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Mechanical Engineering

Paper-II

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Mechanical Engineering : Indian Forest Service Main Examination: (Paper-II)

First Edition: 2017
Second Edition: 2018
Third Edition: 2019
Fourth Edition: 2020
Fifth Edition: 2021
Sixth Edition: 2022
Seventh Edition: 2023

Eighth Edition: 2024

Preface

B. Singh (Ex. IES)

Our country has a vast forest cover of near about 25% of geographical area and if man doesn't learn to treat trees with respect, man will become extinct; Death of forest is end of our life. Scientific management and judicial exploitation of forest becomes first task for sustainable development.

Engineer is one such profession which has an inbuilt word "Engineer – skillful arrangement" and hence IFS is one of the most talked about jobs among engineers to contribute their knowledge and skills for the arrangement and management for sustainable development

In order to reach to the estimable position of Divisional Forest Officer (DFO), one needs to take an arduous journey of Indian Forest Service Examination. 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 Indian Forest Service Examination 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 Indian Forest Service Examination. The book aims to provide complete solution to all previous years' questions with accuracy.

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

CMD, MADE EASY Group

Previous Years Solved Papers

Indian Forest Service Main Examination

Mechanical Engineering

Paper-II

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■■■

1 Thermodynamics

1. Basic Concepts, Heat and Work

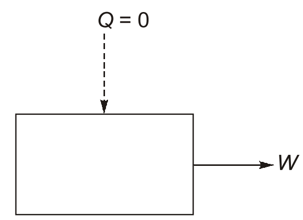
1.1 Explain why PMMK I and PMMKII devices are not practicable. (Perpetual Motion Machine Kind)

[IFS (Mains) 2002 : 10 Marks]

Solution:

The first law states the principle of conservation of energy. Energy is neither created nor destroyed, but only gets transformed from one form to another. There can be no machine which would continuously supply mechanical work without some other form of energy disappearing simultaneously.

Such fictitious machine is called a perpetual motion machine of the first kind or in brief PMMI. A PMMI is thus impossible. The converse of the above statement is also true. There can be no machine which would continuously consume work without some other form of energy appearing simultaneously.

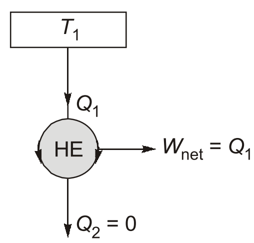


PMM I

The Kelvin Planck statement of second law states: It is impossible for a heat engine to produce a net work in a complete cycle if it exchanges heat only with single reservoir i.e. not rejecting any heat with lower temperature (Q_2 = 0).

Thus,

$$\eta = 1 - \frac{Q_2}{Q_1}$$



PMM II

and if $Q_2 = 0$ (i.e. $W_{net} = Q_1$ or η = 100%) the heat engine will produce net work in a complete cycle by exchanging heat with only one reservoir, thus violating the Kelvin-Planck statement. Such a heat engine is called a perpetual motion machine of the second kind, PMMII. A PMMII is thus impossible.

1.2 State the Zeroth law of thermodynamics and highlight its significance.

[IFS (Mains) 2013 : 5 Marks]

Solution:

When a body A is in thermal equilibrium with a body B, and also separately with a body C, than B and C will be in thermal equilibrium with each other. This is known as Zeroth law of Thermodynamics. It is the basis of temperature measurement.

Significance:

1. It has wide applications in thermometry.
2. If a body C is a thermometer and it is used to measure temperatures of A and B. And if it shows both the readings as same, then (C) is infect showing its own temperature.

1.3 For an isothermal process, show that:

$$\int_1^2 p\,dV = -\int_1^2 V\,dp$$

[IFS (Mains) 2013 : 5 Marks]

Solution:

For an isothermal process, to prove:

$$\int_1^2 PdV = -\int_1^2 VdP$$

Isothermal process is defined as, $PV = \text{Constant} = C$

Differentiating both sides, we get,

$$PdV + VdP = 0$$

or $$PdV = -VdP$$

When system undergoes change in state from state (1) to state (2).

$$\int_1^2 PdV = -\int_1^2 VdP$$

1.4 The readings of two thermometers *A* and *B* agree at ice point and steam point as 0°C and 100°C. The two temperature readings are related by the following expression:

$$t_A = a + bt_B + ct_B^2$$

where *a*, *b* and *c* are constants. In a constant temperature bath, the temperature are shown as 51°C on thermometer *A* and 50°C on thermometer *B*. Determine the reading on thermometer *B* when the thermometer *A* reads 65°C. Can you comment which of the two thermometers is correct?

[IFS (Mains) 2016 : 20 Marks]

Solution:

Given: $t_A = a + bt_B + ct_B^2$

As the reading of two thermometers *A* and *B* agree at ice point (0°C) and steam point (100°C).

When $t_A = 0°C$, t_B is also 0°C

$$= a + bt_B + ct_B^2$$

$$0 = a + b(0) + c(0)^2$$

$$a = 0$$

So, $t_A = bt_B + ct_B^2$

when, $t_A = 100°C$, t_B is also 100°C

$$100 = b(100) + c(100)^2$$

$$b + (100)c = 1 \quad \text{... (i)}$$

when, $t_B = 50°C$, $t_A = 51°C$

$$t_A = bt_B + ct_B^2$$

$$51 = (50)b + (50)^2 c \quad \text{... (ii)}$$

From equations (i) and (ii), we get $b = 1.04$

$$c = -4 \times 10^{-4}$$

$\therefore$ $t_A = 1.04\, t_B - 4 \times 10^{-4}\, t_B^2$

when, t_A reads 65°C $65 = 1.04 t_B - 4 \times 10^{-4}\, t_B^2$

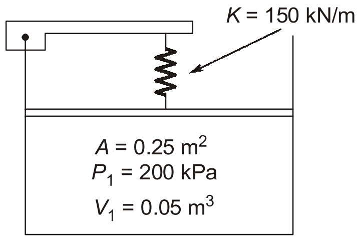
or $t_B = 64.07°C$

None of the two thermometers are ideal. So we cannot comment on to which is more correct.

1.5 A piston-cylinder device contains 0.05 m^3 of a gas initially at 200 kPa. At this state, a linear spring that has a spring constant of 150 kN/m is touching the piston but exerting no force on it. Now heat is transferred to the gas, causing the piston to rise and to compress the spring until the volume inside the cylinder doubles. If the cross- sectional area of the piston is 0.25 m^2, determine:

(i) the final pressure inside the cylinder,

(ii) the total work done by the gas.



[(IFS Mains) 2017 : 10 Marks]

Solution:

Assumptions:

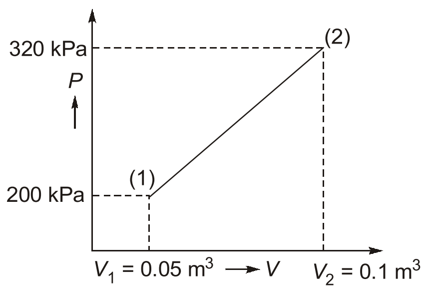
1. Mass conserved in the process.
2. Surrounding conditions are not altered in the process.

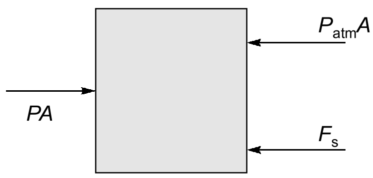
$$\text{Initial volume } (V_1) = 0.05 \text{ m}^3,$$

$$\text{Initial pressure } (P_1) = 200 \text{ kPa},$$

$$\text{Spring constant (k)} = 150 \text{ kN/m, Area } A = 0.25 \text{ m}^2.$$

Let the final pressure and volume inside the cylinder be P_2 and V_2 respectively.





At any state, $PA = P_{atm}A + F_s$

For initial state, $F_s = 0$

$P_1 = P_{atm} = 200 \text{ kPa}$

and $P_2A = P_1A + F_s$

or, $P_2 = P_1 + \dfrac{kx}{A}$

$\Rightarrow$ P $= F(x)$ (linear variations)

where, $x = \dfrac{V_2 - V_1}{A} = \dfrac{2V_1 - V_1}{A} = \dfrac{V_1}{A} = \dfrac{0.05}{0.25} = 0.2 \text{ m}$

$$P_2 = 200 + \frac{150 \times 0.2}{0.25} = 200 + 120 = 320 \text{ kPa}$$

Total work done by the gas, $W = \int_{x_1}^{x_2} PA\,dx = \int_1^2 PdV$ = Area under curve 1–2

$$W_{1-2} = \int_{x_1}^{x_2} (P_{atm}A + kx)\,dx = 200 \times 0.25 \times 0.2 + \frac{1}{2} \times 150 \times 0.2^2 = 13 \text{ kJ}$$

or, W_{1-2} = area under curve 1–2 $= \dfrac{1}{2}[200 + 320] \times 0.2 \times 0.25 = 13$ kJ

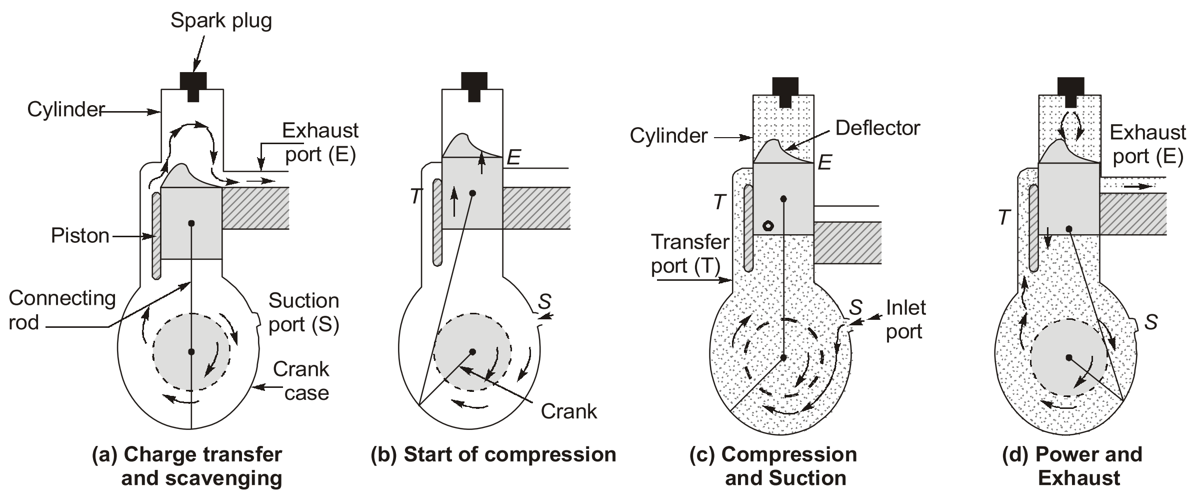
2 I.C. Engines, Fuels and Combustion

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

1.1 With the help of neat sketches, explain the working of 2-stroke and 4-stroke cycle SI engine. Compare them with regard to (i) power to weight ratio, (ii) thermal efficiency and (iii) practical applications.

[IFS (Mains) 2001 : 10 Marks]

Solution:



Operations of a two-stroke petrol engine

Working of 2-stroke SI Engine:

In 2-stroke engines, the cycle is completed in one revolution of the crankshaft. The air-fuel charge is inducted into the crankcase through the spring loaded inlet valve when the pressure in the crankcase is reduced due to upward motion of piston during compression stroke. After the compression and ignition, expansion takes place in the usual way. During the expansion stroke the charge is compressed in the crankcase. Near the end of expansion stroke, the piston uncovers the exhaust ports and the cylinder pressure drops to the atmospheric pressure as combustion products leave the cylinder. Further movement of piston uncovers the transfer ports, permitting the slightly compressed charge in the crankcase to enter the engine cylinder. During the upward motion of the piston from BDC, the transfer ports close first and then the exhaust ports, thereby the effective compression of the charge begins and the cycle is repeated.

4-stroke SI engine: In a four stroke engine, the cycle of operations is completed in four strokes of the piston or two revolutions of the crankshaft. During the four strokes, there are five events to be completed, viz. suction, compression, combustion, expansion and exhaust. Each stroke consists of 180° of crankshaft rotation and hence a 4-stroke cycle is completed through 720° of crank rotation. The cycle of operation for an ideal 4-stroke SI engine consists of the following 4-strokes:

(i) Suction or Intake stroke (ii) Compression stroke

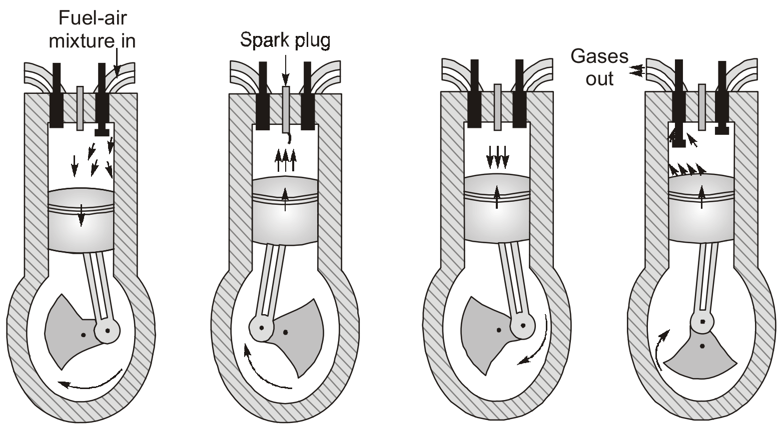
(iii) Expansion or Power stroke (iv) Exhaust stroke

(i) During suction stroke, the charge consisting of fuel-air mixture is drawn into the cylinder. During the stroke, inlet valve is open and exhaust valve is closed.

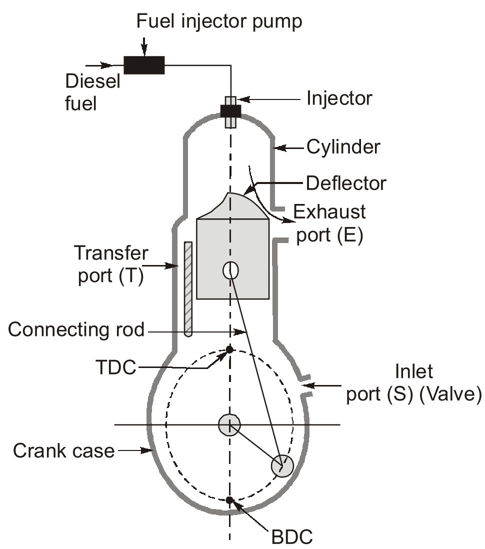
(ii) The charge taken into the cylinder during the suction stroke is compressed by the return stroke of the piston. At the end of the compression stroke, the mixture is ignited with the help of the spark plug located on the cylinder head, and burning takes place instantaneously.

(iii) The high pressure of the burnt gases forces the piston towards the BDC and power is produced during expansion stroke.

(iv) During the exhaust stroke, the piston travelling from BDC to TDC pushes out the products of combustion. The exhaust valve is open and the intake is closed during the stroke.



Operations of four-stroke petrol engine



Schematic of two-stroke Diesel engine

	2-stroke	4-stroke
Power to weight ratio	Because of one power stroke in one revolution, power produced for same size of engine is twice or for the same power, the engine is required lighter.	Because of one power stroke in two revolutions, power produced for same size of engine is less or for the same power, the engine required is heavier.
Thermal efficiency	Thermal efficiency is lower.	Thermal efficiency is higher.
Practical application	Used in mopeds, scooters, motorcycles, hand sprayers, etc.	Used in cars, buses, trucks, tractors, power generators, etc.

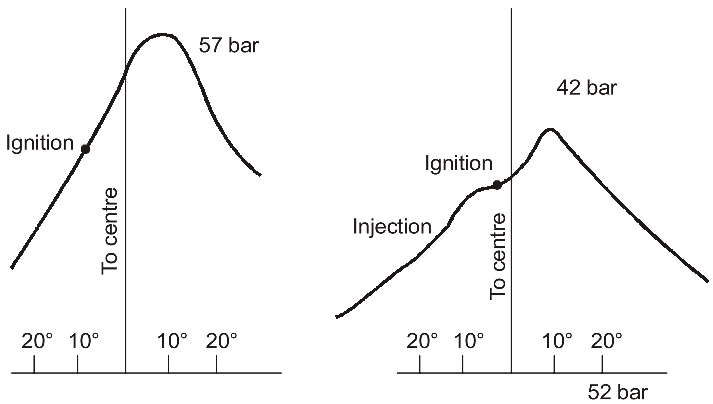
2. **Indirect-Injection (IDI) Type :** In this type of combustion chambers, the combustion space is divided into two parts, one part in the main cylinder and the other part in the cylinder head. The fuel-injection is effected usually into that part of the chamber located in the cylinder head. These chambers are classified further into:
   (a) Swirl chamber in which compression swirl is generated.
   (b) Precombustion chamber in which combustion swirl is induced.
   (c) Air cell chamber in which both compression and combustion swirl are induced.

Direct Injection (DI) versus Indirect Injection (IDI) Engines:

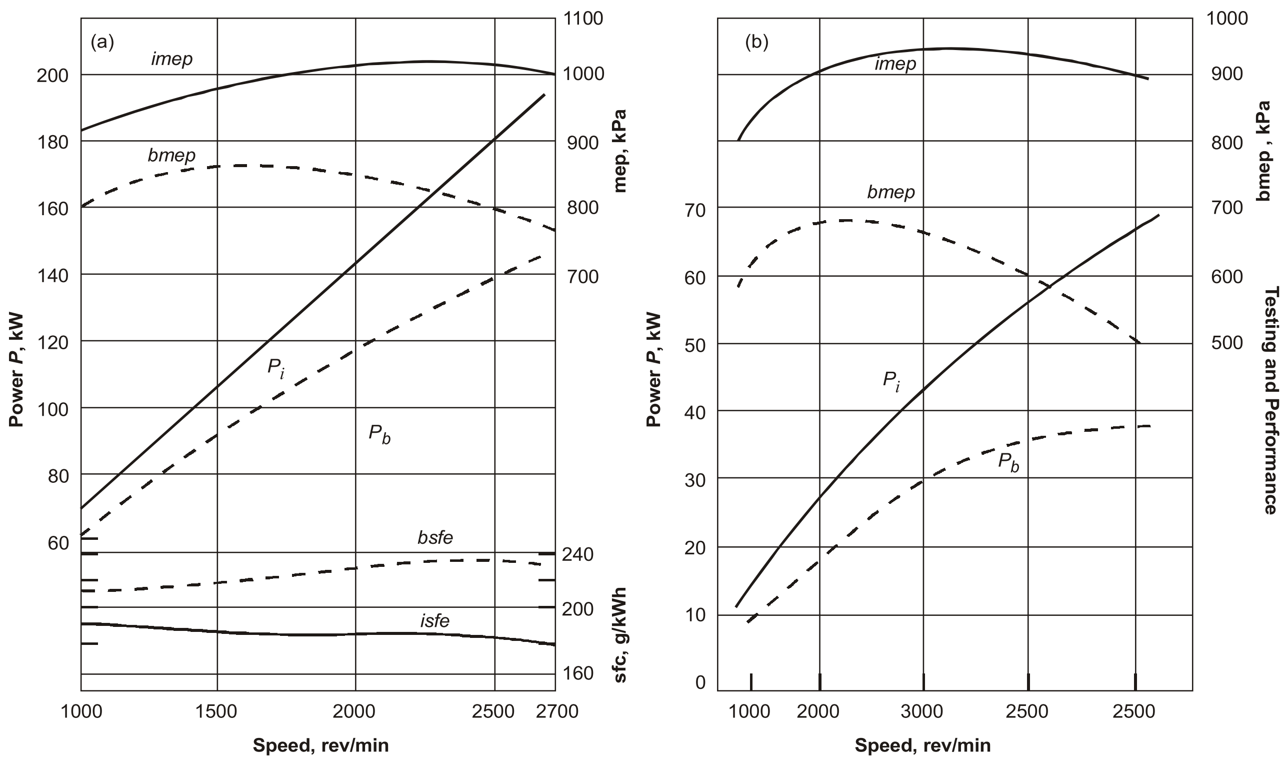
The DI and IDI engines have been in use for many years. The IDI engines were mostly employed in high speed small engine applications. Now, after the development of high speed direction injection (HSDI) engines the IDI engines due to their poor fuel economy are being phased out of production.

The combustion in IDI engines takes place in two stages; a rich mixture burns in the pre-chamber where all the fuel is injected and the partially burned rich fuel-air mixture from the pre-chamber is transported to the main chamber where due to presence of excess air combustion is completed. The jet of high pressure partially burned gases from the pre-chamber enters the main chamber generating high turbulence that causes rapid mixing and most of the fuel burns as lean mixture.

Combustion in CI Engines



(a) Open chamber **(b) Precombustion chamber**



3 Heat Transfer

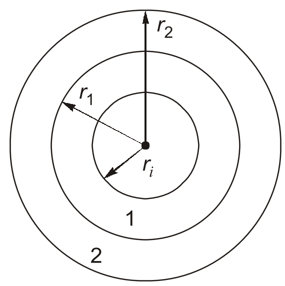
1. Conduction

1.1 A 3 cm outer diameter steam pipe is to be covered with two layers of insulations, each having a thickness of 2.5 cm. The average thermal conductivity of one material is 5 times that of the other. Determine the percent change in heat transfer if better insulating material is next to pipe than when it is in the outer layer. Assume that the outside and inside surface temperatures of the composite insulation are fixed.

[IFS (Mains) 2001, 2017 : 20 Marks]

Solution:

Given that, t_i and t_0 are inner and outer surface temperatures and are constant.



Outer radius of pipe, $r_i = \frac{3}{2}$ cm = 0.015 m

Outer radius of first Insulation, r_1 = (1.5 + 2.50) cm = 0.04 m

Outer radius of second Insulation, r_2 = (4 + 2.5) cm = 0.065 m

Also, Thermal conductivity of one insulation = 5 times of other's

Case 1: When better insulating material is next to pipe.

i.e. if $k_1 = k$

$\Rightarrow$ $k_2 = 5k$

then rate of heat transfer

$$Q_1 = \frac{(t_i - t_0)}{\dfrac{\ln\frac{r_1}{r_i}}{2\pi k_1 L} + \dfrac{\ln\frac{r_2}{r_i}}{2\pi k_2 L}} = \frac{2\pi L(t_i - t_0)}{\dfrac{\ln\left(\frac{0.04}{0.015}\right)}{k} + \dfrac{\ln\left(\frac{0.065}{0.04}\right)}{5k}}$$

$$= 0.9277C \quad [\text{Where } C = 2\pi kL(t_i - t_0)] \qquad \text{... (i)}$$

Case 2 : When better insulating material forms outer layer.

i.e. $k_1 = 5k$

$k_2 = k$

$\Rightarrow$ Heat transfer rate,

$$Q_2 = \frac{(t_i - t_0)}{\dfrac{\ln\frac{r_1}{r_i}}{2\pi k_1 L} + \dfrac{\ln\frac{r_2}{r_1}}{2\pi k_2 L}} = \frac{2\pi L(t_i - t_0)}{\dfrac{\ln\left(\frac{0.04}{0.015}\right)}{5k} + \dfrac{\ln\left(\frac{0.065}{0.04}\right)}{k}}$$

$$= 1.467C \quad [\text{Where } C = 2\pi kL(t_i - t_0)] \qquad \text{... (ii)}$$

So, Percentage change in heat loss

$$= \left(\frac{Q_2 - Q_1}{Q_1}\right) \times 100 = \frac{1.467C - 0.9277C}{0.9277C} \times 100 = 58.13\%$$

So, heat loss increases by 58.13%.

1.2 A steel pipe 120 mm diameter and 5 mm wall thickness, carrying steam at 300°C is insulated with 45 mm of glass wool followed by 50 mm of asbestos felt. The ambient temperature is 25°C. The heat transfer coefficients at the inside and outside surfaces are 650 and 20 W/m^2-K respectively. The thermal conductivities of steel, glass wool and asbestos felt are 55 W/mK 0.09 W/mK and 0.06 W/mK respectively. Calculate the rate of heat loss per unit length of pipe and the temperature of the outside surface. [IFS (Mains) 2001 : 20 Marks]

Solution:

Assumptions:

1. Thermal conductivity is constant, 2. Steady state analysis

3. The pipe is sufficiently long so neglect the edge effect.

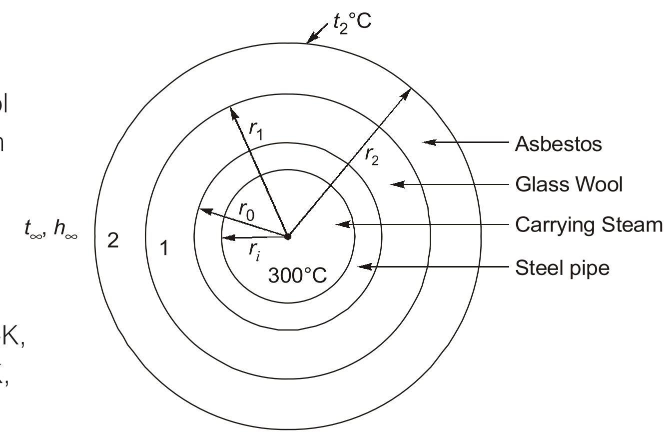
Given that:

r_i = inner pipe radius = $\frac{120}{2}$ mm = 0.06 m

r_o = Outer pipe radius = (60 + 5) mm = 0.065 m

r_1 = Outer radius of glass wool insulation = (65 + 45) mm = 0.11 m

r_2 = Outer radius of asbestos insulation = 0.16 m



Thermal conductivity of steel, k_s = 55 W/m-K,

Thermal conductivity of glass wool, k_1 = 0.09 W/m-K,

Thermal conductivity of asbestos, k_2 = 0.06 W/m-K,

Heat transfer coeff. at inside, h_i = 650 W/m^2-K,

Heat transfer coeff. at outside, h_∞ = 20 W/m^2-K,

t_i = Steam temperature = 300°C

t_∞ = 25°C

So, rate of heat loss per unit length

i.e.
$$\left(\frac{Q}{l}\right) = \frac{(t_i - t_\infty)}{\frac{1}{h_i \times 2\pi r_i} + \frac{\ln\left(\frac{r_0}{r_i}\right)}{2\pi k_s} + \frac{\ln\left(\frac{r_1}{r_o}\right)}{2\pi k_1} + \frac{\ln\left(\frac{r_2}{r_1}\right)}{2\pi k_2} + \frac{1}{h_\infty \times 2\pi r_2}}$$

or
$$\left(\frac{Q}{l}\right) = \frac{2\pi \times (300 - 25)}{\frac{1}{650 \times 0.06} + \frac{\ln\left(\frac{0.065}{0.06}\right)}{55} + \frac{\ln\left(\frac{0.11}{0.065}\right)}{0.09} + \frac{\ln\left(\frac{0.16}{0.11}\right)}{0.06} + \frac{1}{20 \times 0.16}}$$

$$= \frac{550\pi}{0.02564 + 0.0014553 + 5.845 + 6.2449 + 0.3125} = 139.0089 \text{ W}$$

or Heat loss per unit length = 139.0089 W

Again, For temperature of outer surface

$$h_\infty \times A_2 \times (t_2 - t_\infty) = 139.0089 = \text{Heat loss}$$

$$20 \times 2\pi \times 0.16 \times 1 \times (t_2 - 25) = 139.0089$$

$$t_2 = 31.914°\text{C}$$

So, outer surface temperature will be 31.914°C

1.3 A steam pipe 75 mm OD and 30 m long conveys 1000 kg of steam/hour at a pressure of 2 MN/m^2. The steam enters the pipe with a dryness fraction of 0.98 and is to leave the other end of the pipe with a minimum dryness fraction of 0.96. This is to be accomplished by suitably insulating the pipe, the thermal conductivity of insulating material being 0.19 W/mK. Neglecting the temperature drop along the steam pipe, determine the minimum thickness of insulation required to meet the necessary conditions. Take the temperature of outside surface of insulation as 27°C. For steam at 2 MN/m^2, t_s = 212.4°C and h_{fg} = 1888.6 kJ/kg.

[IFS (Mains) 2004 : 10 Marks]

Solution:

Given that, length of pipe, L = 30 m,Diameter, d_o = 75 mm,

$$\text{Steam flow rate, } \dot{m} = 1000 \text{ kg/hr} = \frac{100}{3600} = 0.277 \text{ kg/s}$$

$$\text{Pressure, } P = 2 \text{ MN/m}^2$$

Dryness fraction of entry and exit are

$$x_1 = 0.98 \text{ and } x_2 = 0.96$$

For insulation, k = 0.19 W/mK and t_0 = 27°C

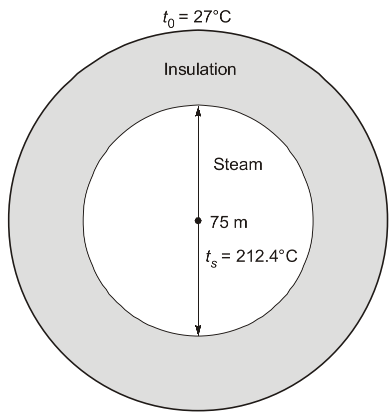
For steam, t_s = 212.4°C and h_{fg} = 1888.6 kJ/kg

So total heat lost by steam from inlet to exit is

$$Q = \dot{m} \times (x_1 - x_2) \times h_{fg} = 0.277 \times (0.98 - 0.96) \times h_{fg} = 10492.222 \text{ J/s}$$

Considering insulation:

Heat post by steam will be conducted through the insulation, so



$$Q = 10492.222 = \frac{(t_s - t_0)}{\left(\dfrac{\ln \dfrac{r_{ins}}{d_0/2}}{2\pi kL}\right)}$$

$$\ln \frac{2r_{ins}}{d_0} = \frac{2 \times \pi \times 0.19 \times 30 \times (212.4 - 27)}{10492.222}$$

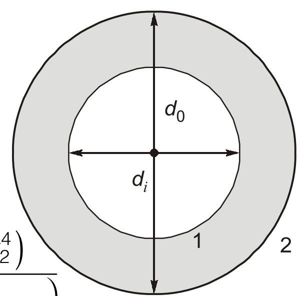
$$r_{ins} = 70.611 \text{ mm}$$

$$\text{Thickness, } t = r_{ins} - \frac{d_0}{2} = 33.11 \text{ mm}$$

1.4 A spherical Dewar flask of 300 mm and 400 mm inner and outside diameters, emissivities 0.05 for both surfaces is used for storing liquid oxygen at 50 K. The outer sphere is at 300 K. Assuming radiation heat transfer only and assuming the flask to be full, find the evaporation rate of liquid O_2, given its latent heat = 214.2 kJ/kg and $\sigma = 5.67 \times 10^{-8}$ W/m^2-K^4.

[IFS (Mains) 2005 : 10 Marks]

Solution:



Given that: d_i = 300 mm = 0.3 m, Emissivity, $\varepsilon_1 = \varepsilon_2 = 0.05$

Liquid oxygen temperature, t_1 = 50 K, t_2 = 300 K

Also given, LH_{O_2} = 214.2 kJ/kg

So heat transfer rate between surfaces 1 and 2

$$Q_{12} = \frac{\sigma\left(t_1^4 - t_2^4\right)}{\dfrac{1-\varepsilon_1}{\varepsilon_1 A_1} + \dfrac{1}{F_{12}A_1} + \dfrac{1-\varepsilon_2}{\varepsilon_2 A_2}} = \frac{\sigma A_1\left(t_1^4 - t_2^4\right)}{\dfrac{1}{\varepsilon_1} + \dfrac{A_1}{A_2} \times \left(\dfrac{1}{\varepsilon_2} - 1\right)}$$

$$Q_{12} = \frac{5.67\times10^{-8}\times\pi\times(0.3)^2\times(50^4-300^4)}{\frac{1}{0.05}+\frac{\pi\times0.3^2}{\pi\times0.4^2}\left(\frac{1}{0.05}-1\right)} = -4.228 \text{ W}$$

Negative sign indicates that heat transfer taking place from surface 2 to 1. Now this heat will cause evaporation of oxygen. Let evaporation rate is $\dot{m}$ kg/s then

$$\dot{m}\times LH = |Q_{12}|$$

$$\dot{m} = \frac{4.228\times3600}{214.2\times10^3} \text{ kg/hr} = 0.07106 \text{ kg/hr}$$

1.5 A 66 kV transmission line carrying a current of 900 ampere and having a diameter of 10 mm is laid in a convective environment of 10 W/m²-K and 35°C. The thermal conductivity and electrical resistivity of the line material are 380 W/m-K and 1.75 × 10⁻⁸ Ω-cm. Calculate the following:

(i) The heat generation per unit volume

(ii) The surface temperature of the line

(iii) The maximum temperature in the line

[IFS (Mains) 2006 : 10 Marks]

Solution:

Given that: Voltage, $V = 66$ kV = 66000 volt, Current, $I = 900$ ampere, Wire diameter, $d = 10$ mm = 0.01 m

$h = 10$ W/m²-K, $t_\infty = 35°C$, Thermal conductivity, $k = 380$ W/m-K

$$\text{Resistivity, } \rho = 1.75\times10^{-6}\ \Omega\text{-cm} = 1.75\times10^{-8}\ \Omega\text{ m}$$

So, as
$$R = \rho\frac{l}{A_c}$$

or
$$\frac{V}{I} = \rho\frac{l}{\frac{\pi}{4}d^2}$$

$$l = \frac{\pi Vd^2}{4I\rho} = \frac{\pi\times66000\times(0.01)^2}{4\times900\times1.75\times10^{-8}} = 329119.23 \text{ m}$$

$$\text{Heat generated, } Q = VI = 66000\times900 = 59.4 \text{ MW}$$

(i) Heat generation per unit volume, $\dot{q}_g = \dfrac{Q}{\frac{\pi}{4}d^2 l} = 2.298 \text{ MW/m}^3$

(ii) Under steady state condition:

Heat generated in wire = Heat convected to surroundings

$$59.4\times10^6 = h\times\pi dl\times(t_s-t_\infty) = 10\times\pi\times0.01\times329119.23\times(t_s-35)$$

where t_s = Surface temperature of wire = 609.49°C

(iii) Maximum temperature in the line,

$$t_{max} = t_s + \frac{\dot{q}_g}{4k}R^2 = 609.49 + \frac{2.298\times10^6}{4\times380}\times\left(\frac{0.01}{2}\right)^2$$

$$= 609.49 + 0.038 = 609.528°C$$

1.6 Temperature profile for heat conduction through a wall of constant thermal conductivity is a straight line, prove that it becomes parabolic in the presence of a heat source.

[IFS (Mains) 2007 : 10 Marks]

$$\text{Reynolds number, Re} = \frac{\rho u D_E}{\mu} = \frac{0.65 \times 1.2 \times 5}{2 \times 10^{-5}} = 195000$$

$$\text{Nu} = 0.193(\text{Pr})^{1/3}\text{Re}^{0.618}$$
$$= 0.193(0.7)^{1/3}(195000)^{0.618}$$
$$= 318.54$$

$$h_o = \frac{kNu}{D_E} = \frac{0.03 \times 318.54}{0.65} = 14.7 \text{ W/m}^2\text{K}$$

Overall heat transfer coefficient:

$$\frac{1}{U_t A_t} = \frac{1}{h_i A_i} + \frac{1}{h_o A_f \eta_f}$$

$$\frac{1}{U_t} = \frac{1}{h_i} \times \frac{A_t}{A_o} \times \frac{A_o}{A_i} + \frac{1}{h_o} \times \frac{1}{\eta_f}$$

$$\frac{1}{U_t} = \frac{1}{2331.83} \times 20\left(\frac{1.35}{1.2}\right)^2 + \frac{1}{14.7 \times 0.9}$$

$$U_t = 11.568 \text{ W/m}^2\text{K}$$

$$\text{Temperature rise of air, } \Delta t_a = \frac{\dot{Q}_k}{\dot{Q}_v}\rho C_p$$

$$= \frac{25 \times 60}{100 \times 1.2 \times 1.005} = 12.44°\text{C}$$

$$\text{Air leaving temperature} = 40 + 12.44$$
$$= 52.44°\text{C}$$

Log mean temperature difference:

$$\Delta T_{lm} = \frac{(55-40)-(55-52.44)}{\ln\left(\frac{55-40}{55-52.44}\right)}$$

$$\Delta T_{lm} = \frac{12.44}{1.768} = 7.036°\text{C}$$

$$\text{Finned surface area, } A_t = \frac{\dot{Q}_k}{U_t \Delta T_{lm}}$$

$$= \frac{25 \times 10^3}{11.568 \times 7.036} = 307.15 \text{ m}^2$$

■■■■

4 Refrigeration and Air Conditioning

1. Introduction and Basic Concepts

1.1 Answer the following questions briefly:

(i) Give names of any two primary and two secondary refrigerants.

(ii) Write the chemical formulae for R134 and R717 refrigerants.

(iii) Why is the evaporator pressure kept above the atmospheric pressure?

(iv) What is meant by eco-friendly refrigerant?

(v) What is halide torch used for?

[IFS (Mains) 2001 : 10 Marks]

Solution:

(i) **Primary refrigerants:** Primary refrigerants are those fluids which are directly used as working fluids in refrigeration process. When these are used in vapour compression or absorption systems, these fluids provides refrigeration by undergoing a phase change process in the evaporator. These are generally non-toxic and pose no possible harm when allowed to flow freely in refrigeration space. They are found to be used commonly in domestic refrigerators and air conditioners.

Name of some primary refrigerants are:

(a) R-11 (Trichlorofluoromethane or CCl_3F)

(b) R-12 (Dichlorodifluoromethane or CCl_2F_2)

(c) R-22 (Chlorodifluoromethane or $CHClF_2$)

Secondary Refrigerants: Secondary refrigerants are those liquids, which are used for transporting thermal energy from one location to other. They are also known under the name brines or antifreezes.

Name of some secondary refrigerants are:

(a) Pure water [if operating temperature is above 0°C]

(b) Sodium chloride brine

(c) Solutions of water and ethylene glycol or calcium chloride

(ii)

Refrigerants	Chemical formula
R–134	$C_2H_2F_4$(Tetrafluoroethane)
R-717	NH_3(Ammonia)

(iii) The saturation temperature of the working fluid at the operating pressure of the evaporator must be less than the temperature of the cold reservoir in order to absorb heat. The saturation pressure of the refrigerant in evaporator should not be less than atmospheric pressure because air may leak into the system and can severely decrease the COP.

(iv) **Eco-friendly refrigerants:** Those refrigerants, which have almost zero ozone depleting potential and negligible global warming potential, are known as eco-friendly refrigerants. Additionally, they are part of the natural biochemical cycles and do not form persistent wastes in the atmosphere, water or biosphere. Most eco-friendly refrigerants are naturally occurring substances such as CO_2, ammonia, water, air and hydrocarbons (HC) such as propane, isobutene and propene.

Chlorofluoro-carbons (CFCs) and hydrochlorofluorocarbons (HCFCs) known as non eco-friendly refrigerants because the chlorine element in these refrigerants has high ozone depleting and high global warming potential. Some of the eco-friendly refrigerants such as HC and HCM (Hydrocarbon Mixtures) are promising alternatives to CFCs and HCFCs which are being regulated because of high ozone depletion. Hydrofluorocarbons (HFCs) is also used only as a short-term replacement for these refrigerants because of its high global warming potential.

(v) A halide torch is used for detection of leaks in cooling systems using halogen based refrigerants. It consists of a small burner assembly mounted on top of a container of gas, for example propane. The burner consists a hand valve and a venturi with an attachment for the exploring tube. Above the orifice of the burner there is a copper ring, a strip or a tube through which the flame passes when the torch is ignited. When the torch is lit the air will be drawn into the venturi via the exploring tube and the flame will burn slightly blue colourless.

When a halogen based refrigerant such as R12 or R22 is sucked through the tube and passed over a surface whose surface temperature is high, the refrigerant vapour breaks down and forms a foul smelling gas known as phosgene ($COCl_2$). When this gas is passed over a glowing copper (heat by the flame of torch itself), it forms copper chloride which changes the colour of the flame from pale blue to bluish green. The halide torch usually burns methyl alcohol, butane gas or acetylene. and leaks as small as 45 to 60 ml can be detected using by this.

1.2 The evaporator and condenser temperatures in a reverse Carnot refrigeration cycle of 1 TR capacity are 263 K and 313 K respectively. The outlet of compression is saturated vapour and inlet to turbine is saturated liquid. Find the mass flow rate, work done by compressor, condenser heat rejection and COP. Properties of refrigerant at saturation in SI units are as follows

t(K)	h_f	h_g	s_f	s_g
263	154.056	1450.22	0.82965	5.755
313	390.587	1490.42	1.64377	5.1558

[IFS (Mains) 2003 : 10 Marks]

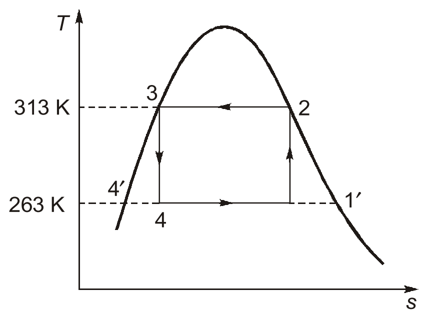
Solution:

Capacity of reverse carnot refrigeration cycle, R.C. = 1 TR = 3.5 kW

From the given table:

h_2 = 1490.42 kJ/kg, h_3 = 390.587 kJ/kg, $h_{1'}$ = 1450.22 kJ/kg, $h_{4'}$ = 154.056 kJ/kg

As in carnot cycle, process 1 – 2 is isentropic compression.



So, $s_2 = s_1 = s_{4'} + x_1(s_{1'} - s_{4'})$

From table $5.1558 = 0.82965 + x_1(5.755 - 0.82965)$

$x_1 = 0.8783$

So, $h_1 = h'_4 + x_1(h'_1 - h'_4)$

$\Rightarrow h_1 = 1292.476$ kJ/kg

Process 3 – 4 is isentropic expansion process so

$s_3 = s_4 = s_{4'} + x_4(s_{1'} - s_{4'})$

$\Rightarrow 1.64377 = 0.82965 + x_4(5.755 - 0.82965)$

$x_4 = 0.1653$

$\Rightarrow h_4 = h_{4'} + x_4(h_{1'} - h_{4'})$

$\Rightarrow h_4 = 154.056 + 0.1653\,(1450.22 - 154.056) = 368.311$ kJ/kg

(i) Let $\dot{m}$ bet the mass flow rate of refrigerant

$\Rightarrow \dot{m}(h_1 - h_4)$ = R.C. = 3.5

Thermodynamic Properties of R134a*

Saturation table of R134a

Temp. °C	Pressure MPa	Density kg/m^3 Liquid	Volume m^3/kg Vapour	Enthalpy (kJ/kg)		Entropy (kJ/kg·K)		Specific Heat c_p, (kJ/kg·K)		c_p/c_v Vapour
				Liquid	Vapour	Liquid	Vapour	Liquid	Vapour	
–103.30[a]	0.00039	1591.1	35.4690	71.46	334.94	0.4126	1.9639	1.184	0.585	1.164
–100.00	0.00056	1582.4	25.1930	75.36	336.85	0.4354	1.9456	1.184	0.593	1.162
–90.00	0.00152	1555.8	9.7698	87.23	342.76	0.5020	1.8972	1.189	0.617	1.156
–80.00	0.00367	1529.0	4.2682	99.16	348.83	0.5654	1.8580	1.198	0.642	1.151
–70.00	0.00798	1501.9	2.0590	111.20	355.02	0.6262	1.8264	1.210	0.667	1.148
–60.00	0.01591	1474.3	1.0790	123.36	361.31	0.6846	1.8010	1.223	0.692	1.146
–50.00	0.02945	1446.3	0.60620	135.67	367.65	0.7410	1.7806	1.238	0.720	1.146
–40.00	0.05121	1417.7	0.36108	148.14	374.00	0.7956	1.7643	1.255	0.749	1.148
–30.00	0.08438	1388.4	0.22594	160.79	380.32	0.8486	1.7515	1.273	0.781	1.152
–28.00	0.09270	1382.4	0.20680	163.34	381.57	0.8591	1.7492	1.277	0.788	1.153
–26.07[b]	0.10133	1376.7	0.19018	165.81	382.78	0.8690	1.7472	1.281	0.794	1.154
–26.00	0.10167	1376.5	0.18958	165.90	382.82	0.8694	1.7471	1.281	0.794	1.154
–24.00	0.11130	1370.4	0.17407	168.47	384.07	0.8798	1.7451	1.285	0.801	1.155
–22.00	0.12165	1364.4	0.16006	171.05	385.32	0.8900	1.7432	1.289	0.809	1.156
–20.00	0.13273	1358.3	0.14739	173.64	386.55	0.9002	1.7413	1.293	0.816	1.158
–18.00	0.14460	1352.1	0.13592	176.23	387.79	0.9104	1.7396	1.297	0.823	1.159
–16.00	0.15728	1345.9	0.12551	178.83	389.02	0.9205	1.7379	1.302	0.831	1.161
–14.00	0.17082	1339.7	0.11605	181.44	390.24	0.9306	1.7363	1.306	0.838	1.163
–12.00	0.18524	1333.4	0.10744	184.07	391.46	0.9407	1.7348	1.311	0.846	1.165
–10.00	0.20060	1327.1	0.09959	186.70	392.66	0.9506	1.7334	1.316	0.854	1.167
–8.00	0.21693	1320.8	0.09242	189.34	393.87	0.9606	1.7320	1.320	0.863	1.169
–6.00	0.23428	1314.3	0.08587	191.99	395.06	0.9705	1.7307	1.325	0.871	1.171
–4.00	0.25268	1307.9	0.07987	194.65	396.25	0.9804	1.7294	1.330	0.880	1.174
–2.00	0.27217	1301.4	0.07436	197.32	397.43	0.9902	1.7282	1.336	0.888	1.176
0.00	0.29280	1294.8	0.06931	200.00	398.60	1.0000	1.7271	1.341	0.897	1.179
2.00	0.31462	1288.1	0.06466	202.69	399.77	1.0098	1.7260	1.347	0.906	1.182
4.00	0.33766	1281.4	0.06039	205.40	400.92	1.0195	1.7250	1.352	0.916	1.185
6.00	0.36198	1274.7	0.05644	208.11	402.06	1.0292	1.7240	1.358	0.925	1.189
8.00	0.38761	1267.9	0.05280	210.84	403.20	1.0388	1.7230	1.364	0.935	1.192
10.00	0.41461	1261.0	0.04944	213.58	404.32	1.0485	1.7221	1.370	0.945	1.196
12.00	0.44301	1254.0	0.04633	216.33	405.43	1.0581	1.7212	1.377	0.956	1.200
14.00	0.47288	1246.9	0.04345	219.09	406.53	1.0677	1.7204	1.383	0.967	1.204
16.00	0.50425	1239.8	0.04078	221.87	407.61	1.0772	1.7196	1.390	0.978	1.209
18.00	0.53718	1232.6	0.03830	224.66	408.69	1.0867	1.7188	1.397	0.989	1.214
20.00	0.57171	1225.3	0.03600	227.47	409.75	1.0962	1.7180	1.405	1.001	1.219
22.00	0.60789	1218.0	0.03385	230.29	410.79	1.1057	1.7173	1.413	1.013	1.224
24.00	0.64578	1210.5	0.03186	233.12	411.82	1.1152	1.7166	1.421	1.025	1.230
26.00	0.68543	1202.9	0.03000	235.97	412.84	1.1246	1.7159	1.429	1.038	1.236
28.00	0.72688	1195.2	0.02826	238.84	413.84	1.1341	1.7152	1.437	1.052	1.243
30.00	0.77020	1187.5	0.02664	241.72	414.82	1.1435	1.7145	1.446	1.065	1.249
32.00	0.81543	1179.6	0.02513	244.62	415.78	1.1529	1.7138	1.456	1.080	1.257
34.00	0.86263	1171.6	0.02371	247.54	416.72	1.1623	1.7131	1.466	1.095	1.265
36.00	0.91185	1163.4	0.02238	250.48	417.65	1.1717	1.7124	1.476	1.111	1.273
38.00	0.96315	1155.1	0.02113	253.43	418.55	1.1811	1.7118	1.487	1.127	1.282
40.00	1.0166	1146.7	0.01997	256.41	419.43	1.1905	1.7111	1.498	1.145	1.292
42.00	1.0722	1138.2	0.01887	259.41	420.28	1.1999	1.7103	1.510	1.163	1.303
44.00	1.1301	1129.5	0.01787	262.43	421.11	1.2092	1.7096	1.523	1.182	1.314
46.00	1.1903	1120.6	0.01687	265.47	421.92	1.2186	1.7089	1.537	1.202	1.326
48.00	1.2529	1111.5	0.01595	268.53	422.69	1.2280	1.7081	1.551	1.223	1.339
50.00	1.3179	1102.3	0.01509	271.62	423.44	1.2375	1.7072	1.566	1.246	1.354
52.00	1.3854	1092.9	0.01428	274.74	424.15	1.2469	1.7064	1.582	1.270	1.369
54.00	1.4555	1083.2	0.01351	277.89	424.83	1.2563	1.7055	1.600	1.296	1.386

5 Turbomachinery

1. Dimensional Analysis, Similitude and Modeling

1.1 The drag force F experienced by the object moving in a fluid of density ρ and viscosity μ depends upon its velocity V and diameter D. Using Buckingham's π theorem, obtain the relevant dimensionless groups.

[IFS (Mains) 2001 : 10 Marks]

Solution:

Given:

$$\text{Drag force, } F = f(\rho, \mu, V, D)$$

Using Buckingham's π - theorem,

$$\text{Number of variables, } n = 5$$

$$\text{Number of fundamental dimensions, } m = 3$$

$$\text{Number of } \pi\text{-terms} = n - m = 2$$

Let these be (π_1, π_2),

First π-term,
$$\pi_1 = (D)^{a_1}(V)^{b_1}(\rho)^{c_1}F$$

$$[M^0L^0T^0] = [L]^{a_1}\left[LT^{-1}\right]^{b_1}\left[ML^{-3}\right]^{C_1}\left[MLT^{-2}\right] = \left[L^{a_1+b_1-3c_1+1}\,T^{-b_1-2}M^{c_1+1}\right]$$

Comparing the exponent of M, L and T:

$$c_1 + 1 = 0$$
$$c_1 = -1$$
$$-b_1 - 2 = 0$$
$$b_1 = -2$$
$$a_1 + b_1 - 3c_1 + 1 = 0$$
$$\Rightarrow \quad a_1 = -1 + 3(-1) - (-2) = -2$$
$$\pi_1 = (D)^{-2}(V)^{-2}(\rho)^{-1}F = \frac{F}{\rho V^2 D^2}$$

Similarly,
$$\pi_2 = (D)^{a_2}(V)^{b_2}(\rho)^{c_2}\mu$$

$$[M^0L^0T^0] = [L]^{a_2}\left[LT^{-1}\right]^{b_2}\left[ML^{-3}\right]^{c_2}\left[ML^{-1}T^{-1}\right] = \left[M^{c_2+1}\,L^{a_2+b_2-3c_2-1}T^{-b_2-1}\right]$$

Comparing the exponent of M, L and T:

$$c_2 + 1 = 0$$
$$\Rightarrow \quad c_2 = -1$$
$$-b_2 - 1 = 0$$
$$\Rightarrow \quad b_2 = -1$$
$$a_2 + b_2 - 3c_2 - 1 = 0$$
$$\Rightarrow \quad a_2 = 1 + 3(-1) - (-1) = -1$$
$$\pi_2 = (D)^{-1}(V)^{-1}(\rho)^{-1}\mu = \frac{\mu}{DV\rho}$$
$$\phi(\pi_1\,\pi_2) = 0$$

$$\phi\left(\frac{F}{\rho V^2 D^2}, \frac{\mu}{\rho VD}\right) = 0$$

or
$$\text{Drag force, } F = \rho V^2 D^2 \phi\left(\frac{\mu}{\rho VD}\right)$$

1.2 (i) Explain clearly geometric, kinematic and dynamic similarities. State atleast two governing parameters for each kind of similarity.

[IFS (Mains) 2002 : 5 Marks]

(ii) Give the advantages of Model analysis.

[IFS (Mains) 2002 : 5 Marks]

Solution:

(i) There are three types of similarities that must exist between the model and the prototype. These are:

(a) Geometric Similarity
(b) Kinematic Similarity
(c) Dynamic Similarity

(a) Geometric Similarity:

The geometric similarity is said to exist between the model and the prototype, when the ratio of all corresponding linear dimensions in the model and the prototype are equal. For geometric similarity between the model and the prototype, we have,

$$\frac{L_P}{L_m} = \frac{b_P}{b_m} = \frac{D_p}{D_m} = L_r$$

$$\frac{A_p}{A_m} = L_r^2 \quad \text{and} \quad \frac{V_p}{V_m} = L_r^3$$

Where L_r is scale ratio.
A_p and A_m represents area of prototype and model respectively.
V_p and V_m represents volume of prototype and model respectively.

(b) Kinematic Similarity:

Kinematic similarity means the similarity of motion between model and prototype. Thus kinematic similarity is said to exist between the model and the prototype if the ratio of the velocity and acceleration at the corresponding points in the prototype are same, i.e.,

$$\frac{V_{p1}}{V_{m1}} = \frac{V_{p2}}{V_{m2}} = V_r \text{ where } V_r \text{ is velocity ratio}$$

For acceleration,
$$\frac{a_{p1}}{a_{m1}} = \frac{a_{p2}}{a_{m2}} = a_r$$

Where a_r is acceleration ratio.

(c) Dynamic Similarity

Dynamic similarity means the similarity of forces between the model and the prototype. Thus dynamic similarity is said to exist between the model and prototype if the ratios of the corresponding forces acting at the corresponding points are equal. Also the directions of the corresponding forces at the corresponding points should be same.

i.e.
$$\frac{(F_i)_p}{(F_i)_m} = \frac{(F_v)_p}{(F_v)_m} = \frac{(F_g)_p}{(F_g)_m} = F_r \text{ (force ratio)}$$

and F_i, F_v, F_g are inertia force, viscous force and gravity force respectively.

(ii) Advantages of model analysis are:

1. Errors can be detected much earlier.

2. Missing functionality can be identified easily.
3. Using dimensional analysis, a relationship between the variable influencing a flow problem is obtained which help in conducting test.
4. The performance of the hydraulic structure can be predicted in advance from its model.
5. The merits of alternative design can be predicted with the help of model analysis to adopt most economical and safe design.

1.3 State Buckingham's π theorem. Using Buckingham's π theorem obtain an expression for drag force on a partially submerged body moving with a relative velocity *V* in a fluid, the other variables being linear dimension *L*, height of surface roughness *K*, the fluid density ρ and gravitational acceleration *g*.

[IFS (Mains) 2003 : 10 Marks]

Solution:

Buckingham's π-theorem states that "If there are '*n*' variable (independent and dependent) in a physical phenomenon and if these variable contain '*m*' fundamental dimensions then the variables are arranged into $(n - m)$ dimensionless terms which are called π-terms".

Let $X_1, X_2, X_3, \ldots X_n$ are the variables involved in a physical problem. Let X_1 be the dependent variable and $X_2, X_3, X_4 \ldots X_n$ are the independent variables on which X_1 depends. Mathematically it can be written as

$$X_1 = f(X_2, X_3, X_4, \ldots X_n)$$

and, $$f(X_1, X_2, X_3, X_4 \ldots X_n) = 0$$

Hence, $$f(\pi_1, \pi_2, \pi_3 \ldots \pi_{n-m}) = 0$$

$$\text{Drag force, } F = f(V, L, K, \rho, g)$$

Here, $$\text{Number of variables, } n = 6$$

$$\text{Number of fundamental dimensions, } m = 3$$

$$\text{Number of } \pi\text{-terms} = n - m = 3$$

Let these be π_1, π_2 and π_3.

The selected repeating variables is (V, L, ρ)

$$\pi_1 = V^{a_1} L^{b_1} \rho^{c_1} F$$

$$[M^0 L^0 T^0] = [LT^{-1}]^{a_1} [L]^{b_1} [ML^{-3}]^{c_1} [MLT^{-2}] = \left[M^{c_1+1} L^{a_1+b_1-3c_1+1} T^{-a_1-2}\right]$$

Comparing the exponent of *M*, *L* and *T*:

$$-a_1 - 2 = 0$$

$$\Rightarrow \quad a_1 = -2$$

$$c_1 + 1 = 0$$

$$\Rightarrow \quad c_1 = -1$$

$$a_1 + b_1 - 3c_1 + 1 = 0$$

$$\Rightarrow \quad b_1 = -2$$

$$\pi_1 = V^{-2} L^{-2} \rho^{-1} F = \frac{F}{\rho L^2 V^2}$$

$$\pi_2 = V^{a_2} L^{b_2} \rho^{c_2} K$$

$$[M^0 L^0 T^0] = [LT^{-1}]^{a_2} [L]^{b_2} [ML^{-3}]^{c_2} [L] = \left[M^{c_2} L^{a_2+b_2-3c_2+1} T^{-a_2}\right]$$

Comparing the exponent of *M*, *L* and *T*:

$$c_2 = 0$$

$$a_2 = 0$$

and $$a_2 + b_2 - 3c_2 + 1 = 0$$

6 Power Plants

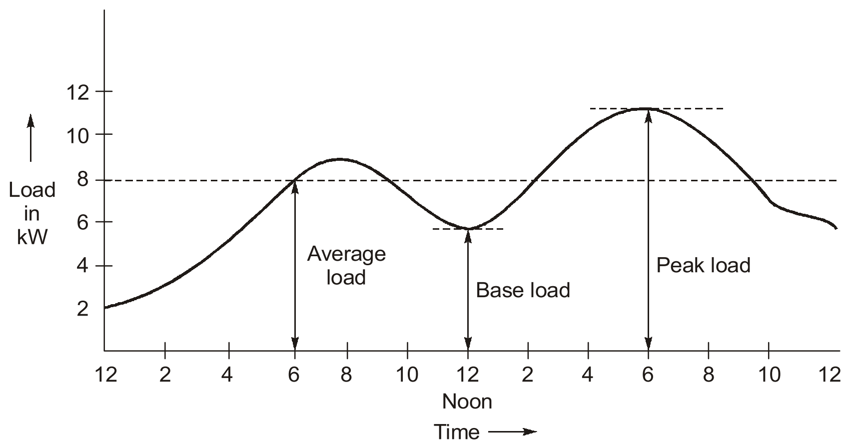
1. Economics of Power Generation

1.1 Sketch a typical load curve of a power plant and define the following terms:
Load factor; Capacity factor ; Plant use factor. How do these factors influence the economics of power plant.

[IFS (Mains) 2001 : 15 Marks]

Solution:

Load curve: A curve showing the load demand (variations) of consumer with respect to time is known as load curve.



The area under this curve gives the number of units generated in a day.

Load Factor: It is defined as the ratio of average load for a given period to the maximum load during the same period.

$$\text{Load factor} = \frac{\text{Average demand over a given period}}{\text{Maximum demand during the same period}}$$

Plant capacity factor: It is defined as the ratio of actual energy produced in kilo watt hours (kWh) to the maximum possible energy that could have been produced during the same period.

Load factor for 1 year,

$$\text{Total hours in one year} = 8760 \text{ hrs}$$

$$\text{Load factor} = \frac{\text{kWh}_{\text{average}} \text{ in a year}}{(\text{kW})_{\max} \times 8760}$$

A low annual load factor refers that most of capacity remains unutilised for the major part of the year. It causes high cost per kWh for consumers. On the other hand high load factor leads maximum utilization of capacity and hence reduces cost per kWh. Thus, the load factor influence significantly to the economic health of the plant.

Capacity Factor: It is defined as the ratio of actual power produced in a period to the rated capacity. It may also be expressed as average load to the plant rated capacity.

$$\text{Capacity factor} = \frac{\text{Actual power/Average power generated in a year}}{\text{Rated capacity of the plant}}$$

The capacity factor shows how near the plants run to its full rating.

Plant use factor: It is expressed as the ratio of energy produced in a given time to maximum possible energy that could have been produced during the actual number of hours of operation.

$$\text{Plant use factor (PUF)} = \frac{\text{Annual power generated}}{\text{Capacity of plant} \times \text{operating hours in a year}}$$

The economics of power plant is influenced by the plant use factor. The cost of electricity produced reduces with the increase of the size of the unit and vice-versa.

1.2 Discuss the criteria for the selection of site for steam and hydroelectric power plants.

[IFS (Mains) 2003 : 10 Marks]

Solution:

The following factors should be considered while selecting the site for steam and hydroelectric power plants.

1. **Availability of water:** The design and capacity of the plant greatly depends on the amount of water available at the site. 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.

2. **Water storage capacity:** It is necessary to store the water for continuous generation of power. The storage capacity can be estimated with the help of mass curve.

3. **Available water head:** In order to generate the desired quantity of power it is necessary that a large quantity of water at sufficient head should be available.

4. **Accessibility of the site:** The site should be easily accessible by rail and road. An inaccessible terrain will jeopardies the movement of men and material.

5. **Distance from the load centre:** If the site is close to the load centre, the cost of transmission lines and the transmission losses will be reduced.

6. **Type of the land of the site:** The land of the site should be cheap and rocky. The power plant should be built in an area with soil and rocky layers that could stand the weight and vibrations of the power plant.

7. **Availability of fuel:** Required quantity of fuel must be available either in vicinity or it should be reasonably economical to transport the fuel to the power plant.

8. **Disposal of waste products:** Ash is the main by-product of combustion of coal in thermal power plant. Disposing of such huge quantities of ash requires a large amount of empty space where it can be safely dumped.

1.3 Explain clearly, 'Heat rate curve' and 'Incremental rate curve'. Show that the incremental rate curve crosses the heat rate curve at the lowest value of heat rate. The incremental fuel costs for two generating units *A* and *B* of a plant are given by

$$dF_a / dP_a = 0.065\, P_a + 25$$

$$dF_b / dP_b = 0.08\, P_b + 20$$

where F is fuel cost in Rs/hr and P is power output in MW. Find

(i) the economic loading of the two units when the total load supplied by the power plant is 160 MW.

(ii) the loss in fuel cost/hr if the load is shared equally by the units.

[IFS (Mains) 2003 : 25 Marks]