta_m$ = 0.98; $P$ = 6000 kW;

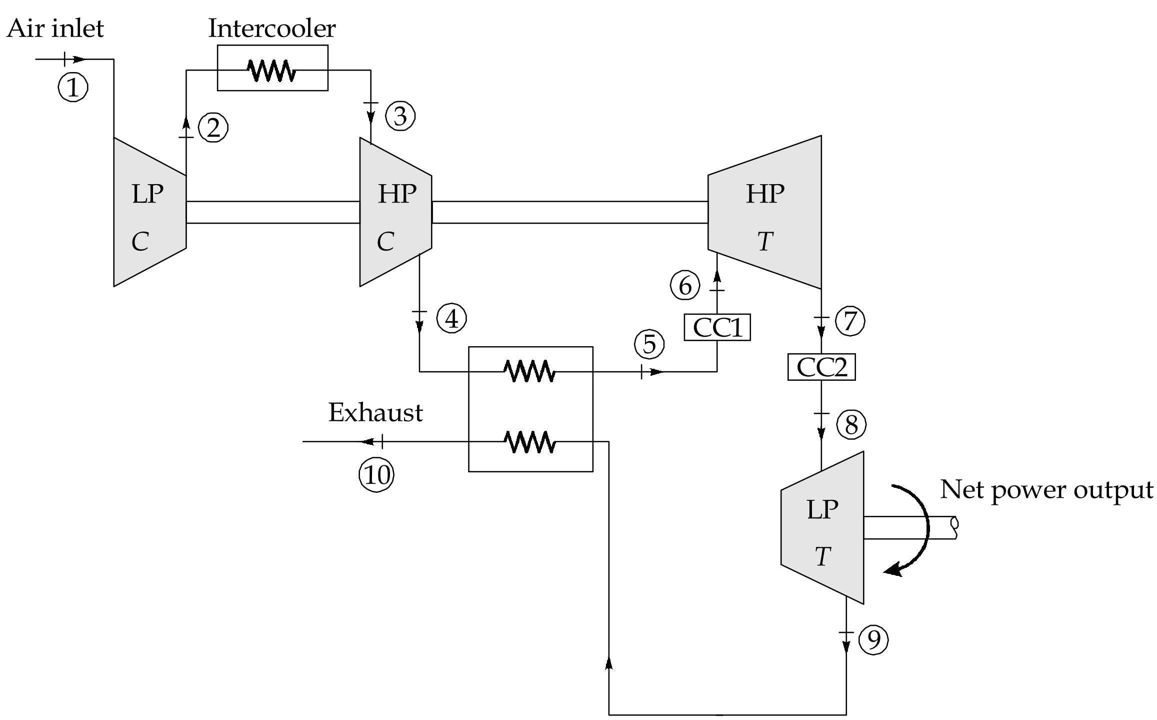
$P_{r,o}$ = 16 : 1; $T_6$ = 850°C = 1123 K; $T_8$ = 850°C = 1123 K; $c_{p_a}$ = 1.005 kJ/kgK; $\gamma_a$ = 1.4;

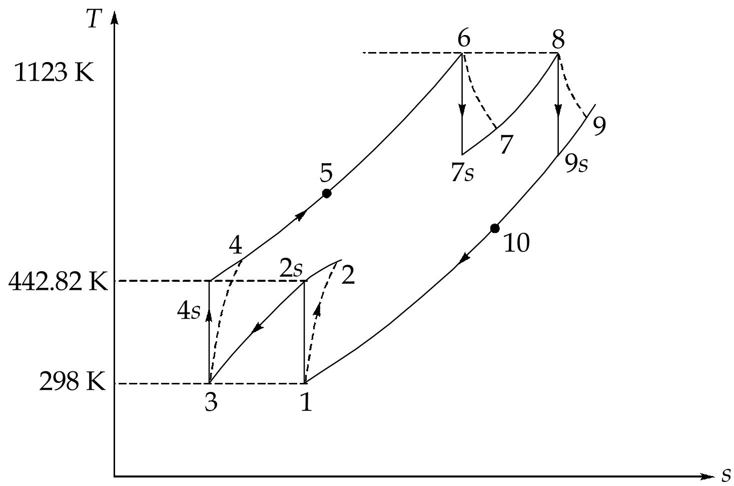
$c_{p_g}$ = 1.15 kJ/kgK and $\gamma_g$ = 1.33

Since, the pressure ratio and isentropic efficiency of each compressor is same, then the work input required for each compressor is the same since both compressors have the same inlet air temperature.

i.e. $T_1 = T_3$ and $T_2 = T_4$

Now, $$\frac{P_2}{P_1} = \sqrt{16} = 4$$






So, $$\frac{T_{2s}}{T_1} = \left(\frac{P_2}{P_1}\right)^{\left(\frac{\gamma_a - 1}{\gamma_a}\right)} = (4)^{\frac{1.4-1}{1.4}}$$

$\Rightarrow$ $$T_{2s} = 298 \times 1.486 = 442.82 \text{ K}$$

and, for LP compressor, $$\eta_{sc} = \frac{T_{2s} - T_1}{T_2 - T_1}$$

$\Rightarrow$ $$0.8 = \frac{442.82 - 298}{T_2 - 298}$$

$\Rightarrow$ $$T_2 = 479.03 \text{ K}$$

Work input per compressor stage = $C_{p_a}(T_2 - T_1)$

$$= 1.005\,(479.03 - 298)$$

$$= 181.93 \text{ kJ/kg}$$

The HP turbine is required to drive both compressors and to overcome mechanical friction,

i.e. work output of HP turbine = $\frac{2 \times 181.93}{0.98} = 371.28$ kJ/kg

therefore, $$c_{p_g}(T_6 - T_7) = 371.28$$

$\Rightarrow$ $$1.15(1123 - T_7) = 371.28$$

$\Rightarrow$ $$T_7 = 800.14 \text{ K}$$

Now, for HP turbine, $$\eta_{ST} = \frac{T_6 - T_7}{T_6 - T_{7s}}$$

$$\Rightarrow \quad 0.9 = \frac{1123 - 800.14}{1123 - T_{7s}}$$

$$\Rightarrow \quad T_{7s} = 764.27 \text{ K}$$

Then,

$$\frac{P_6}{P_7} = \left(\frac{T_6}{T_{7s}}\right)^{\frac{\gamma_g}{\gamma_g - 1}} = \left(\frac{1123}{764.27}\right)^{\frac{1.33}{1.33-1}}$$

$$\frac{P_6}{P_7} = 4.716$$

and

$$\frac{P_8}{P_9} = \frac{16}{4.716} = 3.39$$

$$\frac{T_8}{T_{9s}} = \left(\frac{P_8}{P_9}\right)^{\frac{\gamma_g - 1}{\gamma_g}} = (3.39)^{\frac{0.333}{1.333}} = 1.35$$

$$\Rightarrow \quad T_{9s} = \frac{1123}{1.35} = 831.85 \text{ K}$$

Then, for LP turbine, $\eta_{ST} = \dfrac{T_8 - T_9}{T_8 - T_{9s}}$

$$0.90 = \frac{1123 - T_9}{1123 - 831.85}$$

$$\Rightarrow \quad T_9 = 860.96 \text{ K}$$

Net work output $= c_{p_g}(T_8 - T_9) \times 0.98$

$= 1.15 \times (1123 - 860.96) \times 0.98$

$= 295.32$ kJ/kg

We know,

$$\in_{HE} = \frac{T_5 - T_4}{T_9 - T_4}$$

$$0.75 = \frac{T_5 - 479.03}{860.96 - 479.03}$$

$$\Rightarrow \quad T_5 = 765.48 \text{ K}$$

Now, heat supplied, $\dot{Q} = c_{p_g}(T_6 - T_5) + c_{p_g}(T_8 - T_7)$

$$= 1.15(1123 - 765.48) + 1.15(1123 - 800.14)$$

$$= 782.437 \text{ kJ/kg}$$

So, cycle efficiency $= \dfrac{\dot{W}_{net}}{\dot{Q}} = \dfrac{295.32}{782.437} = 0.3774 = 37.74\%$

and gross work output $= W_{HP} + W_{CP}$

$$= 371.28 + \frac{295.32}{0.98} = 672.63 \text{ kJ/kg}$$

So, work ratio $= \dfrac{\text{Net work output}}{\text{Gross work output}} = \dfrac{295.32}{672.63}$

$$= 0.4391$$

$$= 43.91\%$$

The electrical output is 6000 kW, let mass flow rate be $\dot{m}$ kg/s then,

$$6000 = \dot{m} \times 295.32$$

$\Rightarrow$ $\dot{m} = 20.32$ kg/s

**4.** **(a)**

**Condenser :** It can be defined as a device used for condensation of steam at constant pressure, generally pressure is less than atmospheric pressure.

Condenser is, thus, a closed vessel which is generally maintained at vacuum and cold fluid is circulated for picking heat from steam to cause its condensation.

Condenser can be broadly classified on the basis of type of heat exchanger i.e. direct or indirect contact condensers as follows:

(i) Direct contact type or mixing type or jet condenser.

(ii) Indirect contact type or non-mixing type or surface condenser.

(iii) Evaporative condenser

**(i)** **Jet condenser :** In jet condenser the steam to be condensed and cooling water are intimately mixed by breaking up of water in the form of spray and allowing small sized water particles to fall down through the body of steam. The water may also be discharged out through suitably shaped nozzles into body of steam. Thus, it is desired to atomize water into small sized particles so that increased surface area is available for heat exchange between hot and cold fluid. Number of arrangements for flow of steam and water are available such as: counter flow type having steam entering from bottom and flowing upwards while water enters from top and falls downwards with air pump connected on top where air is colder etc. Jet condenser may be further classified based on relative movement of two fluids, and based on arrangement used for removal of condensate.

Based on relative movement of two fluids, jet condenser can be,

(a) Counter flow jet condenser.

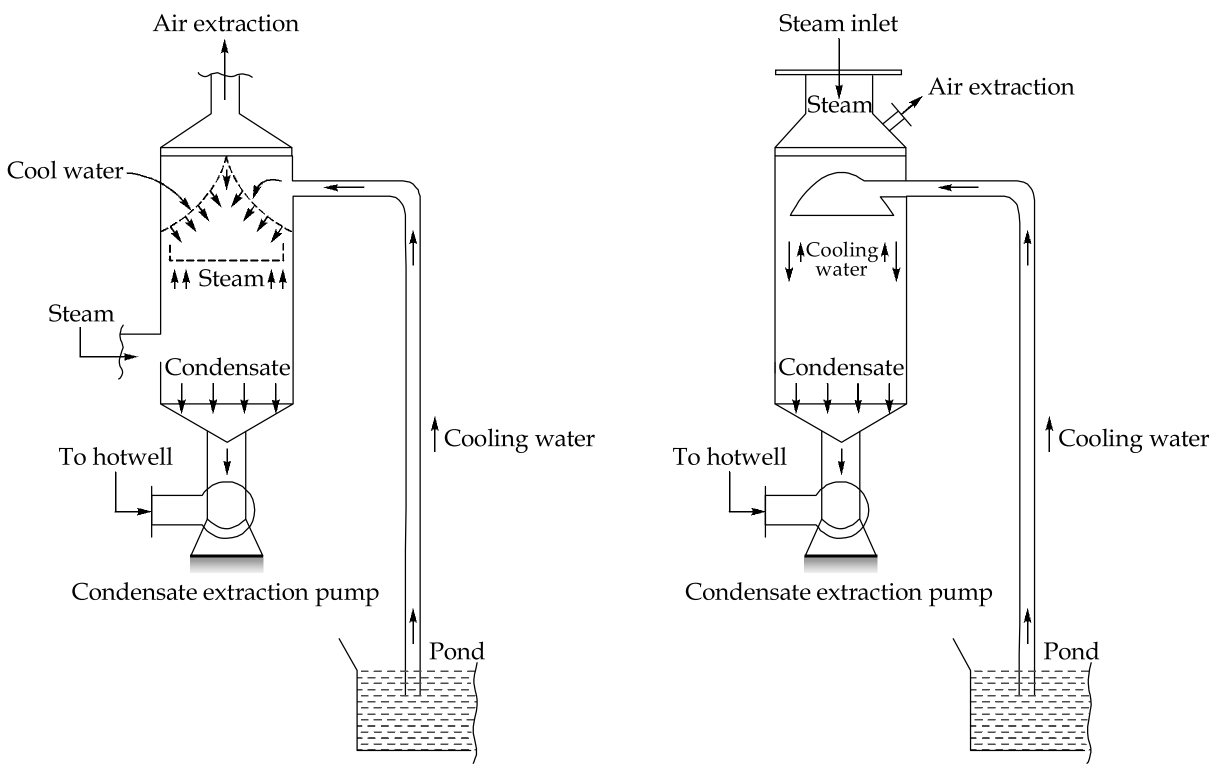
(b) Parallel flow jet condenser

Based on arrangement for removal of condensate, jet condenser can be,

(a) Low level jet condenser

(b) High level jet condenser

(c) Ejector condenser



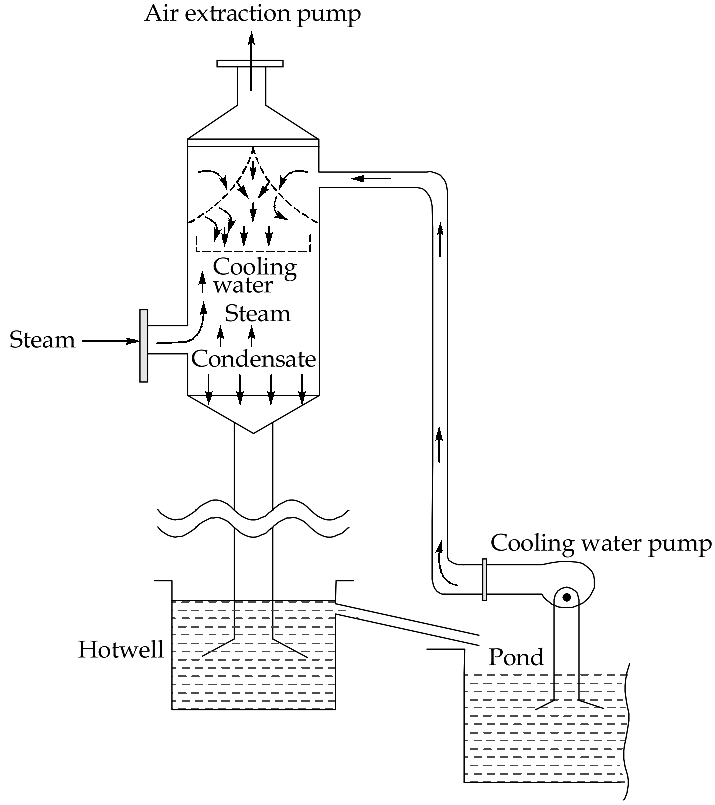

(a) Counterflow type low level jet condenser

(b) Parallel flow type low level jet condenser

***Schematic of low level jet condenser***

(a) Low level jet condenser : Low level jet condenser is the one which is placed at low level such that vacuum inside condenser draws cooling water into condenser from river, pond or cooling tower. Difference between atmospheric pressure (at which cooling water is available) and condenser pressure causes flow of cooling water could be parallel flow or counter flow type. Counter flow type and parallel flow type low level jet condensers are shown in figure. There is provision for extraction of air and dissolved gases from top of condenser by using air extraction pump. Condensate extraction pump is used for taking out condensate from condenser and sending it to hot well.

Cooling water supplied to jet condenser has generally a large percentage of dissolved air which gets liberated due to atomization of water, vacuum and heating of water and is extracted out. Low level jet condenser suffers from inherent drawback that in the event of failure of condensate extraction will flow out of condenser because of gravity. Here no condensate extraction pump is required, instead pump is required for pumping water upto condenser inlet. High level jet condenser is also called as 'barometric condenser'. High level jet condenser is placed at suitable height depending upon efficient drainage and capacity of sump (hot well) into which tail pipe of condenser discharges out. Mathematically, it would be said that jet condenser placed above hotwell by 10.36 m shall be high level jet condenser or barometric condenser.




*Schematic of high level jet condenser*

Absolute pressure in condenser,

$$P_t = (76-70)\times 10^{-2}\times 0.0135951\times 10^{6}\times 9.81$$
$$= 8002.075 \text{ N/m}^2$$
$$= 8.002 \text{ kPa}$$

Partial pressure of steam in condenser = Saturation pressure of steam corresponding to 35°C

$$P_s = 5.60 \text{ kPa}$$

Now, partial pressure of air,

$$P_a = P_t - P_s$$
$$= 8.002 - 5.60$$
$$= 2.402 \text{ kPa}$$

and mass of air per m$^3$ of condenser volume can be obtained from gas equation,

$$m_a = \frac{P_a V}{RT} = \frac{2.402 \times 1}{0.287 \times (273 + 35)} = 0.02717 \text{ kg/m}^3$$

Let the enthalpy of steam entering condenser be $h_s$, so by heat balance

$$\dot{m}_w \times c_{p_w} \times \left(T_{w_o} - T_{w_i}\right) = \dot{m}_s \times \left(h_s - c_{p_w} T_c\right)$$

Given : $\dot{m}_w$ = 800 kg/min; $\dot{m}_s$ =25 kg/min; $T_{w_o}$ = 25°C; $T_{w_i}$ = 15°C; $T_c$ = 30°C

$$\Rightarrow \quad 800 \times 4.18(25 - 15) = 25(h_s - 4.18 \times 30)$$
$$h_s = 1463 \text{ kJ/kg}$$

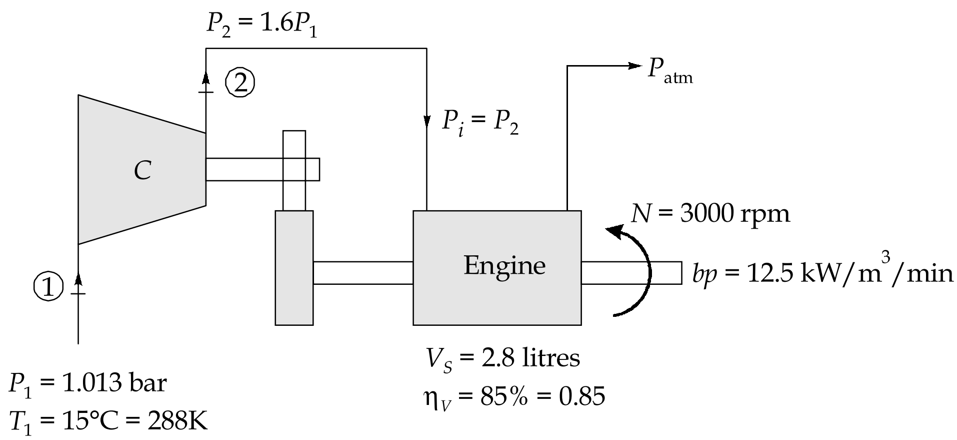
Let dryness fraction of steam be $x$,

$$h_s = h_{f@35°C} + x h_{fg@35°C}$$
$$1463 = 146.68 + x(2418.6)$$
$$x = 0.5442$$

$$\text{Vacuum efficiency} = \frac{\text{Actual vacuum in condenser}}{\text{Theoretical vacuum in condenser}}$$
$$= \frac{P_b - (P_a + P_s)}{P_b - P_s}$$
$$= \frac{\left(76 \times 10^{-2} \times 0.0135951 \times 10^6 \times 9.81\right) - \left[(2.402 + 5.60) \times 10^3\right]}{(76 \times 10^{-2} \times 0.0135951 \times 10^6 \times 9.81) - (5.60 \times 10^3)}$$
$$= \frac{101359.6276 - 8002}{101359.6276 - 5600} = 0.9749 = 97.49\%$$

**4. (b)**

Given : For a four stroke CI engine : $V_s$ = 2.8 litres, $N$ = 3000 rpm, $ip$ = 12.5 kW/m$^3$/min, $\eta_{vol}$ = 85%, $P_{atm} = P_1$ = 1.013 bar, $T_{atm} = T_1$ = 15°C = 288 K, $r_p$ = 1.6, $\eta_{isen}$ = 74%, $\eta_{mech}$ = 78%




Swept volume, $V_S$ = 2.8 litres = $2.8 \times 10^{-3}$ $m^3$

Now, volume swept by the piston per minute,

$$\dot{V}_S(m^3/min) = V_S \times \frac{N}{2}$$

$$= (2.8\times10^{-3})\times\left(\frac{3000}{2}\right)$$

$$= 4.2 \ m^3/min$$

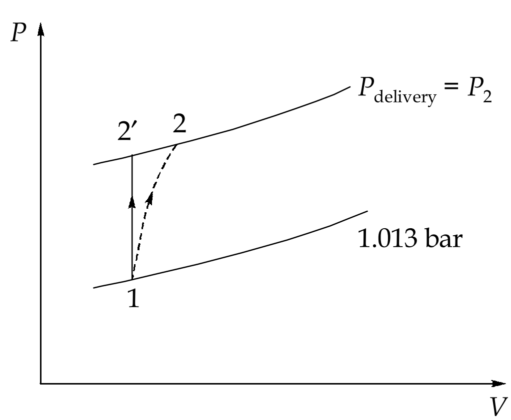
Unsupercharged induced volume,

$$\dot{V}_{induce} = \dot{V}_S \eta_{volumetric}$$

$$= 4.2 \times 0.85$$

$$= 3.57 \ m^3/min$$

For boiler:




$$\frac{P_2}{P_1} = 1.6$$

$\Rightarrow$ $$P_2 = 1.6\ (1.013) = 1.621 \text{ bar}$$

and temperature after isentropic compression,

$$T_{2'} = T_1\left(\frac{P_2}{P_1}\right)^{\frac{\gamma-1}{\gamma}}$$

$$= 288(1.6)^{\frac{1.4-1}{1.4}} = 329.4\text{ K}$$

and, isentropic efficiency of blower,

$$\eta_{s,b} = \frac{T_{2'}-T_1}{T_2-T_1}$$

$$0.74 = \frac{329.4-288}{T_2-288}$$

$$\Rightarrow \quad T_2 = 343.9\text{ K}$$

The blower delivers 4.2 $m^3/min = \dot{V}_{2'}$ at 1.621 bar and 343.9 K

So, equivalent volume at 1.013 bar and 15°C

$$\frac{P_1\dot{V}_{FAD}}{T_1} = \frac{P_{2'}\dot{V}_{2'}}{T_{2'}}$$

$$\Rightarrow \quad \dot{V}_{FAD} = \frac{1.621\times4.2\times288}{343.9\times1.013}$$

$$= 5.628\ m^3/min$$

Now, volumetric efficiency of supercharged engine,

$$(\eta_v)_{supercharged} = \frac{5.628}{4.2} = 1.34 = 134\%$$

Increase in induced volume = 5.628 – 3.57 = 2.058 $m^3/min$

∴ Increase in *ip* from air induced = 12.5 × 2.058 = 25.73 kW

Increase in *ip* due to increased induction pressure $= \dfrac{(P_i - P_{atm})}{60\times1000}\times\dot{V}_S$

$$= (1.621-1.013)\times10^5\times\frac{4.2}{60}\times\frac{1}{1000} = 4.256\text{ kW}$$

So, total increase in *ip* = 25.73 + 4.256

= 29.99 kW

$\therefore$ Increase in engine break power = $ip \times \eta_m = 29.99 \times 0.78$

$= 23.39$ kW

Now, power required to drive the blower must be deduced from this output. Mass of

air delieverd per second by blower = $\dfrac{P_{2'}\left(\dfrac{\dot{V}_s}{60}\right)}{RT_2}$

$$= \frac{1.621 \times 10^5 \times 4.2}{60 \times 287 \times 343.9}$$

$= 0.115$ kg/s

Power input to the blower = $mc_p(T_2 - T_1)$

$= 0.115 \times 1.005\ (343.9 - 288)$

$= 6.46$ kW

$\therefore$ Power required to drive the blower = $\dfrac{6.46}{\eta_m}$

$$= \frac{6.46}{0.78} = 8.28 \text{ kW}$$

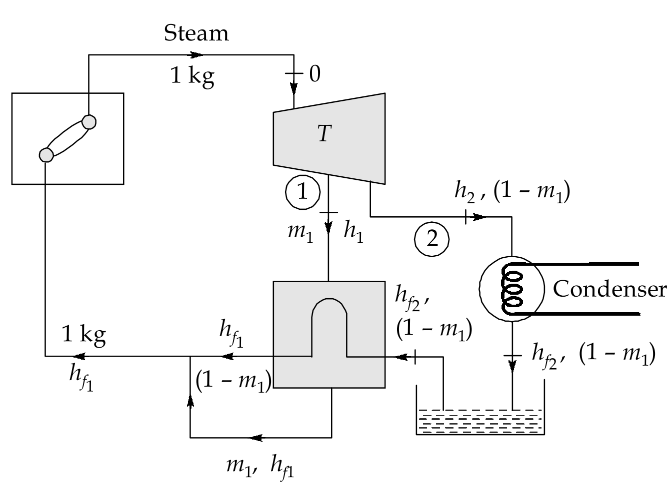
$\therefore$ Net increase in bp = $23.39 - 8.28 = 15.11$ kW

and bp of unsupercharged engine = $12.5 \times 3.57 \times \eta_m$

$= 44.63 \times 0.78$

$= 34.81$ kW

**4. (c)**



**Assumptions:**

1. The bled steam just condenses i.e. gives up its superheat (if any) and all its latent heat only.
2. Feed water is heated to the saturation temperature at the pressure of bled steam.
3. The water condensate is returned to the feed by separate pump at a point down stream from the heater, is fed to *HP* side.
4. There is no undercooling of exhaust in condenser.

The heat balance equation for the heater is

$$m_1 h_1 + (1 - m_1) h_{f_2} = (1 - m_1) h_{f_1} + m_1 h_{f_1} = h_{f_1}$$

Now, thermal efficiency, $\eta = \dfrac{\text{Work done}}{\text{Heat supplied}}$

$$= \frac{(h_0 - h_1) + (1 - m_1)(h_1 - h_2)}{h_0 - h_{f_1}}$$

Now, putting the value of $h_{f_1}$,

$$(\eta_{th})_{reg} = \frac{h_0 - m_1 h_1 - (1 - m_1) h_2}{h_0 - m_1 h_1 - (1 - m_1) h_{f_2}}$$

This may also be written as

$$(\eta_{th})_{reg} = \frac{(h_0 - h_2) - m_1(h_1 - h_2)}{(h_0 - h_{f_2}) - m_1(h_1 - h_{f_2})}$$

Corresponding rankine cycle efficiency,

$$(\eta_{th})_{rank} = \frac{h_0 - h_2}{h_0 - h_{f_2}}$$

Now,

$$(\eta_{th})_{reg} - (\eta_{th})_{rank} = \frac{(h_0 - h_2) - m_1(h_1 - h_2)}{(h_0 - h_{f_2}) - m_1(h_1 - h_{f_2})} - \frac{h_0 - h_2}{h_0 - h_{f_2}}$$

$$= \frac{a - b}{c - d} - \frac{a}{c} \quad \text{(say)}$$

$$= \frac{(a - b)(c) - a(c - d)}{(c - d)(c)}$$

$$= \frac{a \times d - b \times c}{c(c - d)}$$

where, $a \times d = (h_0 - h_2)m_1(h_1 - h_{f_2}) = m_1(h_0h_1 - h_0h_{f_2} - h_2h_1 + h_2h_{f_2})$

$c \times b = (h_0 - h_{f_2})m_1 \times (h_1 - h_2) = m_1(h_0h_1 - h_0h_2 - h_1h_{f_2} + h_2h_{f_2})$

So, $$a \times d - c \times b = m_1(h_2 - h_{f_2})(h_0 - h_1)$$

Since, $$h_2 > h_{f_2} \text{ and } h_0 > h_1$$

So, $a \times d - c \times b$ is always positive in all the cases, $(h_0 - h_{f_2}) > m_1(h_1 - h_{f_2})$

Since, $m_1 < 1$ and $h_1 < h_0$ i.e. $c > d$

So, $$\frac{a \times d - c \times b}{c(c-d)} = \text{positive}$$

$$\Rightarrow \quad (\eta_{th})_{reg} - (\eta_{th})_{rank} > 0$$

$$\Rightarrow \quad (\eta_{th})_{reg} > (\eta_{th})_{rank}$$

## Section : B

**5. (a)**

The photovoltaic effect is the creation of voltage and electric current in a material upon exposure to light and is a physical and chemical phenomenon

When a solar cell is under solar radiation, then electron hole pairs are generated and electric current $I$ is obtained in the circuit.

Electric current $I$ is the difference between the solar light generated current ($I_L$) and diode junction current ($I_J$)

$$I = I_L - I_J$$

$$I_J = I_0\left[\exp\left(\frac{ev}{kT}\right) - 1\right]$$

Where $I_0$ = Dark or saturation current.

$$I = I_{sc} - I_J$$

$I_{sc}$ is current at short circuit and at open circuit $I = 0$

$$\therefore \quad 0 = I_{sc} - I_J$$

$$0 = I_{sc} - I_0\left[\exp\left(\frac{ev}{kT}\right) - 1\right]$$

$V_{oc}$ is open circuit voltage

$$V_{oc} = \frac{kT}{e}\ln\left(\frac{I_{sc} + I_0}{I_0}\right)$$

Power can be defined as,

$$P = VI = V \times \left\{ I_{sc} - I_0 \exp\left(\frac{ev}{KT}\right) + I_0 \right\}$$

Now, in above expression power is function of V.

$$P = f(V)$$

For maximization of power

$$\frac{dP}{dV} = 0$$

$$= I_{sc} - I_0 \exp\left(\frac{ev}{KT}\right) + I_0 - VI_0 \exp\left(\frac{ev}{kT}\right) . \frac{e}{kT} = 0$$

$$= \frac{d^2P}{dv^2} < 0$$

$$\frac{I_{sc} + I_0}{I_0} = \exp\left(\frac{eV_m}{kT}\right)\left\{1 + \frac{eV_m}{kT}\right\}$$

In above expression $V_m$ can be calculated and hence

$$I_m = I_{sc} - I_0 \left\{ \exp\left(\frac{eV_m}{kT} - 1\right) \right\}$$

$$P_{max} = V_m I_m$$

5. **(b)**

**Crevice Corrosion :** It is highly localized corrosion which generally appears in shielded areas like gasket surfaces, lap joints, under bolts and rivet heads where small amount of stagnant solutions (like dust), surface deposits are settled, then these are the means to create an acidic atmosphere to automatically propagate the corrosion into thickness. Furthermore, the resulted corrosive products are prone to improve the acidic nature more and more. It is also called as deposit or gasket carrosion as shown in figure below.

*Crevice corrosion under the nuts due to the gaskets*

**Prevention:**

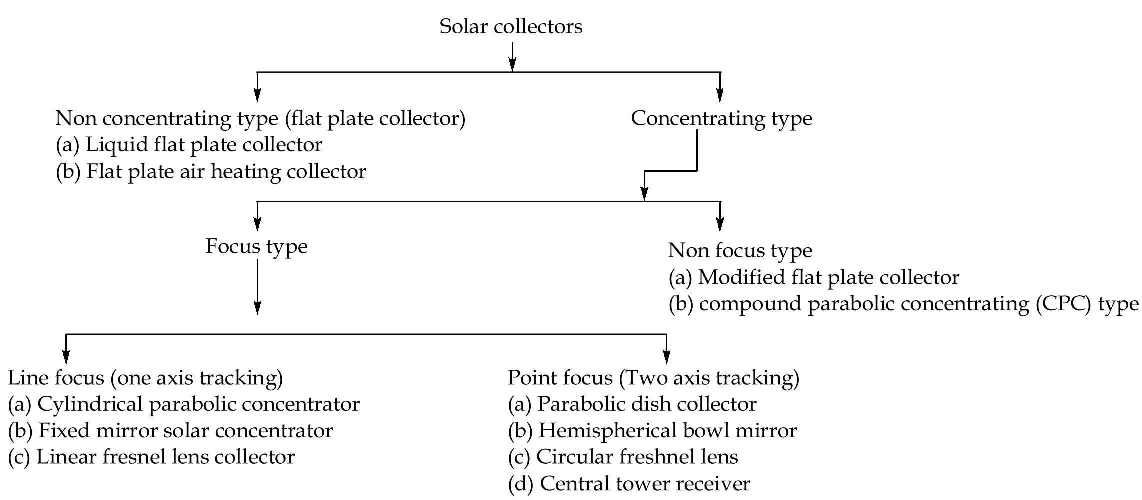
1. Use butt joints instead of lap-joints.
2. Clean thoroughly to remove stagnant solutions.
3. Avoid sharp corners while designing.
4. Use non-absorbable solid gaskets such as Teflon

**Filliform Corrosion:** Filliform corrosion is a special type of crevice corrosion where the corrosion take place under a thin film. It appears on steel, magnesium, and aluminium surfaces covered by tin, silver, gold, phosphate, enamel, and lacquer coatings and it is also observed at the paper-aluminium interface. It moves in between film and metal surfaces like a worm with blue-green head and red-brown tail. It is not a dangerous kind but the appearance of the surface looks very dirty, mainly, on the beverage cans and other food packing therefore the market sales value goes down.

There is no method to prevent the filliform corrosion. It is better to store the coated materials in less humid atmosphere, but still, it is not for long time.

**5. (c)**

**Classification of solar collectors:**




Comparison of concentrating and non-concentrating type solar collectors :

1. In concentrating type solar collectors, solar radiation is converged from large area into smaller area using optical means. Beam radiation which has a unique direction and travels in a straight line, can be covered by reflection or refraction techniques. Diffuse radiation however, has no unique direction and so does not obey optical principles. Therefore, diffuse component cannot be concentrated. Thus concentrating type solar collectors mainly make use of beam radiation component (plus very little diffuse component coming directly over absorber.) , while non-concentrating (flat

plate) collectors absorb both beam as well as diffuse radiation, which is a distinct advantage of flat plate.

2. A flat plate collector is simple in construction and does not require sun tracking. Therefore, it can be properly secured on a rigid platform and thus becomes mechanically stronger than those requiring flexibility for tracking purposes. As the collector is installed outdoors and exposed to atmospheric disturbances (rain, storm) at the flat plate type is more likely to withstand harsh outdoor conditions. Also because of simple stationary design, a flat plate collector requires little maintenance.
3. The principal disadvantage of flat plate collector is that because of absence of optical concentration, the area from which heat lost is large. Also due to some reasons high temperature cannot be attained.
4. Main advantage of concentrating type collectors is that high temperatures can be attained due to concentration of radiation. The also yields high temperature thermal energy.

**Performance indices**

The important performance indices of a solar collectors are:

(i) Collector efficiency

(ii) Concentration ratio

(iii) Temperature range

**(i)** **Collector efficiency :** It is defined as the ratio of the energy actually absorbed and transferred the heat transporting fluid by the collector (useful energy) to the energy incident on the collector.

**(ii)** **Concentration ratio : (CR)** It is defined as the ratio of the area of aperture of the system to the area of the receiver. The aperture of the system is the projected area of the collector facing (normal) to the beam.

**(iii)** **Temperature range :** It is the range of temperature true to which the heat transport liquid is heated up by the collector.

In flat plate collectors no optical system is utilized to concentrate the solar radiation and hence the concentration ratio is only 1 and temperature range is less than 100°C. Line focus collectors have CR up to 100 and temperature range of the order of 150°c to 300°C. Concentration ratio of thousands and temperature range of 500°C to 1000°C can be obtained by using point focus collectors.

**5.** **(d)**

An efficient and effective facility layout can cover following objectives:

(i) To provide optimum space to organize equipment and facilitate movements of goods and to create safe and comfortable work environment.

(ii) To reduce movement of workers, raw material and equipment.

(iii) To promote order in production towards a single objective.

(iv) To promote safety of plants as well as its workers.

(v) To increase production capacity of the organisation.

(vi) To facilitate extension or change in the layout to accommodate new product line or technology upgradation.

**Principles to be adopted to achieve these objectives:**

**(i) Principle of Integration:** A good layout is one that integrates men, materials, machines and supporting services and others in order to get the optimum utilization of resources and maximum effectiveness.

**(ii) Principle of minimum distance:** This principle is concerned with minimum travel (or movement) of men and materials. The facilities should be arranged such that, the total distance travelled by men and materials should be minimum and as far as possible straight line movement should be preferred.

**(iii) Principle of cubic space utilization:** The good layout is one that utilizes both horizontal and vertical space.

**(iv) Principle of flow:** Materials should move in forward direction towards completion stage i.e. there should not be backtracking.

**(v) Principle of maximum flexibility:** A good layout can be altered without much cost and time.

**(vi) Principle of safety, security and satisfaction:** A good layout is one that gives the consideration to worker's safety and satisfaction and safeguards plant and machinery against fire, theft etc.

**(vii) Principle of minimum handling :** A good layout is one that reduces material handling to minimum.

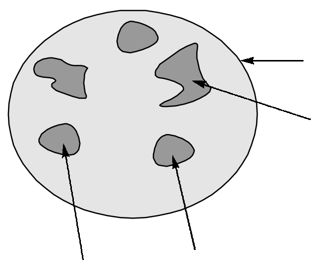
**Process layout:** Equipment is arranged according to function or type. This layout is noted for its flexibility. It can accommodate a great variety of alternative operation sequence.

**Cellular layout:** It is often possible to configure the equipment so that groups of similar parts or products can be made on the same equipment without significant loss of time for changeovers. Here the assembly or processing is accomplished in cells consisting of several workstations or machines. This layout is called cellular layout.

**Product Layout:** The collection of work stations/machines are arranged in sequence to complete the product.

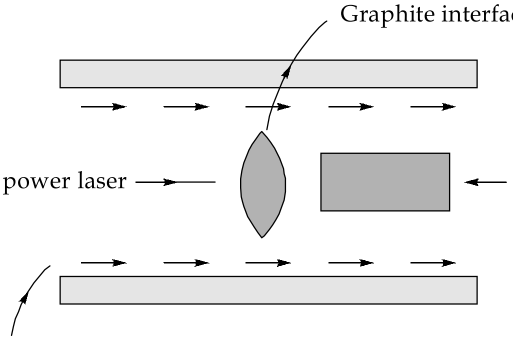
5. (e)

(i) **Mechanical grinding :** It is one of the most popular method to produce nano-materials.




- Work materials alongwith hardened steel balls is placed inside a drum and then drum is rotated.
- When work material is hit repeatedly by hardened steel balls gradually it will convert into nano-material. But this nano-materials will have same contamination of steel. As the mixer of nano-material and steel coming out through the drum, we create a magnetic field in its path. Since, steel is having magnetic behaviour so will be attracted towards magnetic field. But when the nano-material is also having magnetic properties there extensive produces are involved to purify the nano-material.

(ii) **Laser ablation :** To produce CNT




(i) A high power laser bombards the graphite and as a result of that carbon will come out in the atomic form. Since the atmosphere is inert, so carbon will look for stability and only stable form is a nanotube.

(ii) These carbon nanotubes will be collected at finger collector.

**6. (a)**

The total normal direct cost of the project

$$= ₹(20 + 15 + 8 + 11 + 9 + 5 + 3) \times 1000$$
$$= ₹71000$$

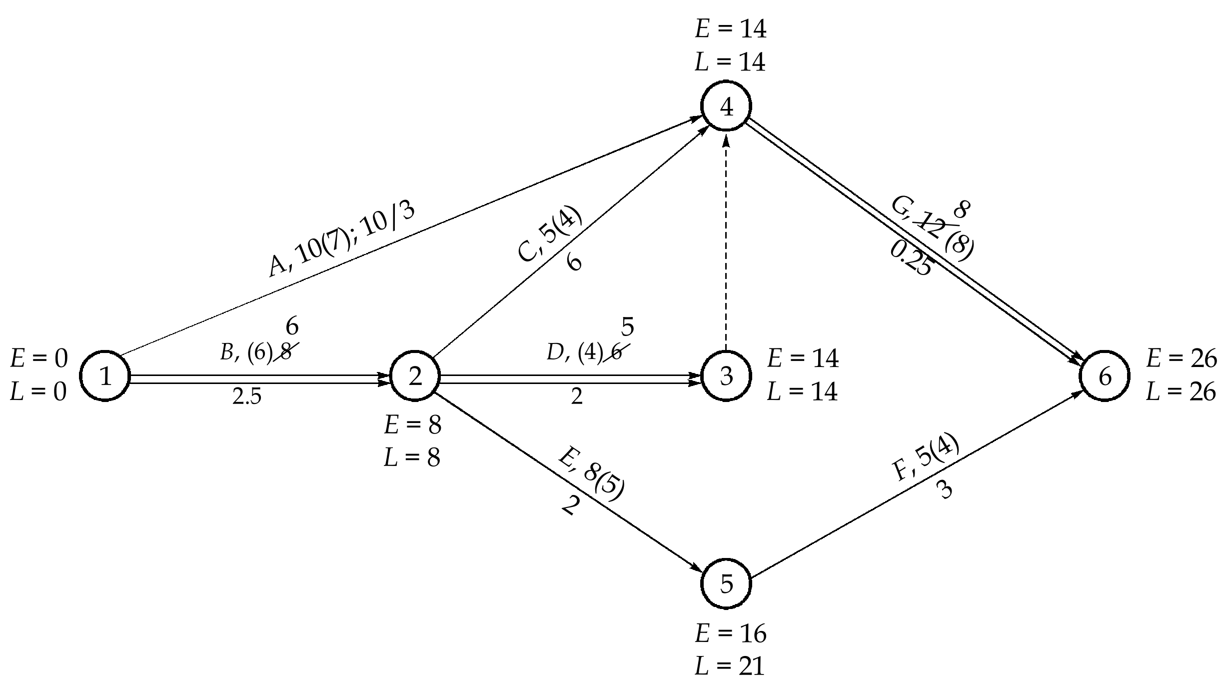
The cost slope for each activity is calculated below:

| Activity | Cost slope (₹1000/week) |
|---|---|
| A | 10/3 |
| B | 2.5 |
| C | 6 |
| D | 2 |
| E | 2 |
| F | 3 |
| G | 0.25 |

Now, the network is drawn and critical path is found as shown in figure below:

Project duration = 26 weeks

and B - D - G is the critical path.




Now, Indirect cost = ₹400 per day or ₹2800 per week

∴ Total cost of project before crashing,

$$TC_1 = \text{Normal direct cost + Indirect cost}$$

$$= 71000 + 26 \times 2800$$
$$= ₹143800$$

Now,

| Total possible path in the Network | Duration before crash |
|---|---|
| A - G | 22, |
| B - C - G | 25, |
| B - D - G | 26, |
| B - E - F | 21, |

Since, activity '*G*' has minimum cost slope on critical path, so crashing '*G*' by four weeks, we get

$$TC_2 = TC_1 + 250 \times 4 - 4 \times 2800$$
$$= ₹133600$$

Again,

| Total possible path | Duration after first crash |
|---|---|
| A - G | 18 |
| B - C - G | 21 |
| B - D - G | 22 |
| B - E - F | 21 |

Since, activity '*G*' cannot be crashed further, so crashing activity 'D' having minimum cost slope on critical path by one week. We get

$$TC_3 = TC_2 + 2000 - 2800$$
$$= 133600 - 800 = ₹132800$$

Again,

| Total possible path | Duration after second crash |
|---|---|
| A - G | 18 |
| B - C - G | 21 |
| B - D - G | 21 |
| B - E - F | 21 |

Now, after second crash, network has three critical path. Considering activities and cost slope on critical path for crashing.

| Activity | $\Delta C/\Delta T$ (₹1000/week) |
|---|---|
| B | 2.5 ← Minimum |
| C, D and E | 6 + 2 + 2 = 10 |
| C, D and F | 6 + 2 + 3 = 11 |

Since, activity 'B' has minimum cost slope, so crashing it by two weeks, we get,

$$TC_4 = TC_3 + 2500 \times 2 - 2 \times 2800$$

$$= 132800 + 5000 - 5600$$

$$TC_4 = ₹132200$$

After crashing activity 'B' it can't be crashed further,

| Total possible path | Duration after third crash |
|---|---|
| A - G | 18 |
| B - C - G | 19 |
| B - D - G | 19 |
| B - E - F | 19 |

Further, the network has three critical path again. i.e. B - C - G, B - D - G and B - E - F options available are

| Activity | ΔC/ΔT (₹1000/week) |
|---|---|
| C, D and E | 6 + 2 + 2 = 10 ← Min |
| C, D and F | 6 + 2 + 3 = 11 |

After crashing activities *C*, *D* and *E* by one week,

$$TC_5 = TC_4 + 10 \times 1000 - 2800$$

$$= 132200 + 10000 - 2800$$

$$= ₹139400$$

Therefore by reducing the project duration by one week further, total cost of the project is increased. Since crash cost becomes more than the indirect cost.

∴ Minimum cost project duration = 19 weeks **Ans.**

Total optimum cost = ₹132200

**6. (b)**

**(i)**

Given : Taylor's tool life equation,

$$VT^n = C$$

$$\Rightarrow \quad T = \left(\frac{C}{V}\right)^{1/n} \quad \text{...(i)}$$

Now,

(a) Machining cost,

$$C_1 = C_m T_m, \text{ where } T_m = \text{Machining time}$$

where, machining time, $T_m = \frac{l}{fN}$

$$= \frac{\pi D l}{fV} \qquad (\because V = \pi DN)$$

So, $C_1 = \frac{C_m \pi D l}{fV}$ ...(ii)

(b) Idle cost, $C_2 = C_m T_n$, where $T_n$ = Idle time

(c) Tool cost, $C_3 = C_e\left(\frac{T_m}{T}\right) = C_e\left(\frac{\pi D l}{fV}\right)\left(\frac{V}{C}\right)^{\frac{1}{n}}$ ...(iii)

(d) Tool changing cost, $C_4 = C_m T_C\left(\frac{T_m}{T}\right) = C_m T_C\left(\frac{\pi D l}{fV}\right)\left(\frac{V}{C}\right)^{\frac{1}{n}}$ ...(iv)

So, Total cost, $C = C_1 + C_2 + C_3 + C_4$

$$= C_m\left(\frac{\pi D l}{fV}\right) + C_m T_n + C_e\left(\frac{\pi D l}{fC^{1/n}}\right)V^{\left(\frac{1}{n}-1\right)} + C_m T_C\left(\frac{\pi D l}{fC^{1/n}}\right)V^{\left(\frac{1}{n}-1\right)}$$

Now, for minimum cost, $\frac{dC}{dV} = 0$

$$-C_m\frac{\pi D l}{f}\left(\frac{1}{V^2}\right) + 0 + C_e\left(\frac{\pi D l}{fC^{1/n}}\right)\left(\frac{1}{n}-1\right)V^{\left(\frac{1}{n}-2\right)} + C_m T_C\left(\frac{\pi D l}{fC^{1/n}}\right)\left(\frac{1}{n}-1\right)V^{\frac{1}{n}-2} = 0$$

$$\left\{\frac{C_e}{C^{1/n}} + \frac{C_m T_C}{C^{1/n}}\right\}\left(\frac{1}{n}-1\right)\left(V^{\frac{1}{n}-2}\right) = \frac{C_m}{V^2}$$

$$\Rightarrow \quad \left(\frac{C_e}{C_m} + T_C\right)\frac{1}{C^{1/n}}\left(\frac{1}{n}-1\right) = \frac{1}{V^{\frac{1}{n}-2+2}}$$

$$\Rightarrow \quad \frac{\left(\frac{C_e}{C_m} + T_C\right)\left(\frac{1}{n}-1\right)}{\frac{1}{C^{1/n}}} = \frac{1}{V^{\frac{1}{n}}}$$

$$\Rightarrow \quad V^{\frac{1}{n}} = \frac{C^{\frac{1}{n}}}{\left(\frac{C_e}{C_m} + T_C\right)\left(\frac{1}{n}-1\right)}$$

$$\Rightarrow \quad V_{opt} = \frac{C}{\left[\left(\frac{C_e}{C_m} + T_C\right)\left(\frac{1}{n}-1\right)\right]^n}$$

**(ii)**

Given : $VT^{0.30} = 90$, $n = 0.30$, $C = 90$, $f = 0.3$ mm/rev, $T_C = 3$ min,

$C_e$ = ₹100/regrind, $C_m$ = ₹8/min

Now, cutting speed for maximum productivity,

$$V_{\text{maximum productivity}} = \frac{C}{\left[\left(\frac{1}{n}-1\right)(T_C)\right]^n}$$

$$= \frac{90}{\left[\left(\frac{1}{0.3}-1\right)(3)\right]^{0.3}} = 50.20 \text{ m/min}$$

and cutting speed for minimum cost,

$$V_{\text{opt}} = \frac{C}{\left[\left(\frac{C_e}{C_m}+T_C\right)\left(\frac{1}{n}-1\right)\right]^n}$$

$$= \frac{90}{\left[\left(\frac{100}{8}+3\right)\left(\frac{1}{0.3}-1\right)\right]^{0.3}}$$

$$= \frac{90}{2.9342} = 30.67 \text{ m/min}$$

**6. (c)**

Given: $\beta = 30°$, $\phi = 28.7°$, $L = 77.2°$, $n = 319$ (for 15th November), Standard time = 1:30 PM

Now, from cooper relationship,

$$\text{Declination angle, } \delta = 23.45 \times \sin\left[\frac{360}{365}(284+319)\right]$$

$$= -19.147° \qquad \text{...Ans (i)}$$

$$\text{Solar time, ST} = 13 \text{ hr } 30 \text{ min} - 4\,(81.73 - 77.2)$$

$$\text{ST} = 13.198 \text{ hrs.}$$

$$\therefore \quad \text{Hour angle, } \omega = [12:00 - \text{ST}] \times 15 \text{ degrees}$$

$$\omega = [12 - 13.198] \times 15$$

$$\omega = -17.97° \qquad \text{...Ans (ii)}$$

Zenith angle, $\theta_z$

$$\cos\theta_z = \sin\phi\sin\delta + \cos\phi\cos\delta\cos\omega$$

$$\cos\theta_z = \sin(28.7°)\sin(-19.147°) + \cos(28.7°) \times \cos(-19.147°)\cos(-17.97°)$$

or, $\cos\theta_z = 0.63$

or, $\theta_z = 50.89°$ **...Ans (iii)**

Angle of incidence, $\theta_i$ $\cos\theta_i = \sin(\phi - \beta)\sin\delta + \cos(\phi - \beta)\cos\delta\cos\omega$

or $\cos\theta_i = \sin(28.7° - 30°)\sin(-19.147°) + \cos(28.7° - 30)\cos(-19.147)\cos(-17.97°)$

or, $\cos\theta_i = 0.905$

$\therefore$ $\theta_i = 25.17°$ **...Ans (iv)**

Now, number of day light hours

$$t_d = \frac{2}{15} \times \omega_{SR}, \quad \text{where } \omega_{SR} = \text{Hour angle at sunrise}$$

$$\therefore \quad t_d = \frac{2}{15}\cos^{-1}(-\tan(\phi - \beta)\tan\delta)$$

$$t_d = \frac{2}{15}\cos^{-1}(-\tan(28.7° - 30°)\tan(-19.147°))$$

$t_d = 12.06$ hours **...Ans (v)**

**7. (a)**

Here Min $A_i = 3$, Max $B_i = 5$, and $C_i = 5$

$\because$ Min $C_i$ = Max $B_i$, problem can be solved by converting into equivalent problem involving 5 jobs and two fictitious machines X and Y. The resulting table is shown below.

| Job | $X = A_i + B_i$ | $Y = B_i + C_i$ |
|---|---|---|
| 1 | 7 | 11 |
| 2 | 13 | 14 |
| 3 | 8 | 6 |
| 4 | 7 | 8 |
| 5 | 7 | 13 |

Now using Johnson's algorithm, we get the optimal sequence as given below

| | | | | |
|---|---|---|---|---|
| 4 | 1 | 5 | 2 | 3 |

Now, minimum elapsed time can now be calculated, the table using the individual machining time is shown below:

| Jobs | Machine A | | Machine B | | Machine C | |
|---|---|---|---|---|---|---|
| | Time in | Time out | Time in | Time out | Time in | Time out |
| 4 | 0 | 5 | 5 | 7 | 7 | 13 |
| 1 | 5 | 8 | 8 | 12 | 13 | 20 |
| 5 | 8 | 12 | 12 | 15 | 20 | 30 |
| 2 | 12 | 20 | 20 | 25 | 30 | 39 |
| 3 | 20 | 27 | 27 | 28 | 39 | 44 |

From table we get,

Minimum elapsed time = 44 hours **Ans.**

Idle time for machine 'A' = 44 - 27 hours

= 17 hours **Ans.**

Idle time for machine 'B' = 5 + 1 + 5 + 2 + (44 – 28)

= 29 hours **Ans.**

Idle time for machine 'C' = 7 hours **Ans.**

Further, there is no waiting of jobs between machines A and B, the jobs have to wait for loading on machine 'C'.

∴ Waiting of jobs 'C' = 1 + 5 + 5 + 11

= 22 hours **Ans.**

**7. (b)**

**(i)**

Interchangeable manufacturing means the production of complete machines or mechanisms, the corresponding parts of which are so nearly alike that they will fit into any assembly of the same type. This manufacturing produces the parts of the machines with such tolerances that any of the parts will properly function in any of the assembly. It offers standardization and many added advantages.

Combination set is the adaptable and commonly used non-precision instrument used in metrology. The combination set consists of a scale, squaring-head, protractor and center-head. It consists of a heavy scale which is grooved all along its length. It is on this groove that the sliding square head is fitted. One surface of the squaring head is always perpendicular to the scale and it can be adjusted at any place by a locking bolt and nut. The squaring head also contains a spirit level that is used to test the surfaces for parallelism.

Tolerance is the limit of random (unintentional) deviation of a dimension from its nominal value. While allowance is the amount of designed (intentional) deviation between two mating dimensions in a fit which, in combination with their respective tolerances, results into a maximum and minimum clearance or interference. Allowance is the planned deviation between actual dimension and desired dimension. Tolerance is the range of variation permitted in maintaining a specified dimension in a machined piece.

**(ii)**

In hole-basis system, hole size is kept constant while the shaft size is varied to give various type of fit. Basic size is taken as lower limit of hole.

In shaft-basis system, shaft size is constant and hole size is varied to get various types of fit. Basic size is taken as the maximum limit size of the shaft.

Hole basis system is extensively used as holes are drilled using standard drills available in selected different sizes. Therefore, it is difficult to vary the tolerances on hole and shaft sizes are varied to get different possible fits.

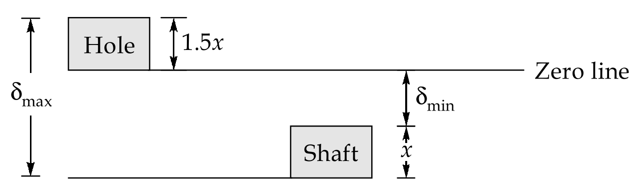
**(iii)**

Given : Basic size = 30 mm, $\delta_{max}$ = 0.06 mm, $\delta_{min}$ = 0.02 mm

$$\text{Let shaft tolerance} = x$$

$$\text{Hole tolerance} = 1.5x$$

**(a) Hole basis system**




$$\delta_{max} = \delta_{min} + x + 1.5x$$

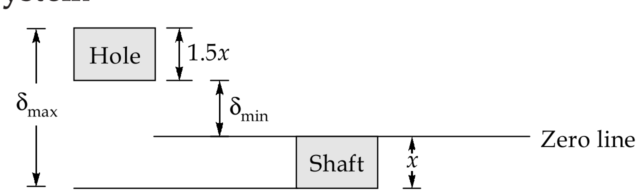
$$0.06 = 0.02 + 2.5x$$

$$x = 0.016 \text{ mm}$$

Hole:
- max size = 30 + 1.5$x$ = 30 + 1.5 (0.016) = 30.024 mm
- min size = 30.00 mm

Shaft:
- max size = 30 – $\delta_{min}$ = 30 – 0.02 = 29.98 mm
- min size = 29.98 – $x$ = 29.98 – 0.016 = 29.964 mm

**(b) Shaft basis system**



$$\delta_{max} = \delta_{min} + 1.5x + x$$
$$0.06 = 0.02 + 2.5x$$
$$x = 0.016 \text{ mm}$$

Hole
- max size = $30 + \delta_{min} + 1.5x$
  $= 30 + 0.02 + 1.5(0.016)$
  $= 30.044$ mm
- min size = $30 + \delta_{min} = 30 + 0.02 = 30.02$ mm

Shaft
- max size = 30 mm
- min size = $30 - x = 30 - 0.016 = 29.984$ mm

**7. (c)**

Given : $\beta = 40°$, $\phi = 30.73°$, $n = 142$ (22nd may), $\rho = 0.4$, $\overline{H}_g = 15275.8 \text{ kJ/m}^2$,

$\overline{H}_d = 3256.7 \text{ kJ/m}^2$

For 22nd may, $n = 142$

$$\delta = 23.45 \times \sin\left(\frac{360}{365}(142 + 284)\right) \text{ degrees}$$
$$\delta = 20.34°$$

Hour angle at sunrises (or sunset) for horizontal surface

$$\omega_{sh} = \pm\cos^{-1}(-\tan\phi\tan\delta)$$
$$\omega_{sh} = 102.73° \text{ or } 1.792 \text{ radians}$$

Hour angle at sunrise (or sunset) at tilted surface

$$\omega_{st} = \pm\min\left[\left|\cos^{-1}(-\tan\phi\tan\delta)\right|, \left|\cos^{-1}(-\tan(\phi-\beta)\tan\delta)\right|\right]$$

$$\omega_{st} = \pm\min\left[\left|\cos^{-1}(-\tan(30.73)\tan(20.34)\right|, \left|\cos^{-1}(-\tan(30.73-40)\tan(20.34)\right|\right]$$

$$\omega_{st} = \pm\min[102.73°, 86.53°]$$

$\therefore$
$$\omega_{st} = 86.53° \text{ or } 1.509 \text{ radians}$$

Now, tilt factor

$$\overline{R}_b = \frac{\omega_{st}\sin\delta\sin(\phi-\beta) + \cos\delta\cos(\phi-\beta)\sin\omega_{st}}{\omega_{sh}\sin\delta\sin\phi + \cos\delta\cos\phi\sin\omega_{sh}}$$

Putting the valves, we get

$$\bar{R}_b = \frac{1.509\sin(20.34°)\sin(30.73° - 40°) + \cos(20.34°)\cos(30.73° - 40°) \times \sin(86.53°)}{1.792\sin(20.34°)\sin(30.73°) + \cos(20.34°)\cos(30.73°) \times \sin(102.73°)}$$

$$\therefore \quad \bar{R}_b = 0.759$$

For diffuse radiation,

$$\bar{R}_d = \frac{1 + \cos 40°}{2} = 0.883$$

For reflected radiation,

$$\bar{R}_r = \frac{\rho(1 - \cos\beta)}{2} = \frac{0.4(1 - \cos 40)}{2} = 0.0467$$

Now, monthly average total daily radiation on tilted surface,

$$\frac{\bar{H}_T}{\bar{H}_g} = \left(1 - \frac{\bar{H}_d}{\bar{H}_g}\right) \times \bar{R}_b + \left(\frac{\bar{H}_d}{\bar{H}_g}\right) \times \bar{R}_d + \bar{R}_r$$

$$\bar{H}_T = 15275.8\left[\left(1 - \frac{3256.7}{15275.8}\right) \times 0.759 + \frac{3256.7 \times 0.883}{15275.8} + 0.0467\right]$$

$$\bar{H}_T = 12711.54 \text{ kJ/m}^2\text{-day}$$ **Ans.**

**8. (a)**

First of all we shall compile a new table of unit costs which consists of both production and transportation costs. The new table or matrix is given below:

| Factories \ Stores | 1 | 2 | 3 | 4 | Production capacity |
|---|---|---|---|---|---|
| A | 2 + 2 | 4 + 2 | 6 + 2 | 11 + 2 | 50 |
| B | 10 + 3 | 8 + 3 | 7 + 3 | 5 + 3 | 70 |
| C | 13 + 1 | 3 + 1 | 9 + 1 | 12 + 1 | 30 |
| D | 4 + 5 | 6 + 5 | 8 + 5 | 3 + 5 | 50 |
| Demand | 25 | 35 | 105 | 20 | |

**Step I :** Make the transportation matrix

Let us again write down the above matrix

| Factories \ Stores | 1 | 2 | 3 | 4 | Production capacity |
|---|---|---|---|---|---|
| A | 4 | 6 | 8 | 13 | 50 |
| B | 13 | 11 | 10 | 8 | 70 |
| C | 14 | 4 | 10 | 13 | 30 |
| D | 9 | 11 | 13 | 8 | 50 |
| Demand | 25 | 35 | 105 | 20 | |

Here total production capacity = 200 units

Total demand = 185 units

Surplus capacity = 15 units

Thus production capacity and demand are not balanced. Therefore, we create a fictitious (dummy) destination (store). The associated cost coefficient are taken as zero.

Therefore our starting cost matrix becomes

**Stores**

| | | 1 | 2 | 3 | 4 | d | Capacity |
|---|---|---|---|---|---|---|---|
| Factories | A | 4 | 6 | 8 | 13 | 0 | 50 |
| | B | 13 | 11 | 10 | 8 | 0 | 70 |
| | C | 14 | 4 | 10 | 13 | 0 | 30 |
| | D | 9 | 11 | 13 | 8 | 0 | 50 |
| Demand | | 25 | 35 | 105 | 20 | 15 | |

**Step II :** Find a basic feasible solution

Using Vogel's approximation method, the initial feasible solution obtained is given below in table.

**Stores**

| | | 1 | 2 | 3 | 4 | d | Capacity |
|---|---|---|---|---|---|---|---|
| Factories | A | 4 (25) | 6 (5) | 8 (20) | 13 | 0 | 50/25/20/0<br>[4] [2] [2] [2] [5] ← |
| | B | 13 | 11 | 10 (70) | 8 | 0 | 70/0<br>[8] [2] [2] [2] [2] [2] ← |
| | C | 14 | (30) 4 | 10 | 13 | 0 | 30/0<br>[4] [6] ← |
| | D | 9 | 11 | 13 (15) | 8 (20) | 0 (15) | 50/35/15/0<br>[8] [1] [1] [3] [5] [5] ← |
| Demand | | 25/0 | 35/5/0 | 105/85/15/0 | 20/0 | 15/0 | |
| | | [5] | [2] | [2] | [0] | [0] | |
| | | [5] | [2] | [2] | [0] | | |
| | | [5] | [5] | [2] | [0] | | |
| | | ↑ | [5] | [2] | [0] | | |
| | | | ↑ | [2] | [0] | | |
| | | | | [3] | [0] | | |

**Step III :** Perform optimality test

From the above matrix we find that

(a) Number of allocations = $m + n - 1 = 4 + 5 - 1 = 8$

(b) These $m + n - 1$ allocations are in independent positions

Therefore optimality test can be performed.

**Substep 1 :** Setup the cost matrix containing costs associated with cells for which allocations have been made:

| | $V_1$ | $V_2$ | $V_3$ | $V_4$ | $V_5$ |
|---|---|---|---|---|---|
| $u_1$ | 4 | 6 | 8 | · | · |
| $u_2$ | · | · | 10 | · | · |
| $u_3$ | · | 4 | | | |
| $u_4$ | | | 13 | 8 | 0 |

**Substep 2 :** Enter a set of number $U_i$ and $V_J$ such that

$$U_1 + V_1 = 4, \quad U_3 + V_2 = 4, \quad U_4 + V_5 = 0$$
$$U_1 + V_2 = 6, \quad U_4 + V_3 = 13, \quad U_2 + V_3 = 10$$
$$U_1 + V_3 = 8, \quad U_4 + V_4 = 8$$

Let $V_1 = 0$, then

$$U_1 = 4, V_2 = 2, V_3 = 4, U_3 = 2,$$
$$U_4 = 9, V_4 = -1, V_5 = -9, U_2 = 6$$

**Substep 3 :** Fill up the vacant cells also. The resulting matrix is shown in table below.

| $u_i$ \ $V_J$ | $V_1 = 0$ | $V_2 = 2$ | $V_3 = 4$ | $V_4 = -1$ | $V_5 = -9$ |
|---|---|---|---|---|---|
| $u_1 = 4$ | | | | 3 | –5 |
| $u_2 = 6$ | 6 | 8 | | 5 | –3 |
| $u_3 = 2$ | 2 | | 6 | 1 | –7 |
| $u_4 = 9$ | 9 | 11 | | | |

**Substep 4 :** Subtract the cell values of the above matrix from the original cost matrix. The resulting matrix is shown below:

| | | | | |
|---|---|---|---|---|
| · | · | · | 10 | 5 |
| 7 | 3 | | 3 | 3 |
| 12 | | 4 | 12 | 7 |
| 0 | 0 | | | |

Since cell values are non-negative, the first feasible solution is optimal. Since matrix contains zero entries, there exist alternate optimal solutions.

∴ The optimum transportation plus production cost is

$$2 = ₹\,(4 \times 25 + 6 \times 5 + 8 \times 20 + 10 \times 70 + 4 \times 30 + 13 \times 15 + 8 \times 20 + 0 \times 15)$$
$$= ₹\,(100 + 30 + 160 + 700 + 120 + 195 + 160 + 0)$$
$$= ₹\,1465$$

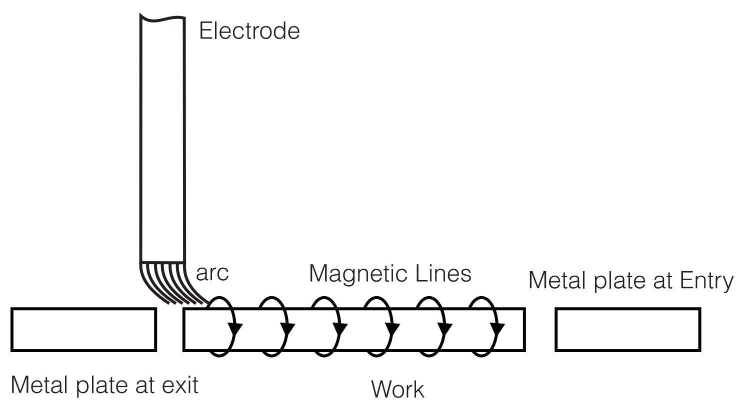
**Ans.**

8. (b)

(i)

(a) **Dip transfer in GMAW :** In dip transfer or short circuiting, the metal is transferred in individual droplets, more than 50 per second as the electrode tip touches the molten weld metal and short-circuits. Low current and voltages are utilized, with $CO_2$ rich gases and small diameter electrodes. The temperature generated are low and is suitable for thin sheets and sections.

(b) **Arc Blow :** Due to fixed polarity magnetic lines form in the work piece material. Upon welding at the center of the work magnetic lines will be equally distributed on both sides. So arc will be straight. But while welding near the edges, since most of the magnetic lines will be concentrated in the material, arc will be deflected towards the workpiece. This phenomenon is called Arc Blow which results in severe spatter and improper bead geometry.



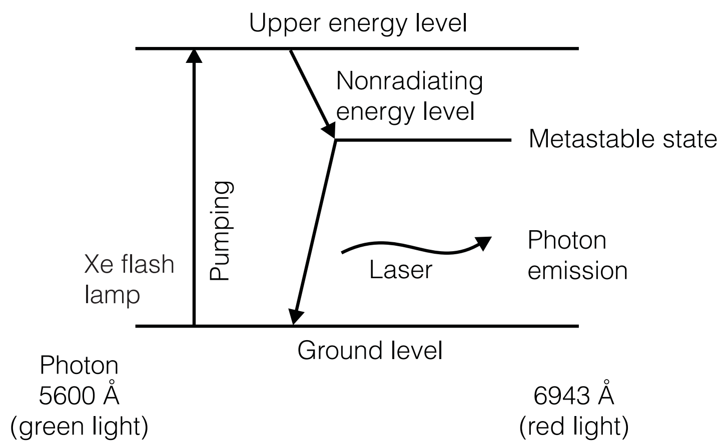

***Arc blow due to magnetic field***

Arc Blow phenomenon will be more intensified while welding with DC with bare electrodes. To avoid this phenomenon metal plates are kept at the entry and at the exit called Tab in and Tab out. These plates also minimize the end defects. Arc Blow phenomenon may also appear when large piece of iron is present at the welding site.

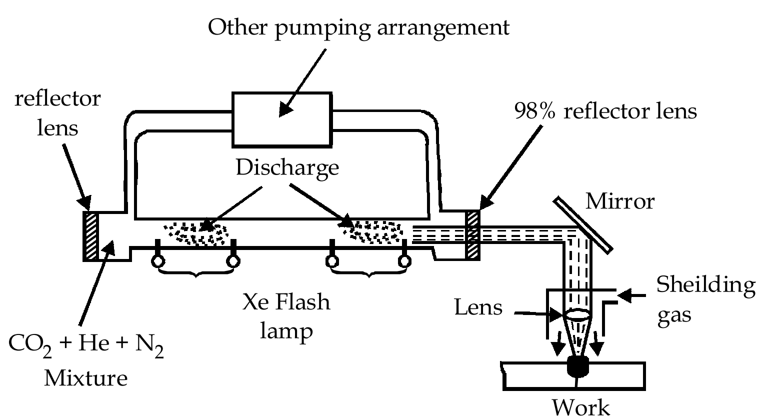
(c) **Key holing in laser welding :** Keyhole mode heating in laser welding achieves its weld penetration in a different way. During keyhole mode welding the power density is great enough that the metal goes beyond just melting, it vaporises. The vaporising metal creates expanding gas that pushes outward. This creates a keyhole from the surface down to the depths of weld.

(ii)

**Laser Beam Welding :** In laser welding a concentrated coherent light beam impinges at the desired spot to melt and weld the metal. Atoms from the ground level are pumped to high energy level with the help of primarily Xenon lamp. From the high energy level atom comes automatically to metastable state and once there is sufficient population inversion, atoms come to the ground level by emitting a bundle of energy called photon. These photons will be directed back and forth in the lasing tube. 98% reflecting lens means photons will not be allowed to come out, unless they are horizontal. Laser beam can be converged to a point. Laser emission is obtained when the upper level is sufficiently populated at the expense of lower level. Such a state is known as population inversion and the method obtained is called pumping. Laser beam welding is more versatile than the electron beam welding because welding is possible in air, through a transparent medium and along a profile.




*(a) Principle of laser emission*




*(b) Set up of $CO_2$ Laser beam welding*

The most useful laser for welding is the laser in which the lasing medium is mixture of $CO_2$, nitrogen, and helium in the ratio of 1: 1: 10 at a pressure of 20 to 50 mm of mercury. A laser consists of a glass tube in which the lasing gas mixture flows. There is one electrode at each of the two ends between which a high voltage discharge is set up.

There is one reflector at each of the ends. The space between the two reflectors is called laser cavity. The laser beam emitted through the semi reflecting surface is focused to the desired spot. For industrial purposes the lasing material often used is ruby. Ruby is aluminium oxide with chromium atoms to the extent of 0.05%. The application of this is in radio engineering, electronics, welding copper and Aluminium alloys etc

**8. (c)**

Hydraulic energy required per day to lift water = $mgh$

$$= 10^3 \times 8 \times 9.81 \times 45$$

$$= 3531600 \text{ Joules}$$

or $$\text{Power} = \frac{3531600}{3600} \text{ Wh}$$

$$P = 981 \text{ Wh}$$

$\therefore$ Required output in 5 hours, $P_0 = \frac{981}{5} = 196.2$ W

Thus, actual output required, $(P_0)_{act} = \frac{196.2}{0.3} = 654$ W

Required panel power considering losses $= \frac{654}{0.8 \times 0.85} = 961.76$ W

$\therefore$ Power obtained from one PV module $= V_P \cdot I_P$

$$= 20 \times 8$$

$$= 160 \text{ W}$$

$\therefore$ Required number of PV module, $n = \frac{961.76}{160} = 6.011$

$n$ = 6 modules required **Ans.**

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