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Civil Services Main Examination Previous Solved Papers : Mechanical Engg. (Paper-II)

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Preface

Civil Service is considered as the most prestigious job in India and it has become a preferred destination by all engineers. In order to reach this estimable position every aspirant has to take arduous journey of Civil Services Examination (CSE). Focused approach and strong determination are the pre-requisites for this journey. Besides this, a good book also comes in the list of essential commodity of this odyssey.



I feel extremely glad to launch the revised edition of such a book which will not only make CSE plain sailing, but also with 100% clarity in concepts.

MADE EASY team has prepared this book with utmost care and thorough study of all previous years papers of CSE. The book aims to provide complete solution to all previous years questions with accuracy.

On doing a detailed analysis of previous years CSE question papers, it came to light that a good percentage of questions have been asked in Engineering Services, Indian Forest Service and State Services exams. Hence, this book is a one stop shop for all CSE, ESE, IFS and other competitive exam aspirants.

I would like to acknowledge efforts of entire MADE EASY team who worked day and night to solve previous years papers in a limited time frame and I hope this book will prove to be an essential tool to succeed in competitive exams and my desire to serve student fraternity by providing best study material and quality guidance will get accomplished.

With Best Wishes

B. Singh (Ex. IES)

CMD, MADE EASY Group

Previous Years Solved Papers of
Civil Services Main Examination

Mechanical Engineering : Paper-II

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1

Thermodynamics

1. Basic Concepts, Heat and Work

Q.1 A rigid insulated tank of 3 m³ volume is divided into 2 compartments. One compartment of volume 1 m³ contains an ideal gas at 0.1 MPa and 300 K while the second compartment of volume 2 m³ contains the same gas at 1 MPa and 1000 K. If the partition between the two compartments is ruptured, calculate the final temperature and pressure of the gas.

[CSE (Mains) 2002 : 20 Marks]

Solution:

Consider the gas contained in 2 compartments *A* and *B* of the rigid tank.

Assumption:

1. Ideal gas behaviour, 2. Rigid tank, 3. Insulated tank

Let the final temperature and pressure of gas after partition is removed be *T* and *P*, respectively.

$$m_A = \frac{P_A V_A}{RT_A} = \frac{0.1 \times 1}{R \times 300} = \frac{1}{3000R}$$

and

$$m_B = \frac{P_B V_B}{RT_B} = \frac{1 \times 2}{R \times 1000} = \frac{1}{500R}$$

$$\Rightarrow \frac{m_A}{m_B} = \frac{1}{6}$$

$$\Rightarrow m_B = 6m_A$$

Comparing final and initial states,

(A)	(B)
Ideal gas	Ideal gas
1 m ³ , 0.1 MPa	2 m ³ , 1 MPa
300 K	1000 K

$$R = \frac{P_A V_A}{m_A T_A} = \frac{P(V_A + V_B)}{(m_A + m_B)T}$$

$$\frac{0.1 \times 1}{m_A \times 300} = \frac{P \times 3}{7m_A \times T}$$

$$\text{or } \frac{P}{T} = \frac{7}{9000}$$

Heat lost by one compartment = Heat gained by other compartment

$$\therefore m_A c_v (T - 300) = m_B c_v (1000 - T)$$

$$m_A (T - 300) = 6 m_A (1000 - T)$$

$$T - 300 = 6000 - 6T$$

$$\text{or } T = \mathbf{900 \text{ K}}$$

$$\therefore P = \frac{7 \times T}{9000} = \frac{7}{9000} \times 900 = \mathbf{0.7 \text{ MPa}}$$

- Q.2 A mass of air initially at 760 kPa and 250°C occupies 0.026 m³. The air is expanded at constant pressure to 0.07 m³. A polytropic process with $n = 1.52$ is then carried out followed by an isothermal process and the cycle is thus completed. Assuming all the processes to be reversible,
- show all the processes on $P-V$ and $T-S$ planes
 - compute the heat received and rejected in the cycle
 - calculate the efficiency of the cycle.

[CSE (Mains) 2002 : 30 Marks]

Solution:Processes can be represented on $P-V$ and $T-S$ diagram as shown in figure.**State 1:** $P_1 = 760$ kPa, $T_1 = 250^\circ\text{C} = 523$ K and $V_1 = 0.026$ m³

$$m = \frac{P_1 V_1}{RT_1} = \frac{760 \times 0.026}{0.287 \times 523} = 0.1316 \text{ kg}$$

State 2: $P_2 = P_1 = 760$ kPa, $V_2 = 0.07$ m³

$$\frac{P_2 V_2}{T_2} = \frac{P_1 V_1}{T_1}$$

or

$$T_2 = \frac{V_2}{V_1} T_1 = 1408.08 \text{ K}$$

State 3: $T_3 = T_1 = 523$ K**Process 1-2:**

$$\text{Heat transfer, } Q_{1-2} = mc_p(T_2 - T_1) = 0.1316 \times 1.005 \times (1408.08 - 523) = 117.098 \text{ kJ}$$

$$\text{Work done, } W_{1-2} = P_1(V_2 - V_1) = 760 \times (0.07 - 0.026) = 33.44 \text{ kJ}$$

Process 2-3: Work done in polytropic process,

$$W_{2-3} = \frac{P_2 V_2 - P_3 V_3}{n-1} = \frac{mR(T_2 - T_3)}{n-1} = \frac{0.1316 \times 0.287 \times (1408.08 - 523)}{1.52 - 1} = 64.28 \text{ kJ}$$

$$\text{Heat transfer in a polytropic process, } Q_{2-3} = \left(\frac{\gamma - n}{\gamma - 1} \right) \times W_{2-3} = \left(\frac{1.4 - 1.52}{1.4 - 1} \right) \times 64.31 = -19.29 \text{ kJ}$$

Process 3-1: Work done in isothermal process,

$$W_{3-1} = mRT \ln \left(\frac{V_1}{V_3} \right)$$

For polytropic process 2-3,

$$T_3 V_3^{n-1} = T_2 V_2^{n-1}$$

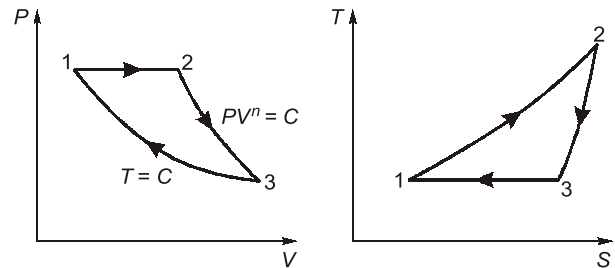
$$\text{or } V_3 = V_2 \left(\frac{T_2}{T_3} \right)^{\frac{1}{n-1}} = 0.07 \times \left(\frac{1408.08}{523} \right)^{\frac{1}{1.52-1}} = 0.47 \text{ m}^3$$

$$\therefore W_{3-1} = 0.1316 \times 0.287 \times 523 \times \ln \left(\frac{0.026}{0.47} \right) = -57.18 \text{ kJ}$$

For an ideal gas internal energy change for an isothermal process = 0.

 \therefore From 1st law of thermodynamics,

$$Q = \Delta U + W = 0 + W$$



$$\Rightarrow Q_{3-1} = W_{3-1} = -57.18 \text{ kJ}$$

∴ Total heat transfer in the cycle

Heat received, $Q_{1-2} = 117.098 \text{ kJ}$

Heat rejected, $Q_{3-1} + Q_{2-3} = 76.47 \text{ kJ}$

Net work output, $W_{\text{net}} = W_{1-2} + W_{2-3} + W_{3-1} = 33.44 + 64.31 - 57.18 = 40.57 \text{ kJ}$

∴ Efficiency of cycle, $\eta = \frac{\text{Net work output}}{\text{Net heat supplied}} = \frac{W_{\text{net}}}{Q_{1-2}} = \frac{40.57}{117.098} = 0.3465 = 34.65\%$

Q.3 A pressure vessel is connected, via a valve, to a gas main in which gas is maintained at a constant pressure and temperature of 1.4 MN/m^2 and 85°C respectively. The pressure vessel is initially evacuated. The valve is opened and a mass of 2.7 kg of gas passes into the pressure vessel. The valve is closed and the pressure and temperature of the gas in the pressure vessel are then 700 kN/m^2 and 60°C , respectively. Determine the heat transfer to or from the gas in the vessel. Determine the volume of gas before transfer.

For the gas, take $c_p = 0.88 \text{ kJ/kgK}$, $c_v = 0.67 \text{ kJ/kgK}$. Neglect the velocity of the gas in the main.

[CSE (Mains) 2004 : 30 Marks]

Solution:

Consider the pressure vessel and main connected by a valve as shown in figure.

Gas flows inside the vessel initially evacuated. Consider control volume as shown in figure.

Applying conservation of energy for variable flow process of this control volume,

$$\begin{aligned} \text{Rate of change of energy} &= \frac{dE_v}{d\tau} \\ &= \text{Rate of inflow of energy} - \text{Rate of outflow of energy} \end{aligned}$$

$$\Rightarrow \frac{dE_v}{d\tau} = h_p \frac{dm}{d\tau} + \frac{\delta Q}{d\tau}$$

$$\Rightarrow \frac{du}{d\tau} = h_p \frac{dm}{d\tau} + \frac{\delta Q}{d\tau} \quad (\text{since velocity of pipe is negligible})$$

Integrating, we get, $m_2 u_2 - m_1 u_1 = h_p (m_2 - m_1) + Q$

Initial mass of gas in control volume, $m_1 = 0$

Final mass of gas in control volume, $m_2 = 2.7 \text{ kg}$

∴ Heat transfer to or from pressure vessel,

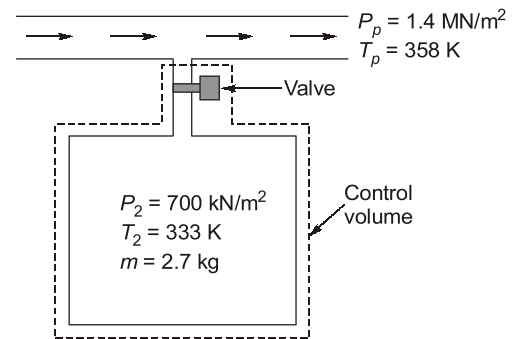
$$\begin{aligned} Q &= m_2 u_2 - m_2 h_p = m_2 [c_v T_2 - c_p T_p] = 2.7 [0.67 \times 333 - 0.88 \times 358] \\ &= -248.211 \text{ kJ} \end{aligned}$$

∴ 248.21 kJ of heat is lost from the pressure vessel. Assume initial volume of gas in pipe before transfer is V_p . Since the gas can be assumed to follow ideal gas behaviour,

$$\frac{P_p V_p}{T_p} = \frac{P_2 V_2}{T_2} = mR = m(c_p - c_v)$$

or $V_p = \frac{T_p}{P_p} m(c_p - c_v) = \frac{358 \times 2.7 \times (0.88 - 0.67)}{1.4 \times 10^3} = 0.145 \text{ m}^3$

Hence, volume of gas before filling is 0.145 m^3 .



$$\therefore \text{Mass of water} = \frac{V_1}{v_1} = \frac{1}{0.001895} = 527.704 \text{ kg}$$

Initial internal energy of the water, $u_1 = 1726.6 \text{ kJ/kg}$ (using steam table)

Applying 1st law of thermodynamics considering containment room as system:

$$\delta q = du + \delta w$$

$$\Rightarrow du = 0$$

$$\Rightarrow u_2 - u_1 = 0$$

$$\Rightarrow u_2 = u_1 = 1726.6 \text{ kJ/kg}$$

Now, at 200 kPa, using steam table:

$$u_f = 504.50 \text{ kJ/kg}$$

$$u_{fg} = 2024.6 \text{ kJ/kg}$$

$$u_g = 2529.1 \text{ kJ/kg}$$

$$\therefore u_2 = u_f + xu_{fg}$$

$$\Rightarrow 1726.6 = 504.5 + x \times 2024.6$$

$$\Rightarrow x = 0.603$$

$$\begin{aligned} \text{Now, } v_2 &= v_f + xv_{fg} \\ &= 0.001061 + 0.603 \times (0.88578 - 0.001061) \\ &= 0.535 \text{ m}^3/\text{kg} \end{aligned}$$

$$\begin{aligned} \text{So, minimum volume of room} &= m \times v_2 \\ &= 527.704 \times 0.535 = 282.374 \text{ m}^3 \end{aligned}$$



2

Fluid Mechanics

1. Fluid Kinematics

Q.1 With the help of a neat sketch explain the concept of a flow net. Clearly mention the various assumptions made. Also explain the uses of flow net. [CSE (Mains) 2012 : 12 Marks]

Solution:

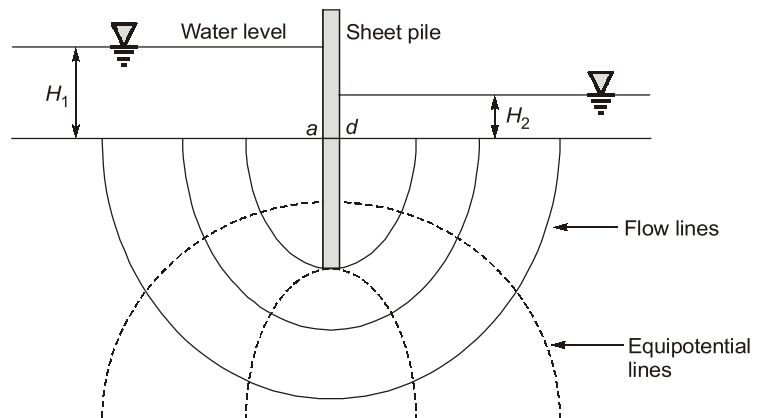
Flow Net: A grid obtained by drawing a series of equipotential lines and stream lines is called a flow net. The flow net is an important tool in analysing two-dimensional irrotational flow problems.

Uses of flow net:

1. Estimation of seepage loss from reservoir: It is possible to use the flow net in the transformed space to calculate the flow underneath the dam.
2. Determination of uplift pressures below dams: From the flow net, the pressure head at any point at the base of the dam can be determined. The uplift pressure distribution along the base can be drawn and then summed up.
3. Checking the possibility of piping beneath dams.

Assumptions:

1. Flow lines and equipotential lines intersect each other at 90 degrees.
 2. The areas bounded by the flow lines and equipotential lines form approximate squares.
 3. Flow nets must satisfy the boundary conditions of flow field.
 4. The potential drop in any two consecutive equipotential lines is same/constant.
 5. Flow lines and equipotential lines are smooth curves.
 6. Flow lines do not show refraction at the interface between two soils having different coefficient of permeability.
- Flow Nets : Flow around sheet pile wall.



2. Fluid Dynamics

Q.1 Write Bernoulli's equation and the conditions for which it is valid. If a fluid obeying Bernoulli's equation has elevation, velocity and pressure at a point as 30 m, 50 m/s and 50 bar respectively, calculate the total energy per unit mass of this fluid if its density is 1000 kg/m³.

[CSE (Mains) 2013 : 10 Marks]

Solution:

Bernoulli's equation is obtained by integrating the Euler's equation of motion as,

$$\int \frac{dp}{\rho} + \int g dz + \int V dV = \text{constant}$$

$$\frac{p}{\rho g} + z + \frac{V^2}{2g} = \text{constant}$$

where,

$$\frac{p}{\rho g} = \text{Pressure energy per unit weight of fluid or pressure head.}$$

$$\frac{V^2}{2g} = \text{Kinetic energy per unit weight of fluid or kinetic head}$$

$$z = \text{Potential energy per unit weight of fluid or potential head}$$

Assumptions:

Following are the assumptions made in the derivation of the Bernoulli's equation:

1. The flow is incompressible
2. The flow is irrotational
3. The flow is steady
4. The fluid is ideal i.e. viscosity is zero.

Given: $z = 30 \text{ m}$, $V = 50 \text{ m/s}$, $p = 50 \text{ bar} = 50 \times 10^3 \text{ N/m}^2$, $\rho = 1000 \text{ kg/m}^3$

$$\begin{aligned} \text{Total energy per unit mass} &= \frac{p}{\rho} + \frac{V^2}{2} + gz = \frac{50 \times 10^3}{1000} + \frac{(50)^2}{2} + 9.81 \times 30 \\ &= 50 + 1250 + 294.3 = 1594.3 \text{ J/kg} \end{aligned}$$

Q.2 Water is pumped from the basement tank of a multistorey building to the terrace tank by a 20 kW motor. The free surface of the terrace tank is 45 m higher than the basement tank. If the flow rate of water is $0.03 \text{ m}^3/\text{s}$, determine the mechanical power that is converted to thermal energy during the process due to friction effect. Write the assumptions made in the calculation.

[CSE (Mains) 2019 : 10 Marks]

Solution:

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

Ideal power required to pump the water,

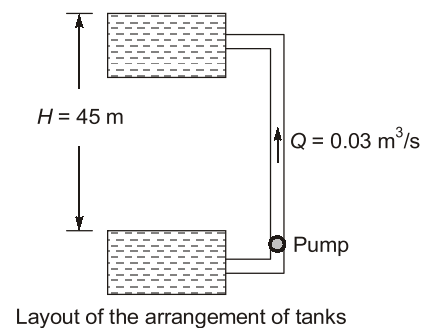
$$\begin{aligned} P_{\text{ideal}} &= \rho g Q H \\ &= 10^3 \times 9.81 \times 0.03 \times 45 \\ &= 13.24 \text{ kW} \end{aligned}$$

∴ Mechanical power converted to thermal energy due to friction,

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

Assumptions made:

- (i) Height between free surfaces of water of the two tanks remain constant i.e. 45 m.
- (ii) Velocity changes are negligible.
- (iii) Mechanical efficiency of the motor and hydraulic efficiency of the pump is 100%.



Q.3 A 45° reducing pipe-bend in a horizontal plane, tapers from 600 mm diameter at inlet to 300 mm diameter at outlet. The gauge pressure at inlet is 140 kPa and the rate of flow of water through the bend is $0.425 \text{ m}^3/\text{s}$. Neglecting friction, calculate the net resultant horizontal force exerted by the water on the bend.

[CSE (Mains) 2019 : 20 Marks]

3

Heat Transfer

1. Conduction

Q.1 Heat is transferred along the axis of a truncated conical cylinder of length l , radius r_1 at the shorter end and radius r_2 at the bigger end. The circumference of the cylinder is completely insulated. Develop an expression to calculate heat transfer along the axis of cylinder. Assume no variation of conductivity with temperature.

[CSE (Mains) 2002 : 20 Marks]

Solution:

Consider a frustum of constant thermal conductivity (k) and apex at 0.

Consider an element of thickness dx at a distance x from the apex.

From similar triangle property.

$$\text{Radius of this element, } r = \left(\frac{r_2 - r_1}{l} \right) x = Cx$$

where,

$$C = \frac{r_2 - r_1}{l}$$

$$\text{Area of this element} = \pi r^2 = \pi C^2 x^2$$

Heat transfer rate through this element,

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

$$\Rightarrow \frac{dx}{A} = \frac{-k}{Q} dT$$

Integrating both sides, we get

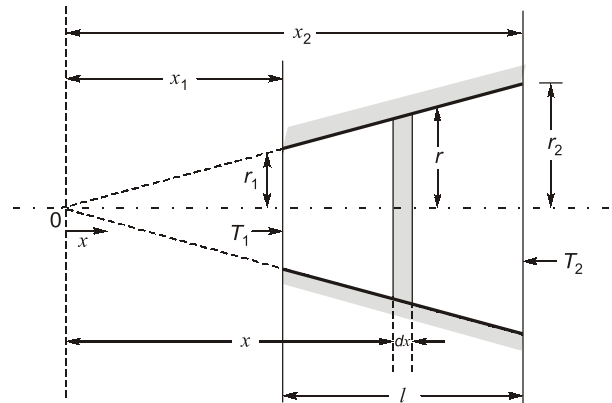
$$\int_{x_1}^{x_2} \frac{dx}{\pi C^2 x^2} = \frac{-k}{Q} \int_{T_1}^{T_2} dT$$

$$\Rightarrow \frac{1}{\pi C^2} \cdot \left[\frac{1}{x_1} - \frac{1}{x_2} \right] = \frac{k}{Q} (T_1 - T_2)$$

$$\text{Also, } r_1 = Cx_1 \text{ and } r_2 = Cx_2$$

$$\Rightarrow \frac{1}{\pi C^2} \left[\frac{C}{r_1} - \frac{C}{r_2} \right] = \frac{k}{Q} (T_1 - T_2)$$

$$\therefore \text{Heat transfer rate, } Q = \frac{T_1 - T_2}{\frac{1}{\pi k C} \left[\frac{1}{r_1} - \frac{1}{r_2} \right]} = \frac{T_1 - T_2}{\frac{l}{\pi k (r_2 - r_1)} \cdot \left[\frac{1}{r_1} - \frac{1}{r_2} \right]} = \frac{T_1 - T_2}{\left(\frac{l}{\pi k r_1 r_2} \right)}$$



Q.2 A spherical thermocouple of 2.5 mm diameter is used to measure the temperature of air flowing in a pipe. Initially both the thermocouple and the air are at a temperature of 30°C. The air is heated to a temperature of 235°C and maintained at this temperature. Find the time required for the thermocouple to reach 200°C. Also find out the time constant of the thermocouple and comment on the suitability of this thermocouple to measure unsteady state temperature. For thermocouple material take: density = 9000 kg/m³, specific heat = 0.4 kJ/kgK and thermal conductivity = 30 W/mK. Convective heat transfer coefficient between thermocouple surface and the air is 120 W/m²K.

[CSE (Mains) 2002 : 30 Marks]

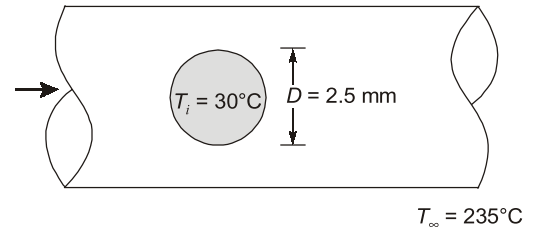
Solution:

Assumptions

1. Constant thermal properties
2. No radiation losses

Consider the spherical thermocouple as shown in figure

Given: $T_i = 30^\circ\text{C}$, $T_f = 200^\circ\text{C}$, $T_\infty = 235^\circ\text{C}$.



$$\text{Biot number of sphere, } Bi = \frac{h L_c}{k}$$

$$\text{For a sphere, characteristic length, } L_c = \frac{\text{Vol.}}{A} = \frac{R}{3}$$

$$\therefore Bi = \frac{120 \times (0.0025 / 2)}{30 \times 3} = 1.67 \times 10^{-3}$$

Since $Bi < 0.1$, entire body can be considered as lumped.

Consider heat exchanged between air and resultant increase in internal energy of sphere, we get

$$mc_p dT = h A_s (T_\infty - T) dt$$

$$\Rightarrow \frac{dT}{T - T_\infty} = -\frac{h A_s}{\rho(\text{Vol.})c_p}$$

Integrating both sides, we get

$$\int_{T_i}^{T_f} \frac{dT}{T - T_\infty} = -\frac{h A_s}{\rho(\text{Vol.})c_p} \int_0^t dt$$

$$\Rightarrow \ln\left(\frac{T_f - T_\infty}{T_i - T_\infty}\right) = \left(-\frac{h A_s}{\rho(\text{Vol.})c_p}\right) \cdot t = -\left(\frac{t}{\frac{\rho(\text{Vol.})c_p}{h A_s}}\right)$$

$$\Rightarrow \ln\left(\frac{T_f - T_\infty}{T_i - T_\infty}\right) = -\frac{t}{\tau} \quad \text{where, } \tau = \text{time constant}$$

$$\text{Time constant in this case, } \tau = \frac{\rho(\text{Vol.})c_p}{h A_s} = 9000 \times \left(\frac{0.0025}{3 \times 2}\right) \times \frac{0.4 \times 10^3}{120} = 12.5 \text{ seconds}$$

Time required by sphere to reach 200°C,

$$t = -\tau \cdot \ln\left(\frac{T_f - T_\infty}{T_i - T_\infty}\right) = -12.5 \times \ln\left(\frac{200 - 235}{30 - 235}\right) = 22.095 \text{ seconds}$$

For measuring unsteady state temperature, the thermocouple should takes least amount of time to reach environment temperature, T_f . Hence the value of time constant should be as small as possible.

In this case, if the temperature of system changes faster than the time required for thermocouple to reach that temperature, then thermocouple cannot be used for temperature measurement. If temperature of air changes from 235°C before 22.1 seconds, it is not a good measuring device.

Not suitable for measuring unsteady state temperature because in unsteady state temperature changes every second while here time constant is as large as 12.5 seconds.

4

Internal Combustion Engines

1. Basics of I.C. Engines and Air Standard Cycles

Q.1 A three litre V 6 S.I. engine operates on a four stroke cycle at 3600 rpm. The compression ratio is 9.5, the length of the connecting rod is 16.6 cm and the engine is square (bore = stroke). At this speed, the combustion ends at 20° ATDC. Calculate:

- (i) cylinder bore and stroke length
- (ii) average piston speed
- (iii) clearance volume of one cylinder
- (iv) piston speed at the end of combustion
- (v) distance the piston has travelled from TDC at the end of combustion.
- (vi) volume in the combustion chamber at the end of combustion.

[CSE (Mains) 2001 : 30 Marks]

Solution:

Given: Swept volume, $V_s = 3 \times 10^{-3} \text{ m}^3$, Number of cylinders, $k = 6$, Speed, $N = 3600 \text{ rpm}$, Compression ratio, $r = 9.5$,

$$(i) \quad \text{Swept volume per cycle} = \frac{\text{Total swept volume}}{\text{Number of cylinders}} = \frac{V_s}{k}$$

$$V_{s, \text{ per cyl}} = \frac{V_s}{6} = \frac{3 \times 10^{-3}}{6} \text{ m}^3 = \frac{\pi}{4} D^2 \times L$$

$$\frac{3 \times 10^{-3}}{6} = \frac{\pi}{4} D^3 \quad (\because D = L)$$

$$\Rightarrow D = L = 0.086 = 8.6 \text{ cm; crank radius} = r_{cr}$$

$$r_{cr} = \frac{L}{2} = 4.3 \text{ cm}$$

$$(ii) \quad \text{Average piston speed, } \bar{V}_p = \frac{2 \times L \times N}{60}$$

$$= 2 \times 0.086 \times \frac{3600}{60} = 10.32 \text{ m/s}$$

$$(iii) \quad r_c = 9.5 = \frac{V_s + V_c}{V_c}$$

$$\Rightarrow V_{c, \text{ per cylinder}} = 59 \text{ cm}^3$$

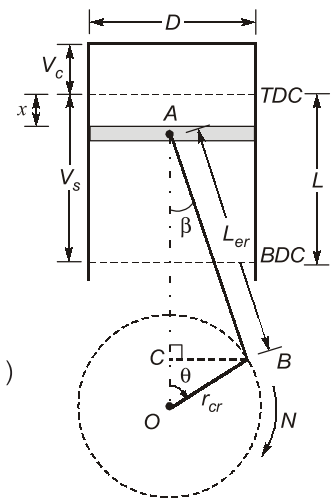
$$V_{c, \text{ total}} = V_{c, \text{ per cylinder}} \times 6 = 354 \text{ cm}^3$$

$$(iv) \quad x = (L_{cr} + r_{cr}) - [r_{cr} \cos \theta + L_{cr} \cos \beta] \dots (1)$$

$$n = \frac{L_{cr}}{r_{cr}} = 3.86$$

$$\omega = 2\pi \frac{N}{60} = 2\pi \times \frac{3600}{60} = 120 \pi \text{ rad/s}$$

$$\sin \beta = \frac{\sin \theta}{n} = \frac{\sin \theta}{3.86}$$



At $\theta = 20^\circ, \beta = 5.083^\circ$

$$x = (L_{cr} + r_{cr}) - [r_{cr} \cos \theta + L_{cr} \cos \beta]$$

$$= (L_{cr} + r_{cr}) - \left[r_{cr} \cos \theta + L_{cr} \frac{\sqrt{n^2 - \sin^2 \theta}}{n} \right]$$

$$= (L_{cr} + r_{cr}) - r_{cr} \left[\cos \theta + \sqrt{n^2 - \sin^2 \theta} \right]$$

$$V_p = \frac{dx}{dt} = -r \left[-\sin \theta + \frac{1}{2\sqrt{n^2 - \sin^2 \theta}} (-2 \sin \theta \cos \theta) \right] \omega$$

$$= r_{cr} \left[\sin \theta + \frac{\sin \theta \cos \theta}{\sqrt{n^2 - \sin^2 \theta}} \right] \quad \dots(2)$$

At $\theta = 20^\circ$

$$V_p = 6.89 \text{ m/s}$$

(v) Distance from TDC,

From equation (1),

$$x = [16.6 + 4.3] - [4.3 \cos 20^\circ + 16.6 \cos 5.083^\circ] = 0.3246 \text{ cm}$$

(vi) Volume in the combustion chamber at the end of combustion

$$V = V_C + \frac{\pi}{4} D^2 x = 59 + \frac{\pi}{4} (8.6)^2 \times 0.3246$$

⇒

$$V = 77.9 \text{ cm}^3$$

Q.2 Define scavenging efficiency trapping efficiency and scavenge factor in two stroke IC engines. Develops a relationship between them.

[CSE (Mains) 2002 : 20 Marks]

Solution:

Scavenging is a process where the exhaust gases are swept out of combustion chamber by the incoming fresh fuel air mixture. Perfect scavenging, which involves sweeping entire combustion products by inlet charge is not possible and some fresh charge is always lost from outlet part.

Define:

V_{del} = Air delivered to the combustion chamber

V_{ret} = Retained air/mixture in the cylinder

V_{short} = Mixture which leaves cylinder no exhaust port.

V_{ch} = Cylinder charge, comprising of retained mixture (V_{ret}) and residual gases (V_{res})

$$\text{Scavenging efficiency, } \eta_{sc} = \frac{V_{ret}}{V_{ch}} = \frac{V_{ret}}{V_{ret} + V_{res}}$$

η_{sc} represents measure of success in cleaning cylinder of residual gases from preceding cycle.

$$\text{Trapping efficiency, } \eta_{trap} = \frac{V_{ret}}{V_{del}}$$

η_{trap} indicates that fraction of fresh air/mixture supplied to the cylinder which is retained in the cylinder, the rest being wasted through the exhaust.

Q.3 The brake thermal efficiency of a diesel engine is 30%. If the air to fuel ratio by weight is 20 and the calorific value of fuel is 41800 kJ/kg, find brake mean effective pressure at S.T.P. (15°C and 760 mm of Hg).

[CSE (Mains) 2003 : 20 Marks]

1. Economics of Power Generation

Q.1 A power generating station has a maximum demand of 20 MW. The daily load on the station is as follows:

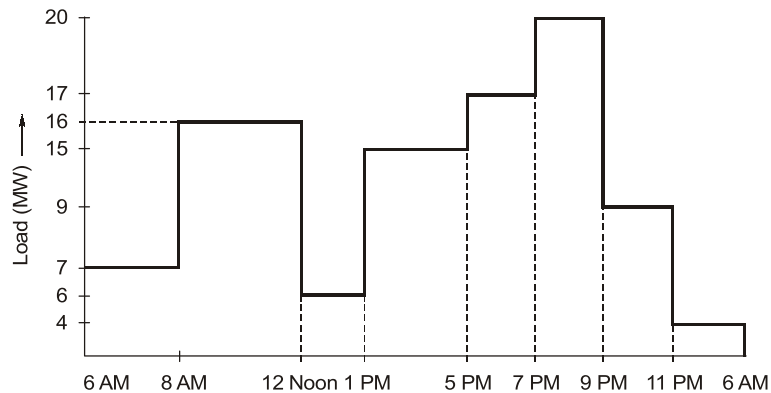
- (i) Draw the load curve and load duration curve for the plant.
- (ii) Decide the capacity and number of units.
- (iii) Prepare the operating schedule of the units.
- (iv) Determine the load factor, plant capacity factor and plant use factor of the station.

Time	Load, MW
6 AM to 8 AM	7
8 AM to 12 NOON	16
12 NOON to 1 PM	6
1 PM to 5 PM	15
5 PM to 7 PM	17
7 PM to 9 PM	20
9 PM to 11 PM	9
11 PM to 6 AM	4

[CSE (Mains) 2001 : 30 Marks]

Solution:

(i)

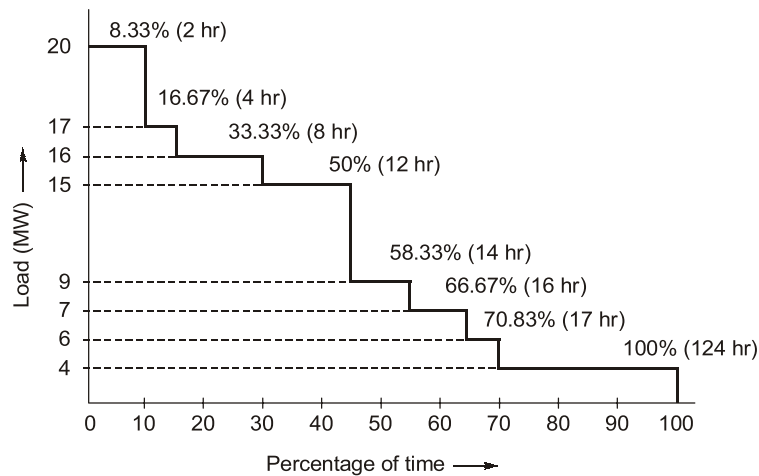


Load Curve

(ii)

Load	Hours in a day	%time
20 MW	2	8.33
17 MW	2 + 2 = 4	16.67
16 MW	2 + 2 + 4 = 8	33.33
15 MW	2 + 2 + 4 + 4 = 12	50
9 MW	2 + 2 + 4 + 4 + 2 = 14	58.33
7 MW	2 + 2 + 4 + 4 + 2 + 2 = 16	66.67
6 MW	2 + 2 + 4 + 4 + 2 + 2 + 1 = 17	70.83
4 MW	2 + 2 + 4 + 4 + 2 + 2 + 1 + 7 = 24	100

$$\begin{aligned} \text{Units generated during 24 hours} &= 2 \times 7 + 4 \times 16 + 1 \times 6 + 4 \times 15 + 2 \times 7 + 2 \times 20 + 2 \times 9 + 7 \times 4 \\ &= 264 \text{ MW hr} \end{aligned}$$



Load Duration Curve

From the load variation over the 24 hours (starting from 6 AM) it can be seen that units, each of 5 MW will suffice. Since we want continuity of supply, a reserve capacity equivalent to the largest unit will be taken.

(iv) Total capacity of the plant = 5 MW × 5 = **25 MW**

Number of units = 5

$$\text{Load factor} = \frac{264}{24 \times 20} = 0.55$$

$$\text{Plant capacity factor} = \frac{264}{25 \times 24} = 0.44$$

With the operation schedule listed above, the energy that could have been generated, by the capacity of the plant actually running for the scheduled time will be

$$= 7 \times 5 + 2 \times 10 + 4 \times 20 + 1 \times 10 + 4 \times 15 + 2 \times 20 + 2 \times 20 + 2 \times 10$$

$$= 35 + 20 + 80 + 10 + 60 + 40 + 40 + 20 = 305 \text{ MW}$$

$$\text{Plant use factor} = \frac{264}{305} = 0.8655 \text{ or } \mathbf{86.55\%}$$

(iii) Operation Schedule

11 PM to 6 AM	One unit of 5 MW
6 AM to 8 AM	Two unit of 5 MW
8 AM to 12 Noon	Four unit of 5 MW
12 Noon to 1 PM	Two unit of 5 MW
1 PM to 5 PM	Three unit of 5 MW
5 PM to 7 PM	Four unit of 5 MW
7 PM to 9 PM	Four unit of 5 MW
9 PM to 11 PM	Two unit of 5 MW

Q.2 A thermal power plant of 200 MW capacity has the maximum load of 160 MW and its annual load factor is 0.65. The coal consumption is kg per kWh of energy generated and the cost of coal is ₹ 800 per ton. Other annual running expenses are ₹ 200 × 10⁶. Calculate:

- the annual revenue earned if the energy is sold at ₹ 1.5 per kWh and
- the capacity factor of the plant.

[CSE (Mains) 2002 : 20 Marks]

Solution:

$$\text{Annual load factor} = \frac{\text{Average load}}{\text{Peak load}}$$

$$\text{Average} = 0.65 \times 160 = 104 \text{ MW}$$

$$\text{Energy generated per year} = 104 \times 24 \times 365 = 911040 \text{ MWh} = 911040 \times 10^3 \text{ kWh}$$

$$\text{Coal required per year} = 911040 \times 10^3 \text{ kg} = 911040 \text{ ton}$$

$$\text{Cost of coal} = ₹800 \text{ per ton}$$

$$\text{Cost of coal per year} = 911040 \times 800 = ₹728.832 \times 10^6$$

$$\text{Cost of energy sold} = ₹1.5 \times 911040 \times 10^3 = ₹1366.56 \times 10^6$$

$$\begin{aligned} \text{(i) Revenue earned by the power plant per year} &= \text{cost of energy sold} - \text{cost of coal} \\ &= ₹1366.56 \times 10^6 - ₹728.832 \times 10^6 = ₹637.728 \times 10^6 \\ &= \mathbf{₹63.773 \text{ crore}} \end{aligned}$$

$$\text{(ii) Capacity factor} = \frac{\text{Average load}}{\text{Capacity of the plant}} = \frac{104}{200} = \mathbf{0.52}$$

Q.3 A power plant of 210 MW installed capacity has the following particulars:

Capital cost = ₹ 4 crores/MW installed

Interest and depreciation = 12%

Annual load factor = 60%

Annual capacity factor = 54%

Annual running charges = ₹ 400 × 10⁶

Energy consumed by power plant auxiliaries = 6%

Calculate:

(i) The cost of power generation per kWh (ii) The reserve capacity

[CSE (Mains) 2004 : 20 Marks]

Solution:

$$\frac{\text{Load factor}}{\text{Capacity factor}} = \frac{\text{Average load}}{\text{Maximum demand}} \times \frac{\text{Capacity of the plant}}{\text{Average load}}$$

$$\frac{0.60}{0.54} = \frac{210 \text{ MW}}{\text{Maximum demand}}$$

$$\text{Maximum demand} = \frac{210 \times 0.54}{0.60} = 189 \text{ MW}$$

$$\text{Reserve capacity} = 210 - 189 = \mathbf{21 \text{ MW}}$$

$$\text{Average load} = \text{Load factor} \times \text{Maximum demand} = 0.6 \times 189 = 113.4 \text{ MW}$$

$$\text{Energy produced per year} = 113.4 \times 10^3 \times 8760 = 993.384 \times 10^6 \text{ kWh}$$

$$\text{Net energy delivered} = 0.94 \times 993.384 \times 10^6 = 933.781 \times 10^6 \text{ kWh}$$

Annual interest and depreciation (fixed cost)

$$= 0.12 \times 4 \times 10^7 \times 210 = ₹100.8 \times 10^7$$

Total annual cost = Fixed cost + Running cost

$$= ₹100.8 \times 10^7 + ₹400 \times 10^6 = ₹140.8 \times 10^7$$

$$\text{Cost of power generation} = \frac{₹140.8 \times 10^7}{933.781 \times 10^6} = ₹ 1.5 / \text{kWh}$$

Q.4 Discuss the factors to be considered in the selection of a site for a hydroelectric power plant.

[CSE (Mains) 2004 : 10 Marks]

Solution:

The following factors should be considered while selecting the site for hydroelectric power plant.

- | | |
|----------------------------------|------------------------------|
| 1. Availability of water | 2. Water storage capacity |
| 3. Available water head | 4. Accessibility of the site |
| 5. Distance from the load centre | 6. Type of land of site |

- 1. Availability of water:** The design and capacity of the hydro-plant greatly depends on the amount of water available at the site. The run-off data along with precipitation at the proposed site with maximum and minimum quantity of water available in a year should be made available to
 - (a) decide the capacity of the plant,
 - (b) set up the peak load plant such as steam, diesel or gas turbine plant,
 - (c) provide adequate spillways or gate relief during flood period,