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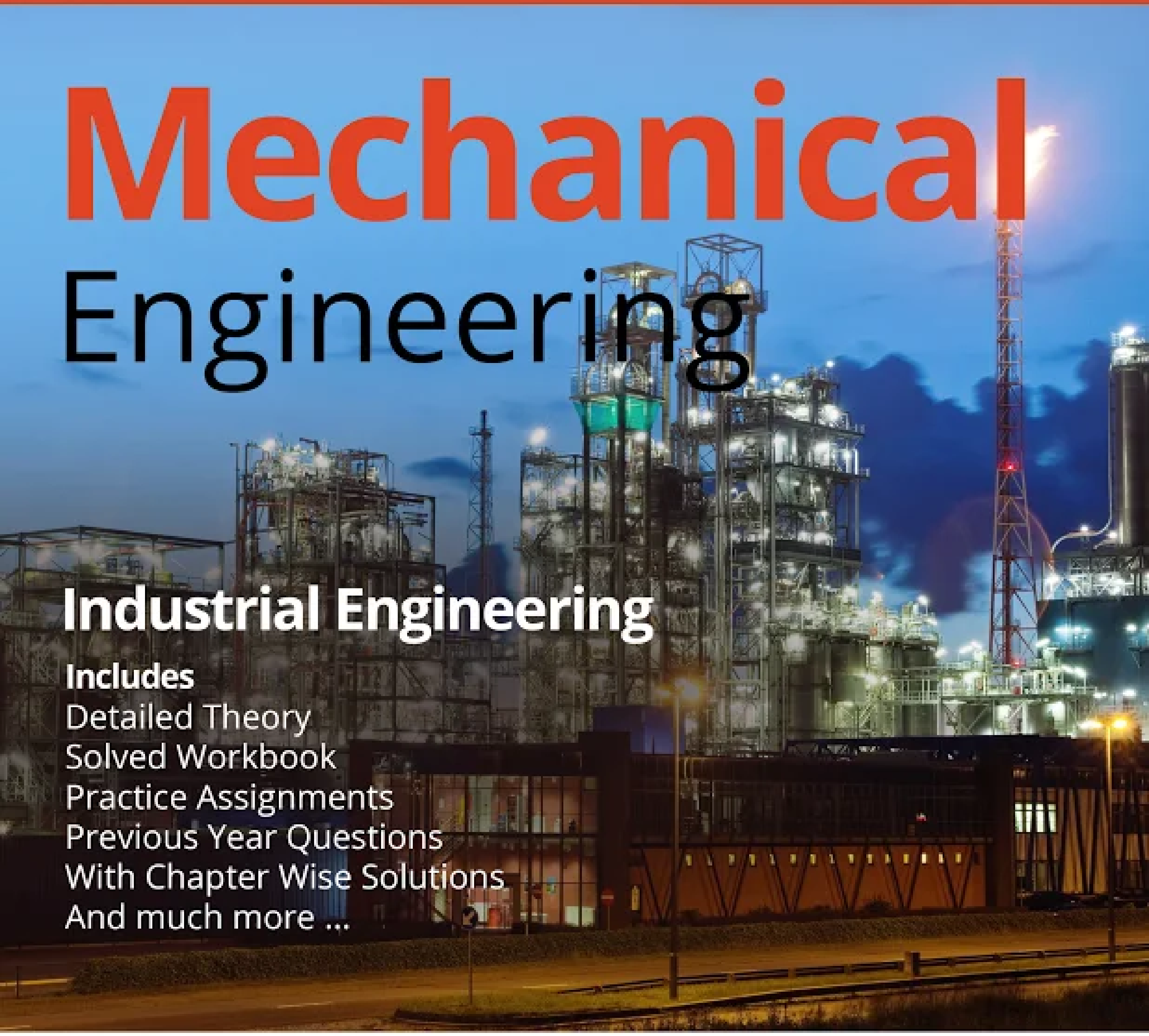

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First Edition: 2016

Price of Book: *INR 430/-*

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SECTION – A (INDUSTRIAL ENGINEERING)

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SECTION- A
INDUSTRIAL ENGINEERING

CHAPTER - 1
LINEAR PROGRAMMING

1.1 INTRODUCTION

1.1.1 LPP (LINEAR PROGRAMMING PROBLEM)
Linear programming is a technique which allocates scare available resources under conditions of certainty in an optimum manner, (i.e. maximum or minimum) to achieve the company objectives which may be maximum overall profit or minimum overall cost.
Linear programming deals with the optimization (maximization or minimization) of linear functions subjects to linear constraints. It is a mathematical method used to determining best optimal solution from a number of possible solutions. It is used mainly for optimization of resources within limited resources.

1.1.2 Example of L.P.P
Solution by graphical method
Maximize (z) = $3x_1 + 4x_2$ …(i)
Subject to $4x_1 + 2x_2 \geq 80$ …(ii)
$2x_1 + 5x_2 \leq 180$ …(iii)
$x_1, x_2 \geq 0$ …(iv)
1.The variable that enters into the problem are called decision variables, e.g., x_1, x_2
2.The expression showing the relationship between the manufacture's goal and the decision variables is called the objective function, e.g. = $3x_1 + 4x_2$ (maximize)
3.The inequalities (ii); (iii); (iv) are called constraints being all linear, it is a linear programming problem (L.P.P).

1.1.3 Graphical Method

1.1.3.1 Working Procedure

Step-I
Formulate the given problem as a linear programming problem.
Step-II
Plot the given constraints as equalities on x_1. x_2 co-ordinate plane and determine the convex region formed by them.
[A region or a set of points is said to be convex if the line joining any two of its points lies completely in the region (or the set)]
Step-III
Determine the vertices of the convex region and find the value of the objective function and find the value of the objective function at each vertex. The vertex which gives the optimal value of the objective function gives the desired optimal solution the problem.

1.1.4 Otherwise
Draw a dotted line through the origin representing the objective function with z = 0. As z is increased from zero, this line moves to the right remaining parallel to itself. We go on sliding this

ASSIGNMENT

1. The while solving a LP model graphically, the area bounded by the constraints is called
(a) Feasible region
(b) Infeasible region
(c) Unbounded solution
(d) None of the above

2. While solving a LP problem, infeasibility may be removed by
(a) Adding another constraint
(b) Adding another variable
(c) Removing a constraint
(d) Removing a variable

3. Which one of the following is true in case of simple method of linear programming?
(a)The constants of constraints equation may be positive or negative
(b)In equalities are not converted into equations
(c)It cannot be used for two variable problems.
(d)The simplex algorithm is an iterative procedure

4. A feasible solution to an LP problem
(a)Must satisfy all of the problem's constraints simultaneously
(b)Need not satisfy all of the constraints
(c)Must be a corner point of the feasible region
(d)Must optimize the value of the objective function

5. The role of artificial variables in the simplex method is
(a)To aid in finding an initial solution
(b)To find optimal dual price in the final simplex table
(c)To start phases of simplex method
(d)All of the above

6. Simplex method of solving linear programming problem uses
(a)All the points in the feasible region
(b)Only the corner points of the feasible region
(c)Intermediate points within the infeasible region
(d) Only the interior points in the feasible region

7. In linear programming a basic feasible solution
(a)Satisfies constraints only
(b)Satisfies constraints and non-negativity restrictions
(c)Satisfies non-negativity
(d)Optimizes the objective function

8. A tie for leaving variables in simplex procedure implies
(a) Optimally (b) Cycling
(c) No solution (d) Degeneracy

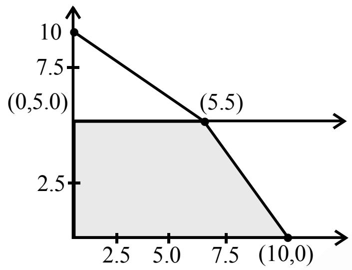
9. The steps followed for the development of linear programming model are
1.State of problem in the form of a linear programming model
2.Determine the decision variable
3.Write the objective variables
4.Developed in equations (or equations) for the constraints.
The correct order is
(a) 1,2,3,4 (b) 2,1,3,4
(c) 4,1,2,3 (d) 4,3,2,1.

10. A constraint in equation $5x_1 - 3x_2 \leq -5$ is converted as, $(3x_2 + \alpha_1) - (5x_1 + s_1) = 5$. Then '$s_1$' is called as
(a) Basic variable
(b) Artificial variable
(c) Surplus variable
(d) Non-basic variable

11. Consider the following Linear Programming Problem (LPP);
Maximize $Z = 3x_1 + 2x_2$
Subject to $x_1 \leq 4, x_2 \leq 6$
$3x_1 + 2x^2 \leq 18, x_1 \geq 0, x2 \geq 0$
(a) The LPP has a unique optimal solution
(b) The LPP is infeasible
(c) The LPP is unbounded
(d) The LPP has multiple optimal solution

GATE QUESTIONS

1. The problem of maximizing $z = x_1 - x_2$ subject to constrai



[GATE - 2018]

(a) No solution (b) One solution
(c) Two solution (d) More solution

2. For minimum Value of 3x + 5y
So that :
$3x + 5y \le 15$,
$4x + 9y \le 8$;
$13x + 2y \le 2$;
$x \ge 0, y \ge 0$
is________.

[GATE - 2018]

3. Maximize $Z = 5x_1 + 3x_2$
nts $x_1 + x_2 \le 10$; $x_1 \ge 0$ and $x_2 \le 5$ has Subject to $x_1 + 2x_2 \le 10$, $x_1 - x_2 \le 8$, $x_1, x_2 \ge 0$
In the starting simplex tableau, x_1 and x_2 are non - basic variables and the value of Z is zero. The value of Z in the next simplex tableau is ____

[GATE - 2017]

4. Two models, P and Q, of product earn profits of Rs. 100 and Rs. 80 per piece, respectively. Production time for P and Q are 5 hours and 3 hours, respectively, while the total production time available is 150 hours. For a total batch size of 40, to maximize profit, the number of units of P to be produced is ____.

[GATE - 2017]

5. Maximize $Z = 15X_1 + 20X_2$
Subject to
$12X_1 + 4X_2 \ge 36$
$12X_1 - 6X_2 \le 24$
$X_1, X_2 \ge 0$
The above linear programming in problem has

[GATE - 2016]

(a) Infeasible solution
(b) Unbounded solution
(c) Alternative optimum solutions
(d) Degenerate solution

6. For linear programming problem
Maximize $Z = 3X_1 + 2X_2$
Subject to
$-2X_1 + 3X_2 \le 9$
$X_1 - 5X_2 \ge -20$
$X_1, X_2 \ge 0$
The above problem has

[GATE - 2015]

(a) Unbounded problem
(b) Infeasible solution
(c) Alternative optimum solution
(d) Degenerate solution

7. Consider an objective function $Z(x_1, x_2) = 3x_1 + 9x_2$ and the constraints
$x_1 + x_2 \le 8$
$x_1 + 2x_2 \le 4$
$x_1 \ge 0, x_2 \ge 0$
The maximum value of the objective function is _________.

[GATE - 2014]

8. A linear programming problem is shown below:
Maximize
3x + 7y
Subject to
$3x + 7y \le 10$
$4x + 6y \le 7$
$X, y \ge 0$
It has

[GATE - 2013]

(a) An unbounded objective function
(b) Exactly one optimal solution

CHAPTER - 2
INVENTORY

2.1 INTRODUCTION

It is the stock of item or resources used in organization. It may be defined as the stock on hand at a given time and it may be held for purpose of letter use or sale. It is usable but idle resources having an economic value and it may include raw material, work in process inventory, semi finished inventory and finished goods.

A fundamental objective of a good system of operation control of Inventories is to be able to place an order at the right time,

From the right source

To acquire the right quantity

At right price

And right quality

"Inventory is the life blood of a production system."

2.2 CATEGORIES

1. Production inventories: go to final product
2. MRO (Maintenance, Repair and operating supplies) e.g. spare parts, oils grease.
3. In-process inventories (semi-finish products at various production stages)
4. Finished goods inventories
5. Miscellaneous inventory

2.3 ANOTHER WAY OF CLASSIFYING INDUSTRIAL INVENTORIES ARE

1. Transition inventory
2. Speculative inventory
3. Precautionary inventory

2.4 SELECTIVE INVENTORY CONTROL

2.4.1 Different type of Inventory Analysis

1. ABC analysis (class A, class B, class C)
2. VED Analysis (vital, Essential, Desirable)
3. SDE Analysis (Scarce, Difficult, Easily Available)
4. HML Analysis (High, Medium, Low Cost)
5. FSN Analysis (Fast, Slow, Non-moving items)

2.4.2 ABC Analysis

The common and important of the selective inventory control of ABC analysis. ABC Analysis is done for items on stock and the basis of analysis is the annual consumption in terms of money value.

Control of A-item: 10 % of the item accounts 70% costs

Control of B-item: 20% of the item accounts 20% costs

Control of C-item: 70% of the items accounts 10% costs

ASSIGNMENT

1. Inventory management consists of
(a) Effective running of stores
(b) State of merchandise methods of storing and maintenance etc.
(c) Stock control system
(d) all of the above

2. Inventory can be in the form of
(a)Raw materials
(b)In process goods
(c)Brought out part, semi finished goods and subassemblies
(d)All of the above

3. Two groups of costs in inventory control are
(a) Carrying costs and ordering costs
(b) Relevant cost and ordering costs
(c) Carrying costs an total costs
(d) Relevant costs and total costs

4. In basic economic order quantity model for the optimal order quantity
(a) Holding cost is more than ordering cost
(b) Holding cost is less than ordering cost
(c) Holding cost is equal to ordering cost
(d) Holding cost is two times the ordering cost

5. In inventory planning, extra inventory is unnecessary carried to the end of the planning period when using one of the following size decision policies.
(a) Lot for lot production
(b) Economic order quantity (EQQ) lot size
(c) Period order quantity (POQ) lot size
(d) Part period total cost balancing

6. The formula for economic order quantity does not contain
(a) Order cost
(b) Carrying cost
(c) Cost of the item
(d) Annual demand

7. For a given annual consumption, the minimum total inventory cost is proportional to square root of the product of
(a) Ordering cost per order
(b) Carrying cost per until per year
(c) Both (a) and (b) above
(d) None of the above

8. When order quantity increases the ordering costs will
(a) Increase
(b) Decrease
(c) Remains same
(d) None of the above

9. One of the important reasons for carrying inventory is to
(a) Improve customer service
(b) Get quantity discounts
(c) Maintain operational capability
(d) All of the above

10. A shop owner with an annual constant demand of `R` units has ordering costs of Rs. 'C_O' per order and carrying costs Rs. 'C_O' per unit per year. The economic order quantity for a purchasing model having no shortage may be determined from
(a) $\sqrt{\dfrac{24R}{C_C R_O}}$ (b) $\sqrt{\dfrac{24RC_O}{C_C}}$
(c) $\sqrt{\dfrac{2RC_O}{C_C}}$ (d) $\sqrt{\dfrac{2RC_C}{C_O}}$

11. Which of the following is not a part of inventory Carrying Cost?
(a) Cost of storage Cost
(b) Cost of obsolescence
(c) Cost of insurance
(d) Cost of inwards goods inspection

ESE OBJ QUESTIONS

1. A particular item has a demand of 9000 units/year. The cost of one procurement is Rs. 108 and the holding cost per unit is Rs. 2.40/year. The replacement is instantaneous and no shortages are allowed. What is the optimum number of orders/year?

[ESE - 2017]

(a) 7 orders/year (b) 8 orders/year
(c) 9 orders/year (d) 10 orders/year

2. A firm's inventory turnover of Rs. 8,00,000 is 5 times the cost of goods sold. If the inventory turnover is improved to 8 with the cost of goods sold remaining the same, a substantial amount of fund is either released from, or gets additionally invested in, inventory. Which one of the following statements is correct?

[ESE - 2017]

(a) Rs.1,60,000 is released
(b) Rs.1,60,000 is additionally invested.
(c) Rs.60,000 is released.
(d) Rs.60,000 is additionally invested

3. A stockiest has to supply 400 units of a product every Monday to his customers. He gets the product at Rs. 50 per unit from the manufacture. The cost of ordering and transportation from the manufacture to the stockist's premises is Rs. 75 per order. The cost of carrying inventory is 7.5% per year of the cost of the product. What are the economic lot size and the total optimal cost (including capital cost) for the stockiest?

[ESE - 2017]

(a) 989 units/order and Rs. 20,065.80/week
(b) 912 units/order and Rs. 20,065.80/week
(c) 989 units/order and Rs. 18,574.50 /week
(d) 912 units/order and Rs. 18,574.50/week

4. The annual demand of a commodity in a supermarket is 80000. The cost of placing an order is Rs 4,000 and the inventory cost of each item is Rs 40. What is the economic order quantity?

[ESE - 2015]

(a) 2000 (b) 4000
(c) 5656 (d) 6666

5. In ABC inventory control of spare parts , the items A, B and C respectively refer to

[ESE - 2015]

(a)High stock out cost, moderate stock-out cost and low stock-out cost
(b)Low stock-out cost, high stock-out cost and low stock-out cost
(c)Moderate stock-out cost, high stock-out cost and low stock-out cost
(d)Stock out costs whose sequence depends on other factors also

6. What is the ratio of annual order cost to annual cost when the order size is determined using Economic Order quantity (EOQ) model?

[ESE - 2015]

(a) 0.5 (b) 0.25
(c) 0.75 (d) 1

7. Large size of inventory is a sign of :

[ESE - 2013]

(a) Better planning
(b) Inefficiency
(c) Reliable control of vendors
(d) Better scheduling

8. Purification of inventory means :

[ESE - 2013]

(a) Cleaning of inventories
(b) Disposing of inventories
(c) Processing of inventories
(d) Storing of inventories in bins

9. In an economic order quantity based inventory control when re-order level id greater than order quantity, the number of orders outstanding at any time is

CHAPTER - 3

TRANSPORTATION

3.1 TRANSPORTATION PROBLEM

These are used for meeting the supply and demand requirement under given conditions.

This is a special class of L.P.P. in which the objective is to transport a single commodity from various origins to different destinations at a minimum cost. The problem can be solved by simplex method. But the number of variables being large, there will be too many calculations.

3.2 FORMULATION OF TRANSPORTATION PROBLEM

There are m plant locations (origins) and n distribution centers (destinations). The production capacity of the i^{th} plant is a_i and the number of units required at the j^{th} destination bj. The Transportation cost of one unit from the i^{th} plant to the j^{th} destination c_{ij}. Our objective is to determine the number of units to be transported from the i^{th} of plant to j^{th} destination so that the total transportation cost is minimum.

Let x_{ij} be the number of units shipped from i^{th} plant to j^{th} destination, then the general transportation problem is:

$$\sum_{i=1}^{m}\sum_{j=1}^{n} C_{ij}\, x_{ij}$$

Subjected to

$x_{i1} + x_{i2} + \text{-------} + x_{in} = a_i$ (for i^{th} origin i = 1, 2, ……..,m)

$x_{ij} + x_{2j} + \text{-------} + x_{mj} = n_j$ (for j^{th} origin i = 1, 2, ……..,n)

$x_{ij} \geq 0$

The two sets of constraints will be consistent if $\sum_{i=1}^{m} a_i = \sum_{j=1}^{n} b_j$, which is the conditions for a transportation problem to have a feasible solution? Problems satisfying this condition are called balanced transportation problem.

3.3 DEGENERATE OR NON-DEGENERATE

A feasible solution to a transportation problem is said to be basic feasible solution of it contains at the most (m + n – 1) strictly positive allocations, otherwise the solution will 'degenerate'. If the total number of positive (non-zero) allocations is exactly (m + n – 1), then the basic feasible solution is said to be non-degenerate, if '(m + n – 1)' $\rightarrow$ no. of allocated cell. Then put an $\varepsilon \rightarrow 0$ at a location so that all ui, vj can be solved and after optimality check put $\varepsilon = 0$.

Optimal solution: The feasible solution which minimizes the transportation cost is called an optimal solution.

3.4 WORKING PROCEDURE FOR TRANSPORTATION PROBLEMS

Step-I.

Construct transportation table: if the supply and demand are equal, the problem is balance. If supply and demand is not same then add dummy cell to balance it.

Step-II.

Find the initial basic feasible solution. For this use **Vogel's approximation Method (VAM)**. The VAM takes into account not only the least cost c_{ij} but also the costs that just exceed the least cost

ASSIGNMENT

1. The occurrence of degeneracy while solving a transportation problem means that
(a) Total supply equals total demand
(b) The solution so obtained is not feasible
(c) The few allocations become negative
(d) None of the above

2. Penalty cost method is
(a) Least cost method
(b) North West corner method
(c) Vogel's approximation method
(d) None

3. One disadvantage of using North-West corner Rule of find initial solution to the transport-tation problem is that
(a)It is complicated to use
(b)It does not take into account cost of transportation
(c)It leads to a degenerate initial solution
(d)All of the above

4. The degeneracy in the transportation problem indicates that
(a) Dummy allocation(s) needs to be added
(b) The problem has no feasible solution
(c) The multiple optimal solution exist
(d) (a) and (b) but not (c)

5. The solution in a transportation model (of dimension m x n) is said to be degenerate if it has
(a) Exactly (m + n – 1) allocations
(b) Fewer than (m + n – 1)
(c) More than (m + n -1) allocations
(d) (m x n) allocations

6. In a transportation problem, the materials are transported from 3 plants to 5 warehouses. The basic feasible solution must contain exactly, which one of the following allocated cells?
(a) 3 (b) 5
(c) 7 (d) 8

7. Which one of the following is not the solution method of transportation problems?
(a) Hungarian method
(b) Northwest corner method
(c) Least cost method
(d) Vogel's approximation method

8. The supply at three sources is 50, 40 and 60 units respectively while the demand at the four destinations is 20, 30, 10 and 50 units. In solving this transportation problem.
(a)A dummy sources of capacity 40 units is needed
(b)A dummy destination of capacity 40 units is needed
(c)No solution exists as the problem is infeasible
(d)None solution exists as the problem is degenerate.

9. Consider the following statements:
(a) For the application of optimality test in case of transportation model, the number of allocations should be equal to m + n, where m is the number of rows and n is the number of columns of the matrix.
(b) Transportation problem is a special case of a linear programming problem.
(c) In case of assignment problem the first step is to make a square matrix by adding a dummy row or dummy column.
Which of these statements is/are correct?
(a) 1, 2 and 3 (b) 1 and 2
(c) 2 and 3 only (d) 2 only

10. The linear programming is used for optimization problems which satisfy the following conditions:
1.Objective function expressed as a linear function of variables
2.Resources are unlimited
3.The decision variables are inter-related and non-negative.
Which of these statement is/are correct?
(a) 1, 2 and 3 (b) 2 and 3
(c) 1 only (d) 1 and only

CHAPTER - 4
ASSIGNMENT

4.1 INTRODUCTION

An assignment problem is a special type of transportation problem in which the objective is to assign a number of origins to an equal number of destinations at a minimum cost (for maximum profit).

Assignment problems differs from **transportation** problem on two grounds:

(i) Matrix must be always square i.e, m = n

(ii) Allocation in each row and column will be only one.

$\text{Min } Z = \sum_{i=1}^{n} \sum_{j=1}^{n} c_{ij}\, x_{ij}$ and all $a_i = 1$ and $b_j = 1$ and $x_{ij} = 0$ or 1

4.2 FORMULATION OF AN ASSIGNMENT PROBLEM

There are n new machines m_i (I = 1, 2, ….., n) which are to be installed in a machine shop. There are n vacant spaces s_i (j = 1, 2, …., n) available. The cost of installing the machine m_i at space S_j is C_{ij} rupees.

Let us formulate the problem of assigning machines to spaces so as to minimize the overall cost.

Let x_{ij} be the assignment of machine m_i to space s_j i.e. Let x_{ij} be a variable such that

$$x_{ij} = \begin{cases} 1, \text{if } i^{th} \text{ machine is installed at } j^{th} \text{ space} \\ 0, \text{ otherwise} \end{cases}$$

Since one machine can only be installed at each place, we have

$x_{i1} + x_{i2} + \ldots\ldots\ldots x_{in} = 1$ for $m_i (I = 1, 2, 3, \ldots., n)$

$x_{1i} + x_{2i} + \ldots\ldots.. x_{ij} = 1$ for $s_i (j = 1, 2, 3, \ldots., n)$

Thus assignment problem can be stated as follows:

Determine $x_{ij} \geq 0$ (j = 1, 2, 3, ….., n) so as to minimize $(z) = \sum_{i=1}^{n} \sum_{j=1}^{n} C_{ij} x_{ij}$

Subject to the constraints

$\sum_{i=1}^{n} x_{ij} = 1, j = 1, 2, \ldots., n$ and $\sum_{j=1}^{n} x_{ij} = 1, i = 1, 2, 3, \ldots., n$

This problem is explicitly represented by the following n × n cost matrix:

ESE OBJ QUESTIONS

1. Consider the following statements
The assignment problem is seen to be the special case of the transportation problem in which
1. $m = n$
2. all $a_i = 1$
3. $x_{ij} = 1$
(The symbols have the usual meaning)
Which of these statements are correct?

[ESE - 2007]

(a) 1, 2 and 3 (b) 1 and 2 only
(c) 2 and 3 only (d) 1 and 3 only

2. Consider the following statements in respect of assignment method of optimization
1. The matrix format of the method must be a square matrix
2. Some type of rating has to be given to the performance of each pairing ?
Which of these above is/are correct?

[ESE - 2006]

(a) Only 1 (b) Only 2
(c) Only 1 and 2 (d) Neither 1 nor 2

3. Which one of the following statement is NOT correct?

[ESE - 2000]

(a) Assignment model is a special case of a linear programming problem
(b) In queuing models, Poisson arrivals and exponential services are assumed
(c) In transportation problems, the non-square matrix is made square by adding a dummy row or a dummy column
(d) In linear programming problems, dual of a dual is a primal

4. The assignment algorithm is applicable to which of the following combined situations for the purpose of improving productivity
1. Identification of the sales force market.
2. Scheduling of operator machine
3. Fixing machine-location
Select the correct answer using the codes given below?

[ESE - 1998]

(a) 1, 2 and 3 (b) 1 and 3
(c) 2 and 3 (d) 1 and 2

5. Match List-I (Or technique) with List-II (Application) and select the correct answer using the codes given below the lists :

List-I
A. Linear programming
B. Transportation
C. Assignment
D. Queuing

List-II
(i) Ware house location decision
(ii) Machine allocation decision
(iii) Product mix decision
(iv) Project management decision
(v) Number of servers decision

[ESE - 2000]

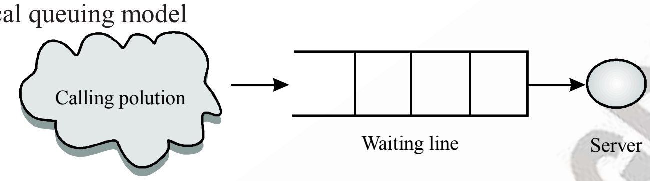
Codes:
(a) A-i, B-ii, C-iii, D-v
(b) A-iii, B-i, C-ii, D-v
(c) A-i, B-iii, C-iv, D-v
(d) A-iii, B-ii, C-i, D-iv

CHAPTER - 5
QUEUING THEORY

5.1 QUEUING THEORY OF WAITING LINE

The goal of queuing model is the achievement of economic balance between the cost of providing services and the cost associated with the wait required for the service. This theory is applicable in service oriented organization machine repairs shops, production system, semi-finished parts waiting for finished operation etc.

A simple but typical queuing model



Typical measures of system performance are sever utilization, length of waiting lines, and delays of customers.

5.2 KEY ELEMENTS OF QUEUING SYSTEMS

Customers

Refers to anything that arrives at a facility and requires service, e.g., people, machines, truck, emails.

Server

Refers to any resource that provides the requested service, e.g, receptionist, repairpersons, retrieval machines, runways at airport.

1. Calling Population

The population of potential customers may be assumed to be finite or infinite.

Finite Population Model

If arrival rate depends on the number of customers being served and waiting, e.g., model of one corporate jet, if it is being repaired, the repair arrival rate becomes zero.

Infinite Population Model:

If arrival rate is not affected by the number of customers being served and waiting, e.g., systems with large population of potential customers.

5.3 SOME APPLICATION OF WAITING LINE PROBLEM

S. No.	Application area	Arrival	Waiting line	Service facility
1.	Factory	Material/tools	In-process inventory (WIP)	Work stations
2.	Assembly line	Sub-assemblies	WIP	Employees currently
3.	Machine maintenance	Repair tools & equipment	Machine needing repair	Maintenance crew
4.	Airport	Plane	Planes ready to fly	Runway
5.	Bank	Customer	Deposit/withdrawal	Bank employed & computer
6.	Walk-in interview	Job seekers	Applicants	Interviewers
7.	Phone exchange	Dialed number	Caller	Switchboard

ASSIGNMENT

1. In the Kendall's notation for representing queuing models the first position represents
(a) Probability law for the arrival
(b) Probability law for the service
(c) Number of channels
(d) Capacity of the system

2. In queueing models, M/M/c denotes a Poisson arrival process and
(a)Exponentially distributed service times and c servers in series
(b)Constant service times and c servers in series
(c)Exponentially distributed service times and c servers in parallel
(d)Constant service times and c servers in parallel

3. Queuing theory is used for
(a) Inventory problems
(b) Traffic congestion studies
(c) Job-shop scheduling
(d) All of the above

4. Queuing theory is associated with
(a) Sales
(b) Inspection time
(c) Waiting time
(d) Production time

5. In a queuing problem, if the arrivals are completely random, then the probability distribution, of number of arrivals in a given time follows :
(a) Poisson distribution
(b) Normal distribution
(c) Binomial distribution
(d) Exponential distribution

6. Length of the System (L_S) in queuing is equal to
(a) $\frac{\rho}{1-\rho}$ (b) $\frac{1}{\lambda}(\frac{\rho}{1-\rho})$
(c) $\frac{1}{\mu}(\frac{\rho}{1-\rho})$ (d) $\frac{p^2}{1-\rho}$

7. Queue length(L_q) in queuing is qua to
(a) $\frac{\rho}{1-\rho}$ (b) $\frac{\rho^2}{1-\rho}$
(c) $\frac{1}{\lambda}(\frac{\rho}{1-\rho})$ (d) $\frac{1}{\mu}(\frac{\rho}{1-\rho})$

8. In a single server queuing system with arrival rate of 'λ' and mean service time of 'μ' the expected number of customers in the system is $\left(\frac{\lambda}{\mu-\lambda}\right)$
What is the expected waiting time per customer in the system?
(a) $\frac{\lambda^2}{(\mu-\lambda)}$ (b) $\frac{\lambda}{(\mu-\lambda)}$
(c) $\frac{1}{(\mu-\lambda)}$ (d) $\frac{(\mu-\lambda)}{\lambda}$

9. In a M/M 1 queue, the service rate is
(a) Poisson
(b) Exponential
(c) Linear
(d) None of the above

10. In a single server infinite population queuing model, arrivals follow a Poisson distribution with mean λ=4 per hour. The service times are exponential with mean service time equal to 12 minutes. The expected length of the queue will be
(a) 4 (b) 3.2
(c) 1.25 (d) 5

11. Patients arrive at a doctor's clinic according to the Poisson distribution. Check up time by the doctor follows an exponential distribution. If

ESE CONV QUESTIONS

1. Explain Queuing model and its applications.

[ESE - 2014]

Solution.

Customers (m/c, vehicles, students, people etc) arrive at a constant or variable rate for services at service facilities. If the service facility is free, they are served immediately. If the service facility is busy providing services to other customers, the newly arrived customers have to wait. Thus if they must wait for services, they either begin a queue or join no existing queue, and remain in the queue until they are served.

Queuing models with Poisson input-Exponential service

Model-1: Infinite queue, infinite source, single server.

Model-2: Infinite queue, infinite source, multiple server.

Model-3: Finite queue, infinite source, single server.

Model-4: Finite queue, infinite source, multiple server.

Application of queuing model:

Retail shops

1. Doctor's office
2. Airports check-in
3. Traffic congestion
4. Automobile service centers
5. Railways wagon yard

2. In a machine shop, certain type of machines break-down at an average rate of 6 per hour. The Break-downs are in accordance with Poisson process. The estimated costs of idle machine is Rs. 15 per hour. Two repairmen A and B with different skills are being considered to be hired as repairmen. Repairmen A takes six minutes on an average to repair a machine and his wages are Rs. 8 per hour, whereas the repairman B takes five minutes to repair and the wages are Rs. 10 per hour. Which repairman's service should be used and why? Assume the work shift of 8 hours.

[ESE - 2004]

Solution.

Given, $\lambda = 6$/hour, i.e., machines break-down rate

Ideal time cost of the machines = Rs. 15/hour

Repairman A: (whose wage is Rs. 8 per hour)

Service rate, $\mu_A = \frac{1}{6}/\text{min} = 10/\text{hour}$

Average number of units in the system, $L_S = \frac{\lambda}{\mu_A - \lambda} = \frac{6}{10-6} = 1.5$

Machine hours lost in 8 hour day = 1.5 × 8 = 12 hours

CHAPTER - 1
FORECASTING

1.1 FORECASTING

Forecasting is the prediction of future sales or demand for a product. It is defined as the estimation of future activities i.e. the estimation of time, quality, quantity of future work. These estimate provide the basis for determining the demand of man power, machines and material in future.

It is a calculated economical analysis.

It is not a guess work but a projection based on passed sales figure and human judgment.

1.2 NEED OF FORECASTING

1. It helps in determining the volume of production and production rate.
2. It forms the basis for production budget, labour budget, material budget etc.
3. It suggest the need for plant expansion
4. It helps in product design & development.
5. It helps in determining price policies.
6. Helps in determining the extent of marketing, advertisement and distribution required.

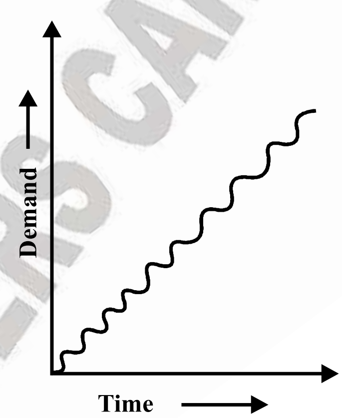
1.3 TYPES OF DEMAND VARIATION

1. Trend Variation

It shows a long term upward or downward movement in the demand or sales of a product. It shows a regular pattern.

Example.

Newspaper, Cellphones etc.



GATE QUESTIONS

1. The time series forecasting method that gives equal weightage to each of the m most recent observation is

[GATE - 2018]

(a) Moving average method

(b) Exponential smooting with linear trends

(c) Triple Exponential smoothing

(d) Kaiman Filter

2. For a canteen, the actual demand for disposable cups was 500 units in January and 600 units in February .The forecast for the month of January was 400 units .The forecast for the month of March considering smoothing coefficient as 0.75 is_______

[GATE - 2015]

3. Sales data of a product is given in the following table :

Month	January	February	March	April	May
Number of unit sold	10	11	6	19	25

Regarding forecast for the month of June, which one of the following statements is **TRUE**?

[GATE - 2014]

(a)Moving average will forecast a high value compared to regression

(b)Higher the value of order N , the greater will be the forecast value by moving a average

(c)Exponential smoothing will force cast a higher value compared to regression

(d)Regression will forecast a higher value compared to moving average

4. The actual sales of a product in different months of a particular year are given below:

Sep.	**Oct.**	**Nov.**	**Dec.**	**Jan.**	**Feb.**
180	280	250	190	240	?

The forecast of the sales, using the 4 months moving average method, for the month of February is _________

[GATE - 2014]

5. In exponential smoothening method, which one of the following is true?

[GATE - 2014]

(a) $0 \le \alpha \le 1$ and high value of a is used for stable demand

(b) $0 \le \alpha \le 1$ and high value of a used for unstable demand

(c) $\alpha \ge 1$ and high value of a is used for stable demand

(d) $\alpha \le 0$ and high value of a is use for unstable demand.

6. In simple exponential smoothing forecasting, to give higher weight age to recent demand information, the smoothing constant must be close to

[GATE - 2013]

(a) –1 (b) zero

(c) 0.5 (d) 1.0

7. The demand and forecast for February are 12000 and 10275, respectively. Using single exponential smoothening method (smoothening coefficient = 0.25), forecast for the month of March is

[GATE - 2010]

(a) 431 (b) 9587

(c) 10706 (d) 11000

8. Which of the following forecasting methods takes a fraction of forecast error into account for the next period forecast?

[GATE - 2009]

(a) Simple average method

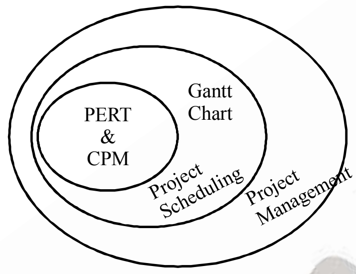
(b) Moving average method

(c) Weighted moving average method

(d) Exponential smoothening method

CHAPTER - 2
PERT AND CPM

2.1 PROJECT MANAGEMENT
(Project Planning and Scheduling)-Gantt Chart
Special Scheduling Techniques: PERT and CPM



1. Gantt Chart
Is one of the first scientific techniques for project planning and scheduling.

2. CPM
Critical Path Method.

3. PERT
Program Evaluation and Review Technique.

4. Project
Project is a group of Inter-related activities which must be executed in a certain order before the entire task can be completed. The activities are related in a Logical and sequential order in the sense that some activities cannot start until all the activities prior to them are completed. When all the activities are executed then only the project is completed.

5. Event
The event are point in time & denotes the beginning and the end point of an activity. An Event defines an accomplishment occurring at an instantaneous point of time which neither consumes any time nor resources for its completion.

6. Activity
It is a recognizable and identifiable part of a project which consumes time & resources for its completion and may involves physical or mental work.

7. Network Diagram
It represents the sequence of different activities that make a project.

2.1.1 Rules for Network Diagram
1. No activity can be started until all the activities prior to it has been completed.

ASSIGNMENT

1. The performance of a specific task in CPM is known as
(a) Dummy (b) Event
(c) Activity (d) Contract

2. In CPM network critical path denotes the
(a) Path where maximum resources are used
(b) Path where minimum resources are used
(c) Path where delay of one activity prolongs the duration of completion of project
(d) Path that gets monitored automatically

3. In PERT, the distribution of activity times is assumed to be
94.
(a) Normal (b) Gamma
(c) Beta (d) Exponential

4. A dummy activity is used in PERT network to describe
(a) Precedence relationship
(b) Necessary time delay
(c) Resource restriction
(d) Resource idleness

5. In PERT analysis a critical activity has
(a) Maximum float (b) Zero float
(c) Maximum cost (d) Minimum cost

6. The expected time(t_e) of a PERT activity in terms of optimistic time(t_o), pessimistic time(t_p) and most likely time(t_m) is give by

(a) $t_e = \frac{t_o + 4t_m + t_p}{6}$

(b) $t_e = \frac{t_o + 4t_p + t_m}{6}$

(c) $t_e = \frac{t_O + 4t_m + t_p}{3}$

(d) $t_e = \frac{t_o + 4t_p + t_m}{3}$

7. The critical path of a network is the path that
(a) Takes the shortest time
(b) Takes the longest time
(c) Has the minimum variance
(d) Has the maximum variance

8. In PERT the span of time between the optimistic and pessimistic time estimates of an activity is
(a) 3σ (b) 6σ
(c) 12σ (d) none

9. In an activity has zero slack, it implies that
(a) It lies on the critical path
(b) It is a dummy activity
(c) The project is progressing well
(d) None

10. Activity-on-Arrow (AOA) diagram s preferred over Activity on Node (AON) diagram because
(a)AOA diagrams are simple to construct
(b)AOA diagrams give a better sense of the flow of time throughout a project
(c)AOA diagrams do not involve dummy activities
(d)All of the above

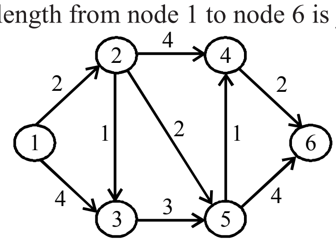
11. The most likely time (m) is `mode` of the
(a) Normal distribution
(b) Bea distribution
(c) Binomial distribution
(d) None of the above

12. Fulkerson's rule is connected with
(a) Numbering of event in PERT/CPM
(b) The simulating model
(c) Queuing theory
(d) None of the above

13. The variance of the completion time of a project in the sum of variance of
(a) All activity times

GATE QUESTIONS

1. The arc lengths of a directed graph of a project are as shown in the figure. The shortest path length from node 1 to node 6 is ________.



[GATE - 2017]

2. A project starts with activity A and ends with activity F. The precedence relation and durations of the activities are as per the following table:

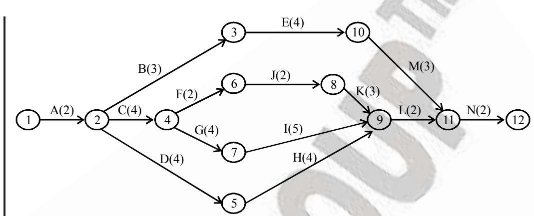
Activity	Im Predecessors	Duration (days)
A	–	4
B	A	3
C	A	7
D	B	14
E	C	4
F	D,E	9

The minimum project completion time (in days) is ________.

[GATE - 2017]

3. A project consists of 14 activities, A to N.The duration of these activities (in days) are shown in bracelets on the network diagram. The latest finish time (in days) for node 10 is

[GATE - 2016]

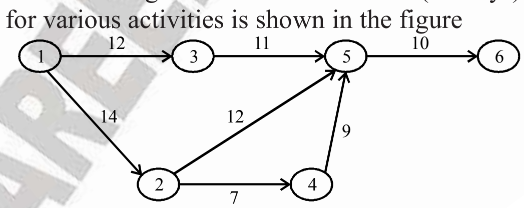


4. In PERT chart, the activity time distribution is

[GATE - 2016]

(a) Normal
(b) Binomial
(c) Poisson
(d) Beta

5. A project consists of 7 activities. The network along with the time durations (in days) for various activities is shown in the figure



The minimum time (in days) for completion of the project is_______.

[GATE - 2016]

6. Following data refers to the activities of a project ,where node I refers to the start and node 5 refers to the end of the project

Activity	Duration (days)
1-2	2
2-3	1
4-3	3
1-4	3
2-5	3
3-5	2
4-5	4

The critical path (CP) in the network is

[GATE - 2015]

CHAPTER - 3
ROUTING & SCHEDULING

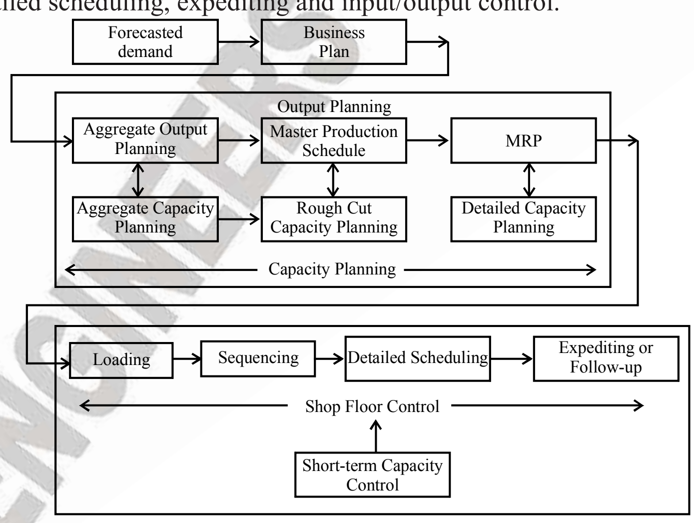
3.1 ROUTING

3.1.1 Routing includes the planning
What work shall be done on the material to produce the product or part, where and by whom the work shall be done. It also includes the determination of path that the work shall follow and the necessary sequence of operations which must be done on the material to make the product.

3.1.2 Routing procedure consists of the following steps
The finished product is analyzed thoroughly from the manufacturing stand point, including the determination of components if it is an assembly product. Such an analysis must include:
1. Material or parts needed.
2. Whether the parts are to be manufactured, are to be found in stores (either as raw materials or worked materials), or whether they are-to be purchased.
3. Quantity of materials needed for each part and for the entire order.
The following activities are to be performed in a particular sequence for routing a product
(i) Analysis of the product and breaking it down into components.
(ii) Taking makes or buys decisions.
(iii) Determination of operations and processing time requirements.
(iv) Determination of the lot size.

3.2 SCHEDULING

3.2.1 Introduction
Scheduling is used to allocate resources over time to accomplish specific tasks. It should take account of technical requirement of task, available capacity and forecasted demand. Forecasted demand determines plan for the output, which tells us when products are needed. The output plan should be translated into operations, timing and schedule on the shop-floor. This involves loading, sequencing, detailed scheduling, expediting and input/output control.



The Planning and Scheduling Function

GATE QUESTIONS

1. Processing times (including step times) and due dates for six jobs waiting to be processed at a work centre are given in the table. The average tardiness (in days) using shortest processing time rule is______(correct to two decimal places).

Job	Processing time (days)	Due date (days)
A	3	8
B	7	16
C	4	4
D	9	18
E	5	17
F	13	19

[GATE - 2018]

2. Following data refers to the jobs (P, Q, R, S) which have arrived at a machine for scheduling. The shortest possible average flow time is _______ days.

[GATE - 2015]

Job	Processing Time (days)
P	15
Q	9
R	22
S	12

Ave

Common Data for Q.3 & Q.4
Four jobs are to be processed on a machine as per data listed in the table.

Job	Processing Time (in days)	Due date
1	4	6
2	7	9
3	2	19
4	8	17

3. Using the Shortest Processing Time (SPT) rule, total tardiness is

[GATE - 2010]

(a) 0 (b) 2
(c) 6 (d) 8

4. If the Earliest Due Date (EDD) rule is used to sequence the jobs, the number of jobs delayed is

[GATE - 2010]

(a) 1 (b) 2
(c) 3 (d) 4

5. Six jobs arrived in sequence as given below:

Jobs	Processing Time (days)
I	4
II	9
III	5
IV	10
V	6
VI	8

Average flow time (in days) for the above jobs using Shortest Processing Time rule is

[GATE - 2009]

(a) 20.83 (b) 23.16
(c) 125.00 (d) 139.00

6. A set of 5 jobs is to be processed on a single machine. The processing time (in days) is given in the table below. The holding cost for each job is Rs. K per day.

CHAPTER - 4
BREAK EVEN ANALYSIS

4.1 AGGREGATE PLANNING
It is Dynamic Process and requires continuous updating. We develop an aggregate plan that identifies the best thing to do during each period of the planning horizon to optimize the long term goal of the organization. Then we implement the first passed of the plan. Now we gather more information and update and revise the plan. This is called ``Rolling Horizon``.

4.1.1 Strategies of Aggregate Planning
1. Traditional Approach
(i) Demand unalterable must be satisfied.
(ii) Subcontracting and overtime options modified.
(iii) Work force may vary.

2. Chase Strategy
(i) Production level is adjusted to match demand.
(ii) Hiring and training cost increases
(iii) Productivity losses due to poor moral of workers
(iv) Lay off cost severance pay
(v) Inventory cost decreases

3. Level Strategy
(i)Steady output
(ii)Inventory build up during the pared of row demand and repletion during period of high demand.

4. Pure Strategy
A single alternative is used rather than a combination of alternatives. It Maintain level workforce.

5. Mixed Strategy
A combination of alternatives is sued rather than a single one.

> No need of aggregate planning if demand is continuous.

4.2 BREAK-EVEN ANALYSIS
A. It usually refers to the number of pieces for which a business neither makes a profit nor incurs a loss. In other words, the selling price of the product is the total cost of production of the component.

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CONTENTS

CHAPTER - 1
BASIC CONCEPTS

1.1 INTRODUCTION
Thermodynamics is a combination of two words: thermo+dynamics where thermo: heat and dynamics: power it can be called as the science which deals with energy conversion form one from to another from like heat to power.
It can deals with energy interactions between system and surrounding. Excellently it is also defined as the science of three E′s: Equilibrium, Energy and Entropy. It is based four laws: Zeroth law, First law, Second law and Third law.
Whereas, the principles of thermodynamics one can derive general relations between such quantities as coefficients of expansion, compressibility, specific heat capacities, heats of transformation, and magnetic and dielectric coefficients.
The thermodynamics is basically used to design energy conversion devices like: Boiler, Turbine, Compress, Heat exchanger etc.
Thermodynamics is an experimental science based on a small number of principles that are generalizations made from experience. It is concerned only with macroscopic or large-scale properties of matter and it makes no hypotheses about the small-scale or microscopic structure of matter.

1. In Microscopic Thermodynamics
The behavior of the gas is described by summing up the behavior of each molecule. It may be calculated by the statistical techniques.

2. In Macroscopic Thermodynamics
The behavior of the gas is described by the net effect of action of all the molecules, which can be observed by human senses. It may be calculated by the classical techniques.

1.2 EQUILIBRIUM
It is a state in which the system is not capable of finite spontaneous change to another state without a finite change in the state of the surroundings or the state where spontaneous changes does not occur. It may classified as:

1. Mechanical Equilibrium
It attains with equality of Pressure in any system.

2. Thermal Equilibrium
It attains with equality of Temperature in any system.

3. Chemical Equilibrium
It attains with equality of Chemical potential in any system.

4. Thermodynamic Equilibrium
When there is no change in any macroscopic property, if system is isolated from its surroundings. A system will be in a state of thermodynamic equilibrium if the system will be in Mechanical, Thermal and Chemical Equilibrium.

GATE QUESTIONS

1. The volume and temperature of air (assumed to be an ideal gas) in a closed vessel is $2.87m^3$ ans 300K, respectively. The gauge pressue indicated by manometer fitted to the wall of the vessel is 0.5bar. If the gas constant of air is R = 287J/KgK and yhe atmospheric presure is 1bar, the mass of air(in Kg) in the vessel is

[GATE - 2017]

(a) 1.67 (b) 3.33
(c) 5.00 (d) 6.66

2. Assuming constant temperature condition and air to be an ideal gas, the variation in atmospheric pressure with height calculated from fluid statics is.

[GATE - 2016]

(a) Linear (b) Exponential
(c) Quadratic (d) Cubic

3. The internal energy of an ideal gas is a function of

[GATE - 2016]

(a) Temperature and pressure
(b) Volume and pressure
(c) Entropy pressure
(d) Temperature only

4. Temperature of nitrogen in a vessel of volume 2 m^3 is 288 K. A U-tube manometer connected by the vessel shows a reading of 70 cm of mercury (level higher in the end open to atmosphere). The universal gas constant is 8314 J/kmol-K, atmospheric pressure is 1.01325 bar, acceleration due to gravity is 9.81 m/s^2 and density of mercury is 13600 kg/m^3. The mass of nitrogen (in kg) in the vessel is _______

[GATE - 2015]

5. A mixture of ideal gases has the following composition by mass:

N_2	O_2	CO_2
60%	30%	10%

If the universal gas constant is 8314 J/kmol-K, the characteristic gas constant of the mixture (in J/kg-K) is ________

[GATE - 2015]

6. The Van der Waals equation of state is $\left(p+\frac{q}{v^2}\right)(v-b)=RT$ where p is pressure, v is specific volume, T is temperature and R is characteristic gas constant. The SI unit of a is

[GATE - 2015]

(a) J/kg-K (b) m^3/kg
(c) $m^5/kg\text{-}s^2$ (d) Pa/kg

7. A certain amount of an ideal gas is initially at a pressure P and temperature T_1. First, it undergoes a constant pressure process 1-2 such that $T_2 = 3T_1/4$. Then, it undergoes a constant volume process 2-3 such that $T_3 = T_1/2$. The ratio of the final volume to the ideal gas is

[GATE - 2014]

(a) 0.25 (b) 0.75
(c) 1.0 (d) 1.5

8. A pure substance at 8MPa and 400°C is having a specific internal energy of 2864 kJ/kg and a specific volume of 0.03432 m^3/kg. Its specific enthalpy (in kJ/kg) is _________.

[GATE - 2014]

9. An isolated thermodynamic system executes a process, choose the correct statement(s) form the following

[GATE - 1999]

(a) No heat is transferred
(b) No work is done
(c) No mass flows across the boundary of the system
(d) No chemical reaction takes place within the system

10. Match List-I with List-II
List I

CHAPTER - 2
WORK AND HEAT TRANSFER

2.1 INTRODUCTION

A closed system and its surroundings can interact in two ways:
1. By work transfer
2. By heat transfer
Also known as Energy Interactions and these bring about changes in the properties of the system. Heat and work are form of energy.

2.2 SIMILARITIES BETWEEN HEAT AND WORK

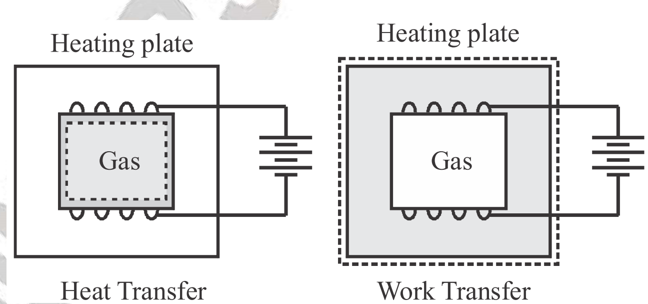
Similarities between Heat and Work as discussed below:
1. Both exist in transit state.
2. Both referred as Boundary phenomenon.
3. Both are path functions.
4. Both are inexact differentials denoted by symbol delta. (δQ/dQ or δW Dw)

2.3 DISSIMILARITIES BETWEEN HEAT AND WORK

Dissimilarities between Heat and Work as discussed in table below:

Heat	Work
Heat can only be transferred when there is difference of temperature between the system and surroundings.	Work transfer can measured in terms of displacement in the surroundings.
Heat is low grade energy.	Work is high grade energy.
Heat can transfers under stable or unstable condition.	Work cannot transfer under stable system.

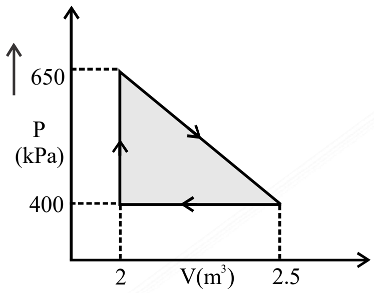
The concept of either heat transfer or work transfer can be understand with following consideration:



When gas considered as system the energy which cross the boundary due to temperature difference takes place between gas and surrounding. The energy which transfers due to temperature difference is called as heat transfer.
When heating plate considered as system the electrical energy cross the boundary of system which is considered as work transfer.

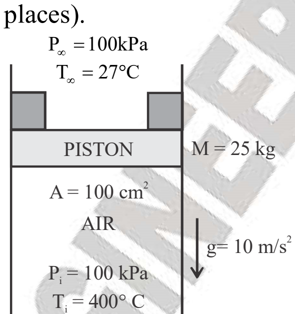
GATE QUESTIONS

1. An engine operates on the reversible cycle as shown in the figure. The work output from the engine (in kJ/cycle) is _______ (correct to two decimal places).



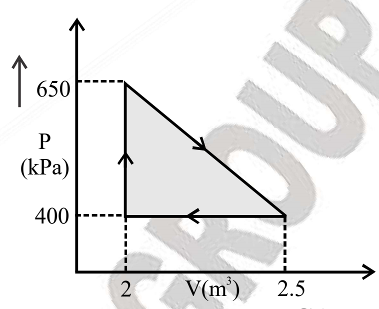
[GATE - 2018]

2. Air is held inside a non-insulated cylinder using a piston (mass M = 25 kg and area A = 100 cm^2) and stoppers (of negligible area), as shown in the figure. The initial pressure P_1 and temperature T_1 of air inside the cylinder are 200 kPa and 400°C, respectively. The ambient pressure P_∞ and temperature T_∞ are 100 kPa and 27°C respectively. The temperature of the air inside the cylinder (°C) at which the piston will begin to move is _________ (correct to two decimal places).



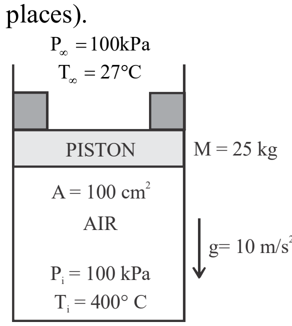
[GATE - 2018]

3. An engine operates on the reversible cycle as shown in the figure. The work output from the engine (in kJ/cycle) is _______ (correct to two decimal places).



[GATE - 2018]

4. Air is held inside a non-insulated cylinder using a piston (mass M = 25 kg and area A = 100 cm^2) and stoppers (of negligible area), as shown in the figure. The initial pressure P_1 and temperature T_1 of air inside the cylinder are 200 kPa and 400°C, respectively. The ambient pressure P_∞ and temperature T_∞ are 100 kPa and 27°C respectively. The temperature of the air inside the cylinder (°C) at which the piston will begin to move is _________ (correct to two decimal places).



5. Which of the following statements are TRUE with respect to heat and work?

(i) They are boundary phenomena

(ii) They are excact differentials

(iii) They are path functions

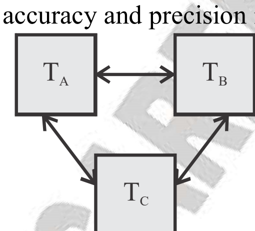
[GATE - 2016]

(a) Both (i) and (ii)
(b) Both (i) and (iii)
(c) Both (ii) and (iii)
(d) Only (iii)

CHAPTER - 3
ZEROTH LAW OF THERMODYNAMICS

3.1 INTRODUCTION TO TEMPERATURE
Temperature may be defined as:
1. Degree of hotness and coldness of a body on a definite scale.
2. Driving force or potential causing the flow of energy as heat.
3. Measure of the mean kinetic energy of the molecules of the system.
4. Determination of parameter like thermal equilibrium for two different systems.
If two systems are equal in temperature, since there will be no change occurs in any property when they brought into communication is called **equality of temperature**.

3.2 ZEROTH LAW OF THERMODYNAMICS
When two systems attain thermal equilibrium with third system, they in turn have equality of temperature with each other.
1. Zeroth law provides the basis of the measurement of temperature of a system.
2. Temperature measuring device is thermometer
3. To measuring of temperature with accuracy and precision is called thermometry.



$T_A = T_B$	$T_A = T_B$
$T_A = T_C$	$T_B = T_C$
$T_B = T_C$	$T_A = T_C$

3.3 THERMOMETRIC PROPERTY
A property which changes in valve as a function of temperature is called the thermometric property. The substance which has the thermometric property is called the thermometric substance.

Thermometers	Thermometric Properties
Liquid thermometer	Length
Constant volume gas thermometer	Pressure
Constant pressure gas thermometer	Volume
Electric resistance thermometer	Resistance
Thermocouple	Thermal e.m.f
Radiation pyrometer	Thermal radiation
Optical pyrometer	Monochromatic radiation
Pyrometric cone	Fusion

3.4 TEMPERATURE SCALES
A quantitative measure of the temperature of a system requires reference to some datum plane or reference condition, and the establishment of a suitable temperature unit.

GATE QUESTIONS

1. The definition of 1 K as per the internationally accepted temperature scale is **[GATE - 1994]**

(a) 1/100th the difference between normal boiling point and normal freezing point of water
(b) 1/273.15th the normal freezing point of water
(c) 100 times the difference between the triple point of water and the normal freezing point of water
(d) 1/273.16th of the triple point of water

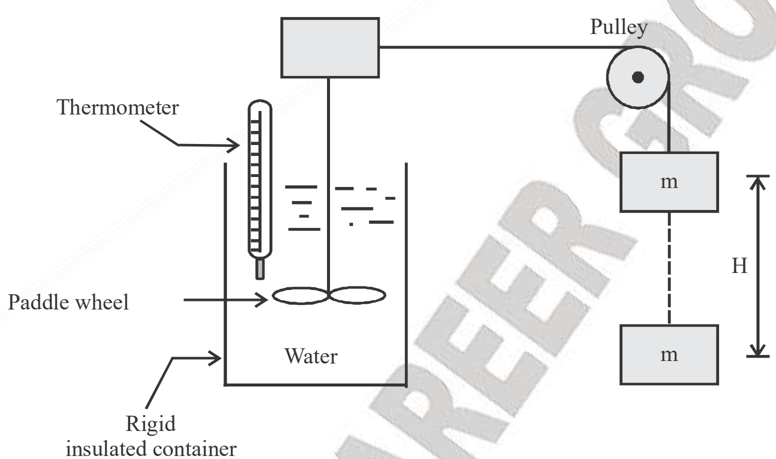
SOLUTIONS

Sol. (d)

CHAPTER - 4
FIRST LAW OF THERMODYNAMICS

4.1 INTRODUCTION
Joule conducted number of experiments involving different types of work interactions, and found that the work expended was proportional to increase in thermal energy.

Thus, $Q \propto W$



4.1.1 Examples of Energy Transformations
1. The heat of fuel input to an internal combustion engine can be accounted for as output in the form of mechanical energy and heat loss to cooling medium and surroundings etc.
2. After brakes applied on running vehicle, it brought to rest. The Kinetic energy of the brake leathers converted into heat energy through friction.
3. The conversion of energy also takes place during a current flow through a resistance.

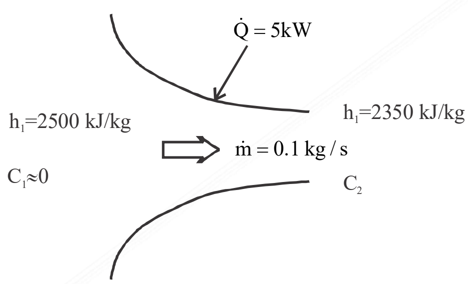
4.2 FIRST LAW OF THERMODYNAMICS
First law of thermodynamics stipulates that:
1. Energy can neither be created nor destroyed; it can change from one kind to another or it always conserved.
2. For isolated system; total energy remains constant in its all forms.
3. Energy never vanishes; it has ability that- all the energy goes into a system comes out in some other form of energy.
4. No machine can produce energy with zero expenditure of energy.
5. Energy cannot appear from nothing, nor can it convert into nothing.

4.2.1 First law for Cyclic Process
A cyclic process is; if the initial and final states of the system executing the process are identical.
1. Cyclic integral of heat $\oint \partial Q$ is equal to cyclic integral of work $\oint \partial W$.
2. If a system is taken through a cycle of processes so that it returns to the same state or condition from which it started, the sum of heat and work effects will be zero.

GATE QUESTIONS

1. Steam flows through a nozzle at mass flow rate of m = 0.1 kg/s, respectively. Assuming negligible velocity at inlet ($C_1 = 0$), the velocity (C_2) of stream (in m/s) at the nozzle exit is _______ (correct to two decimal places)

[GATE - 2018]



2. The molar specific heat at constant volume of an ideal gas is equal to 2.5 times the universal gas constant(8.314J/mol.K). When the temperature increases by 100K, the change in molar specific enthalpy is _____ J/mol.

[GATE - 2017]

3. A mass m of a perfect gas at pressure p_1 and volume V_1 ndergoes an isothermal process. The final pressure is p_2 and volume is V_2. The work done on the system is considered positive. If R is the gas constant and T is the temperature, then the work done in the process is

[GATE - 2017]

(a) $p_1V_1 \ln\frac{V_2}{V_1}$ (b) $-p_1V_1 \ln\frac{p_1}{p_2}$

(c) $RT\ln\frac{V_2}{V_1}$ (d) $-mRT\ln\frac{p_2}{p_1}$

4. A calorically perfect gas (specific heat at constant pressure 1000 J/kgK) enters and leaves a gas turbine with the same velocity. The temperatures of the gas at turbine entry and exit are 1100K and 400K, respectively. The power produced is 4.6 MW and heat escapes at the rate of 300 kJ/s through the turbine casing. The mass flow rate of the gas (in kg/s) through the turbine is

[GATE - 2017]

(a) 6.14 (b) 7.00
(c) 7.50 (d) 8.00

5. A piston-cylinder device initially contains 0.4 m^3 of air (to be treated as an ideal gas) at 100 kPa and 80°C. The air is now isothermally compressed to 0.1 m^3. The work during this process is __________kJ.
(Take the sign convention such that work done on the system is negative).

[GATE - 2016]

6. Steam at an initial enthalpy of 100 kJ/kg and inlet velocity of 100 m/s, enters and insulated horizontal nozzle. It leaves the nozzle at 200 m/s. The exit enthalpy (in kJ/kg) is __________.

[GATE - 2016]

7. For an ideal gas with constant values of specific heats, for calculation of the specific enthalpy.

[GATE - 2015]

(a) It is sufficient to know only the temperature
(b) Both temperature and pressure are required to be known
(c) Both temperature and volume are required to be known
(d) Both temperature and mass are required to be known

8. Work is done on an adiabatic system due to which its velocity changes from 10m/s to be 20 m/s, elevation increases by 20 m and temperature increases by 1 K. The mass of the system is 10 kg. C_v = 100 J(kg-K) and gravitational acceleration is 10 m/s^2. If there is no change in any other component of the energy of the energy of the system, the magnitude of total work done (in kJ) on the system is _____

[GATE - 2015]

CHAPTER - 5
SECOND LAW OF THERMODYNAMICS

5.1 INTRODUCTION

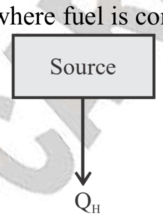
There are some limitations of first law of thermodynamics which stated as follows:
1. First law fixes the exchange rate between heat and work, and places no restrictions on the direction of change.
2. Processes proceed spontaneously in certain directions, but the reverse is not automatically attainable even though the reversal of the processes does not violate the first law.
3. First law provides a necessary but not a sufficient condition for a process to occur, and there does exist some directional law which would tell whether a particular process occurs or not. Answer is provided by the second law of thermodynamics.
For engineering purposes, the second law is best expressed in terms of the conditions which govern the production of work by a thermodynamic system operating cycle.

5.2 THERMAL ENERGY RESERVOIR (TER)

A thermal energy reservoir is a large body of infinite heat capacity, which is capable of absorbing or rejecting an unlimited quantity of heat without changing its thermodynamic properties.

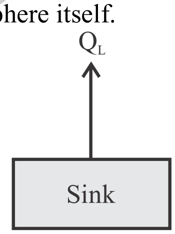
5.2.1 Source

It is the thermal energy reservoir from which heat Q (say) is absorbed by the system. A source may or may not be at constant temperature where fuel is continuously burn.



5.2.2 Sink

It is a thermal energy reservoir to which heat Q' is rejected from the system during a cycle. A typically sink is a river or sea or the atmosphere itself.



5.3 MECHANICAL ENERGY RESERVOIR (MER)

A mechanical energy thermal reservoir is a large body enclosed by an adiabatic wall which is capable of storing work as potential energy or kinetic energy. It receives and delivers mechanical energy quasi-statically.

GATE QUESTIONS

1. A heat pump absorbs 10kW of heat from outside environment at 250K while absorbing 15kW of work. It delivers the heat to a room that must be kept warm at 300K. The coefficient of performance(COP) of the heat pump is_____

[GATE - 2017]

2. The heat removal rate from a refrigerated space and the power input to the compressor are 7.2 kW and 1.8 kW, respectively. The coefficient of performance (COP) of the refrigerator is ______.

[GATE - 2016]

3. A reversible cycle receives 40 kJ of heat from one heat source at a temp[erature of 127°C and 37 kJ from another heat source at 97°C. The heat rejected (in kJ) to the heat sink at 47°C is _________.

[GATE - 2016]

4. A Carnot engine (CE-1) works between two temperature reservoirs A and B, where $T_A = 900$ K and $T_B = 500$ K. A second Carnot engine (CE-2) works between temperature reservoirs B and C, where $T_C = 300$ K. In each cycle of CE-1 and CE-2, all the heat rejected by CE-1 to reservoir B is used by CE-2. For one cycle of operation, if the net Q absorbed by CE-1 from reservoir A is 150 MJ, the net heat rejected to reservoir C by CE-2 (in MJ) is ________

[GATE - 2015]

5. The COP of a Carnot heat pump operating between 6ºC and 37ºC is _______

[GATE – 2015]

6. Two identical metal blocks L and M (Specific heat = 0.4 kJ/kg.K), each having a mass of 5 kg, are initially at 313K. A reversible refrigerator extracts heat from block L and rejects heat to block M until the temperature of block L reaches 293K. The final temperature(in K) of block M is ______.

[GATE - 2014]

7. A reversible heat engine receives 2 kJ of heat form a reservoir at 1000 K and a certain amount of heat form a reservoir at 800 K. It rejects 1 kJ of heat to a reservoir at 400K. the net work output (in kJ) of the cycle is

[GATE - 2014]

(a) 0.8 (b) 1.0
(c) 1.4 (d) 2.0

8. A source at a temperature of 500 K provides 1000 kJ of heat. The temperature of environment in 27°C. The maximum useful work (in kJ) that can be obtained from the heat source is_________

[GATE - 2014]

9. Which one of the following pairs of equations describes an irreversible heat engine?

[GATE - 2014]

(a) $\oint \delta Q > 0$ and $\oint \frac{\delta Q}{T} < 0$

(b) $\oint \delta Q < 0$ and $\oint \frac{\delta Q}{T} < 0$

(c) $\oint \delta Q > 0$ and $\oint \frac{\delta Q}{T} > 0$

(d) $\oint \delta Q < 0$ and $\oint \frac{\delta Q}{T} > 0$

10. Consider the following two processes;

[GATE - 2010]

Process-I: A heat source at 1200 K loses 2500 kJ of heat to a sink at 800K
Process-II: A heat source at 800 K loses 2000 kJ of heat to a sink at 500 K
Which of the following statements is ture?
(a) Process I is more irreversible than Process II
(b) Process II is more irreversible than Porcess I
(c) Irreversibility associated in both the processes are equal
(d) Both the processes are reversible

ESE CONV QUESTIONS

1. Give reasons why the Carnot cycle cannot be considered as the theoretical cycle for steam power plants even though its efficiency is the highest for the given heat source and sink temperature. A Carnot cycle heat engine has an efficiency of 40%. If the high temperature is raised by 10%, what is the new efficiency keeping the same low temperature.

[ESE - 2014]

Solution.

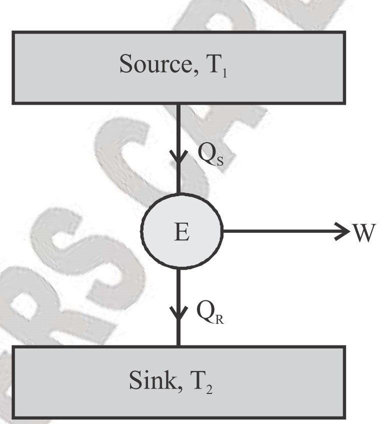
The Carnot cycle cannot be considered as the theoretical cycle for steam power plants due to following reasons:

Boiler: Isothermnal heat transfer eliminates the possibility of using subscooled liquid boiler feed or producing superheated vapour in the boiler effluent.

Turbine: Adiabatic expansion yields low steam quality in the turbine feed. This can result in damage to the turbine rotor.

Condenser: Isothermal heat transfer eliminates the possibility of using superheated vapour in the condenser feed.

Pump: Quality > 0 in the pump feed. This can result in damage to the pump rotor. If the condenser is designed and operated to produce a saturated liquid effluent, isotropic pump will yield a subcooled liquid at the pressure of the boiler. This will make it impossible to operate the boiler isothermally.



$$\eta = 0.4 = 1 - \frac{T_2}{T_1}$$

$$\frac{T_2}{T_1} = 0.6$$

$$T_1' = 1.1 \times T_1 \text{(New high temperature)}$$

$$\eta_{NEW} = 1 - \frac{T_2}{T_1} = 1 - \frac{T_2}{1.1 \times T_1}$$

$$= 1 - \frac{1}{1.1} \times \frac{T_2}{T_1} = 1 - \frac{0.6}{1.1} = \frac{0.5}{1.1} = 0.4545 \text{ or } 45.45\%$$

CHAPTER - 6
ENTROPY AND AVAILABILITY

6.1 INTRODUCTION

The cyclic integral of quantity $\oint_R \frac{\delta Q}{T} = 0$ for reversible process is zero. Where the quantity $\frac{\delta Q}{T}$ represent a point function and it is a property of the system. This property of the system called as entropy(S) and its change from initial to final state during a reversible process is:

$$\int_i^f \left(\frac{\delta Q}{T}\right)_R = \int_i^f dS = S_f - S_i$$

Unit of entropy is kJ/K and for specific entropy is kJ/kgK. The entropy can be measured due to molecule disorder or molecular randomness. As the system becomes more disorder higher will be the entropy.

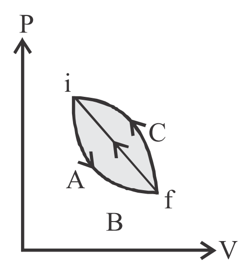
For a reversible adiabatic process $\delta Q = 0$ and so the entropy change will be zero. It clearly stated that entropy is a property of the system that remains constant during a reversible adiabatic process. The reversible adiabatic process during which entropy remains constant is called isentropic process.

1. The entropy for process can be negative, positive and zero.
2. The net entropy for a system can never be less than zero.
3. $S_{gas} > S_{liquid} > S_{solid}$
4. Entropy for pure crystal is always zero at 0K.
5. Every isentropic process can never be reversible adiabatic process

6.2 ENTROPY IS A POINT FUNCTION

Consider a system taken from initial sate i to final state f by following the reversible path A. subsequently the system may be brought back to initial state by following the reversible paths B or C.

The paths A and B or A and C individually constitutes a reversible cycle. Then accordance with clausius theorem:



CHAPTER - 7
THERMODYNAMIC PROPERTY RELATIONS

7.1 INTRODUCTION

The thermodynamic property pressure (P), volume (V), temperature (T) and mass can be easily possible to measure but the properties like: internal energy, enthalpy and entropy cannot measure directly however the properties like density and specific volume can be easily determined by using some specific relations. Thus, it is necessary to drive some fundamental relation between commonly used thermodynamic properties.

7.2 PARTIAL DIFFERENTIAL RELATION

Consider of function that depends on two (or more) variables, such as z = z(x, y). It represents the value of z depends upon both x and y.

The total differential of y can be written as:

$$dz = \left(\frac{\partial z}{\partial x}\right)_y dx + \left(\frac{\partial z}{\partial y}\right)_x dy \quad \ldots(i)$$

dz = M dx + N dy

where $M = \left(\frac{\partial z}{\partial x}\right)_y$ and $N = \left(\frac{\partial z}{\partial y}\right)_x$

Taking partial derivative of M and N with respect to y and x respectively. We get,

$$\left(\frac{\partial M}{\partial y}\right)_x = \frac{\partial^2 z}{\partial x \partial y} \text{ and } \left(\frac{\partial N}{\partial x}\right)_y = \frac{\partial^2 z}{\partial y \partial x}$$

$$\left(\frac{\partial M}{\partial y}\right)_x = \left(\frac{\partial N}{\partial x}\right)_y \quad \ldots(ii)$$

This is important relation for partial derivatives, and it is commonly used in calculus to check weather differential dz is exact or inexact.

In thermodynamic the above relation helps to form Maxwell relations.

7.2.1 Reciprocity and cyclic relation

The function z = z (x,y) can also be expressed as x = x(y,z) if y and z are taken to be independent variables.

The total differential of x can be written as:

$$dx = \left(\frac{\partial x}{\partial y}\right)_z dy + \left(\frac{\partial x}{\partial z}\right)_y dz \quad \ldots(iii)$$

Put equation (iii) into equation (i) to eliminate dx from equation (i),

$$dz = \left(\frac{\partial z}{\partial x}\right)_y \left[\left(\frac{\partial x}{\partial y}\right)_z dy + \left(\frac{\partial x}{\partial z}\right)_y dz\right] + \left(\frac{\partial z}{\partial y}\right)_x dy$$

$$dz = \left(\frac{\partial z}{\partial x}\right)_y \left(\frac{\partial x}{\partial y}\right)_z dy + \left(\frac{\partial z}{\partial y}\right)_x dy + \left(\frac{\partial z}{\partial x}\right)_y \left(\frac{\partial x}{\partial z}\right)_y dz$$

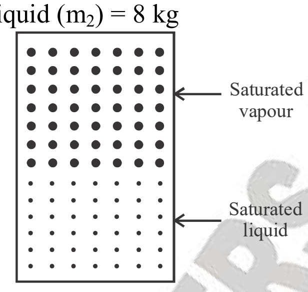
GATE QUESTIONS

1. A tank of volume 0.05 m^3 contains a mixture of saturated water and saturated steam at 200°C. the mass of the liquid present is 8 kg. the entropy (in kJ/kg K) of the mixture is ________(correct of two decimal places)
Property data for saturated steam and water are:
At 200°C, P_{sat} = 1.5538 MPa
V_f = 0.001157 m^3/kg, V_t =0.12736 m^3/kg
S_{fg} = 4.1014 kJ/kgK, S_f = 2.3309 kJ/kgK
[GATE - 2018]

2. For water at 25°C, dp_s/dT_s = 0.189 kPa/K (p_s is the saturation pressure in kPa and T_s is the saturation temperature in K) and the specific volume of dry saturated vapour is 43.38 m^3/kg. Assume that the specific volume of liquid is negligible in comparson with that of vapour. Using the Clasius–Calpeyron equation, estimate of the enthalpy of evaporation of water at 25°C (in kJ/kg) is ______.
[GATE - 2016]

SOLUTIONS

Sol. 1. (2.49 kJ/kg-K)
Total volume of tank (V) = 0.05 m^3
Means of liquid (m_2) = 8 kg



$$x = \frac{m_v}{m_v + m_L} \text{ (dryness fraction)}$$

$$V = V_L + V_V \qquad \begin{bmatrix} V_L - \text{v of liquid in tank} \\ V_V - \text{v of vapour in tank} \end{bmatrix}$$

$V_V = m_v v_v$
V_V = @ 200° C
=0.12736 m^3/kg
$V_V = m_L v_L$
$V_L = v_f$ @ 200° C
= 0.00157m^3/kg
V_L = 8×0.00157 = 9.256×10^3 m^3
0.05 = 9.256×10^{-3} + V_V
V_v = 0.0474 m^3
So, 0.04074=m_v×0.12736
M_v = 0.3198 kg

$$x = \frac{0.3198}{0.3198 + 8}$$

⇒ x = 0.0384
Specific entropy of mixture (s)
S= S_f + xS_{fg}
S=2.3309 + 0.0384 + 4.1014
S=2.4884 kJ/kg-K

Sol. 2. (2443.25 kJ/kg)

$$\frac{dP_s}{dT_s} = 0.189 \frac{kPa}{K}$$

T_{sat} = 275 c+ 25 = 298 K
V_g = 43.38 m^3/kg
V_f = 0
$V_{fg} = V_g - V_f$
= 43.38 – 0 = 43.38m^3/kg

$$\frac{dP}{dT} = \frac{h_{fg}}{T_{sat} \times V_{fg}}$$

$$0.189 = \frac{h_{fg}}{T_{sat} \times V_{fg}} = \frac{h_{fg}}{298 \times 43.38}$$

h_{fg} = 2443.25 kJ/kg

ESE

2019

FLUID MECHANICS & MACHINERY-I

MECHANICAL ENGINEERING

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CONTENTS

FLUID MECHANICS & MACHINERY-I

FLUID MECHANICS & MACHINERY-II

CHAPTER - 1
PROPERTIES OF FLUIDS

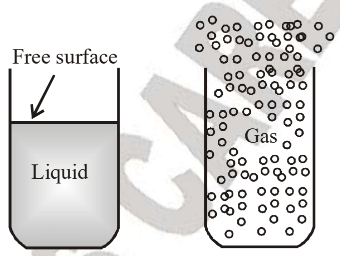
1.1 INTRODUCTION

The fluid a substance in the liquid or gas phase is referred to as a fluid.

A solid can resist an applied shear stress by deforming, whereas a fluid deforms continuously under the influence of a shear stress, no matter how small. In solids, stress is proportional to strain but in fluids, stress is proportional to strain rate. When a constant shear force is applied, a solid eventually stops deforming at some fixed strain angle, whereas a fluid never stops deforming and approaches a constant rate of strain.

The normal component of a force acting on a surface per unit area is called the normal stress, and the tangential component of a force acting on a surface per unit area is called shear stress (fig). In a fluid at rest, the normal stress is called pressure. A fluid at rest is at a state of zero shear stress. When the walls are removed or a liquid container is tilted, a shear develops as the liquid moves to re-establish a horizontal free surface.

In a liquid, groups of molecules can move relative to each other, but the volume remains relatively constant because of the strong cohesive forces between the molecules. As a result , a liquid takes the shape of the container it is in and it forms a free surface in a larger container in a gravitational field. A gas, on the other hand, expands until it encounters the walls of the container and fills the entire available space. This is because the gas molecules are widely spaced, and the cohesive forces between them are very small. Unlike liquids, a gas in an open container cannot form a free surface (fig.)



Unlike a liquid, a gas does not form a free surface, and it expands to fill the entire available space.

1.2 CONTINUUM

A fluid is composed of molecules which may be widely spaced apart, especially in the gas phase. Yet it is convenient to disregard the atomic nature of the fluid and view it as continuous, homogeneous matter with no holes that is continuum. The continuum idealization allows us to treat properties as point functions and to assume that the properties vary continually in space with no jump discontinuities. This idealization is valid as long as the size of the system we deal with is large relative to the space between the molecules. The continuum idealization is implicit in many statements we make, such as “the density of water in a glass is the same at any point.”

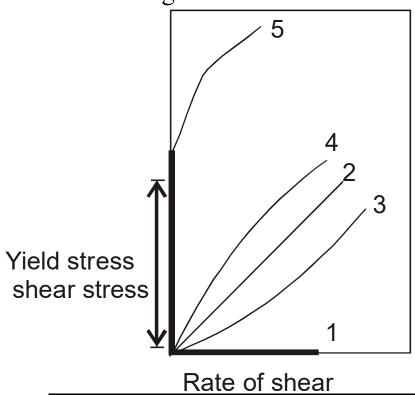
1.3 DENSITY AND SPECIFIC GRAVITY

Density is defined as mass per unit volume

Density $\rho = \frac{m}{V} (kg/m^3)$

GATE QUESTIONS

1. Group I contains the types of fluids while Group II contains the shear stress –rate of shear relationship of different types of fluids , as shown in the figure



Group I	Group II
A.Newtonian fluid	(i)Curve 1
B. Pseudo plastic fluid	(ii)Curve 2
C. Plastic fluid	(iii)Curve 3
D. Dilatant fluid	(iv)Curve 4
	(v)Curve 5

The correct match between Group I and Group II is

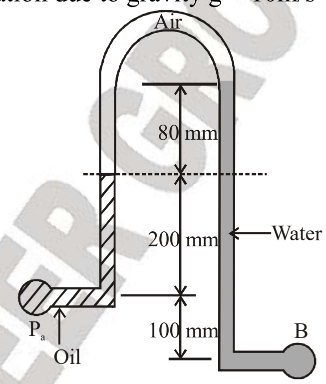
[GATE - 2016]

(a) A-ii, B-iv, C-i, D-v
(b) A-ii, B-v, C-iv, D-1
(c) A-ii, B-iv, C-v, D-iii
(d) A-ii, B-i, C-iii, D-iv

2. Oil (kinematic viscosity , v_{oil} = $1\times10^{-5}m^2/s$) flow through a pipe diameter with a velocity of 10m/s v_w = $0.89\times10^{-6}m^2$ /s) diameter flowing through a model pipe of diameter 10mm for satisfying the dynamic similarity , the velocity of water (in m/s) is _________

[GATE - 2016]

3. An inverted U-tube manometer is used to measure the pressure difference between two pipes A and B, as shown in the figure .Pipe A is carrying oil (specific gravity =0.8) and pipe B is carrying water .The densities of air and water are 1.16kg/m^3 and 1000kg/m^3 , respectively. The pressure difference between pipes A and B is _______kPa.
Acceleration due to gravity g = 10m/s^2



[GATE - 2016]

4. The difference in pressure (in N/m^2) across an air bubble of diameter 0.001 m immersed in water (surface tension = 0.072 N/m) is ___.

[GATE - 2014]

5. The dimension for kinematics viscosity is

[GATE - 2014]

(a) L/MT (b) L/T^2
(c) L^2/T (d) ML/T

6. The necessary and sufficient condition for a surface to be called as a 'free surface' is

[GATE - 2006]

(a) No stress should be acting on it
(b) Tensile stress acting on it must be zero
(c) Shear stress acting on it must be zero
(d) No point on it should be under any stress

7. In the inclined manometer shown in the figure below, the reservoir is large. Its surface may be assumed to remain at a fixed elevation . A is connected to a gas pipeline and the deflection noted on the inclined glass tube is 100 mm.

CHAPTER - 2
FLUID STATICS

2.1 INTRODUCTION

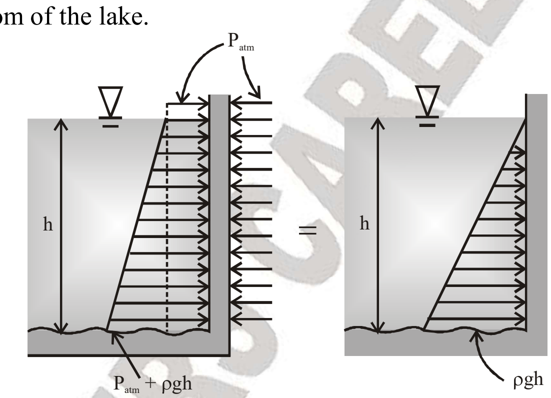
Fluid statics deals with problems associated with fluids at rest.

In fluid statics, there is no relative motion between adjacent fluid layers, and thus there are no shear (tangential) stresses in the fluid trying to deform it. The only stress we deal with in fluid statics is the normal stress, which is the pressure, and the variation of pressure is due only to the weight of the fluid.

The design of many engineering systems such as water dams and liquid storage tanks requires the determination of the forces acting on their surfaces suing fluid statics.

2.2 HYDROSTATIC FORCES ON SUBMERGED PLANE SURFACES

A plate (such as a gate valve in a dam, the wall of a liquid storage tank, or the full of a ship at rest) is subjected to fluid pressure distributed over its surface when exposed to a liquid. On a plane surface, the hydrostatic forces form a system of parallel forces, and we often need to determine the magnitude of the force and its point of application, which is called the centre of pressure. In most cases, the other side of the plate is open to the atmosphere (such as the dry side of a gate), and thus atmospheric pressure acts on both sides of the plate, yielding a zero resultant. In such cases, it is convenient to subtract atmospheric pressure and work with the gage pressure only. For example, $P_{gage} = \rho gh$ at the bottom of the lake.



(a) P_{atm} consider (b) P_{atm} subtracted

When analyzing hydrostatic forces on submerged surfaces, the atmospheric pressure can be subtract for simplicity when it acts on both sides of the structure.

Consider the top surface of a flat plate of arbitrary shape completely submerged in a liquid, as shown in fig. together with its normal view. The plane of this surface (normal to the page) intersects the horizontal free surface at angle θ, and we take the line of intersection to be the x-axis (out of the page). The absolute pressure above the liquid is P_0, which is the local atmospheric pressure P_{atm} if the liquid is open to the atmosphere (but P_0 may be different than P_{atm} if the space above the liquid is evacuated or pressurized). Then the absolute pressure at any point on the plate is

$P = P_0 + \rho gh = P_0 + \rho gy \sin\theta$

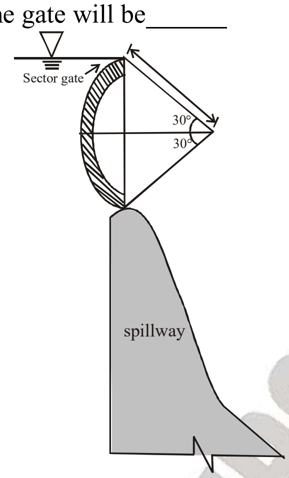
GATE QUESTIONS

1. For the stability of a floating body the

[GATE - 2017]

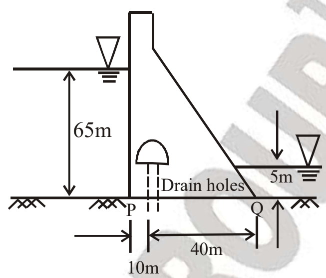
(a)Centre of buoyancy must coincide with the centre of gravity
(b)Centre of buoyancy must be above the centre of gravity
(c)Centre of gravity must be above the centre of buoyancy
(d)Metacentre must be above the centre of gravity.

2. A section gate is provided on a spillway as shown in the figure. Assuming g = 10m/s^2 , the resultant force per meter length (expressed in kN /m) on the gate will be______



[GATE - 2016]

3. A concrete gravity dam section is shown in the figure .Assuming unit weight of water as 10kN m^3 and unit weight of concrete as 24kN/m^3 , the uplift force per unit length of the dam(expressed in kN/m) at PQ is



[GATE - 2016]

4. A triangular gate with a base width of 2m and a height of 1.5m lies in a vertical plane. The top vertex of the gate is 1.5m below the surface of a tank which contains oil of specific gravity 0.8. Considering the density of water and acceleration due to gravity to be 1000 kg/m^3 and 9.81 m/s^2, respectively, the hydrostatic force (in kN) exerted by the oil on the gate is _______.

[GATE - 2015]

5. For a completely submerged body with centre of gravity 'G' and centre of buoyancy 'B'. The condition of stability will be

[GATE - 2014]

(a) G is located below B
(b) G is located above B
(c) G and B are coincident
(d) Independent of the locations of G and B

6. An aluminum alloy (density 2600 kg/m^3) casting is to be produced. A cylindrical hole of 100 mm diameter and 100 mm length is made in the casting using sand core (density 1600 kg/m^3). The net buoyancy force (in newton) acting on the core is ___.

[GATE - 2014]

7. A spherical balloon with a diameter of 10m, shown in the figure below is used for advertisements. The balloon is filled with helium (R_{He} = 2.08 kJ/kg. K) at ambient conditions of 15°C and 100 kPa. Assuming no

ESE OBJ QUESTIONS

1. An ocean linear, 240m long and 24m wide, displaces 654 MN of sea-water ($\rho = 1025kgf/m^3$). The second moment of inertia of the water plane about its fore-aft axis is 2/3 of that of the circumscribing rectangle. The position of the centre of buoyancy is 2.30m below the centre of gravity. How high is the meta centre above the centre of buoyancy (to the nearest)

[CE ESE - 2017]

(a) 49m (b) 53m
(c) 58m (d) 65m

2. Consider the following statements pertaining to stability of floating bodies:
1.A floating body will be stable when the centre of gravity is above the centre of buoyancy.
2.The positions of metacentres corresponding to different to different axes of rotation are generally different for the same floating object.
3.For cargo ships, the metacentric height varies with loading.
Which of the above statements are correct?

[ME ESE - 2017]

(a) 1, 2 and 3 (b) 1 and 2 only
(c) 1 and 3 only (d) 2 and 3 only

3. Statement (I): Depth of centre of pressure of any immersed surface is independent of the density of the liquid.
Statement (II): Centre of area of the immersed body lies below the centre of pressure.

[ME ESE - 2017]

(a) Both statements (I) and Statement (II) are individually true and Statement (II) is the correct explanation of statement (I).
(b) Both Statement (I) and Statement (II) are individually true but Statement (II) is not the correct explanation of Statement (I).
(c) Statement (I) is the true but Statement (II) is false.
(d) Statement (I) is false but Statement (II) is true.

4. Uniform fluid occurs when

[ME ESE - 2016]

(a) At every point the velocity is identical in magnitude and direction at any given instance
(b) The flow is steady
(c) Discharge through a pipe is constant
(d) Conditions do not change with at any time

5. What is the specific gravity of a marble stone, which weighs 400N in air ,and 200N in water ($g = 10m/s^2$)**?**

[ME ESE - 2015]

(a) 8 (b) 6
(c) 4 (d) 2

6. Consider the following statements :
1.If a small upward displacement is given to a floating body , it results in the reduction of the buoyant force acting on the body
2.A slight horizontal displacement does not change either the magnitude or the location of the buoyant force
Which of the above statement is /are correct?

[ME ESE - 2015]

(a) Both 1 and 2 (b) 1 only
(c) 2 only (d) Neither 1 nor 2

7. A tank of length, breadth and height in the ratio of 2:1:2 is full of water. The ratio of hydrostatic force at the bottom to that any larger vertical surface is

[ME ESE - 2015]

(a) 1 (b) 4
(c) 2 (d) 3

8. A mercury water manometer has a gauge difference of 0.8 m. The difference in pressure measured in meters of water is

[CE ESE - 2015]

(a) 0.8 (b) 1.06
(c) 10.05 (d) 8.02

CHAPTER - 3
FLUID KINEMATICS

3.1 INTRODUCTION
The Science which deals with the geometry of motion of fluids without reference to the forces causing the motion is known as hydro kinematics or simply kinematics. Thus kinematics involves merely the description of the motion of fluids in terms of space-time relationship. One the other hand the science which deals with the action of the forces in producing or changing motion of fluids is known as hydro kinematics or simply kinetics.
There are in general two methods by which the motion of a fluid may be described. These are the Lagrangian method and the Eulerian method.
In the Lagrangian method any individual fluid particle is selected, which is pursued throughout its course of motion and the observation is made about the behavior of this particle during its course of motion through space. In the Eulerian method any point in the space occupied by the fluid is selected and observation is made of whatever changes of velocity, density and pressure which take place at that point. Out of these two methods the Eulerian method is commonly adopted in fluid mechanics and therefore the same is used in the following analysis.

3.2 VELOCITY OF FLUID PARTICLES
If ds is the distance travelled by a fluid particle in time dt then the velocity V o the fluid particle at this point may be expressed as

$$V = \lim_{dt \to 0} \frac{ds}{dt}$$

The velocity is a vector quantity and hence it has magnitude as well as direction. Therefore the velocity V at any point in the fluid can be resolved into three components u, v and w along three mutually perpendicular directions x, y and z respectively. Thus if dx, dy and dz are the components of the displacement ds in x, y and z directions respectively, then

$$u = \lim_{dt \to 0} \frac{dx}{dt}, v = \lim_{dt \to 0} \frac{dy}{dt} \text{and } w = \lim_{dt \to 0} \frac{dz}{dt}$$

Since the velocity V at any point in a flowing mass of fluid in general depends on x, y and z, i.e, the coordinate position of the point under consideration and the time t. Hence the velocity V and its components, u, v and w may be expressed in terms of the following functional relationships

$$\left.\begin{aligned} V &= f_1 x, y, z, t) \\ u &= f_2(x, y, z, t) \\ v &= f_3(x, y, z, t) \\ w &= f_4(x, y, z, t) \end{aligned}\right\}$$

In vector notation velocity V may be expressed in terms of its components as V = iu + jv + kw

3.3 TYPES OF FLUID FLOW
According to different consideration fluid flows may be classified in several ways as indicated below:
1. Steady flow and unsteady flow
2. Uniform flow and Non-uniform flow
3. One-dimensional flow, Two-dimensional flow and Three-dimensional flow
4. Rotational flow and Ir-rotational flow

CHAPTER - 4

FLUID DYNAMICS, FLOW OVER NOTCHES & WEIRS

4.1 INTRODUCTION

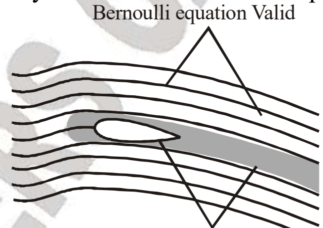
This chapter deals with three equations commonly used in fluid mechanics: the mass, Bernoulli, and energy equations. The mass equation is an expression of the conservation of mass principle. The Bernoulli equation is concerned with the conservation of kinetic, potential, and flow energies of a fluid stream and their conversion to each other in regions of flow where net viscous forces are negligible and where other restrictive conditions apply. The energy equation is a statement of the conservation of energy principle.

4.2 THE BERNOULLI EQUATION

The Bernoulli equation is an approximate relation between pressure, velocity, and elevation, and is valid in regions of steady, incompressible flow where net frictional forces are negligible (fig.) Despite its simplicity, it has proven to be a very powerful tool in fluid mechanics. In this section, we derive the Bernoulli equation by applying the conservation of linear momentum principle, and we demonstrate both its usefulness and its limitations.

The key approximation in the derivation of the Bernoulli equation is that viscous effects are negligibly small compared to inertial, gravitational, and pressure effects. Since all fluids have viscosity (there is no such thing as an “inviscid fluid”), this approximation cannot be valid for an entire flow field of practical interest.

Care must be exercised when applying the Bernoulli equation since it is an approximation that applies only to inviscid regions of flow. In general, frictional effects are always important very close to solid wall (boundary layers) and directly down stream of bodies (wakes). Thus, the Bernoulli approximation is typically useful in flow regions outside of boundary layers and wakes, where the fluid motion is governed by the combined effects of pressure and gravity forces.



The Bernoulli equation is an approximate equation that is valid only in inviscid regions of flow where net viscous forces are negligibly small compared to inertial, gravitational, or pressure forces. Such regions occur outside of boundary layers and wakes.

4.2.1 Derivation of the Bernoulli Equation

Consider the motion of a fluid particle in a flow field in steady flow. Applying Newton’s second law (which is referred to as the linear momentum equation in fluid mechanics) in the s-direction on a particle moving along a streamline gives

$$\Sigma F_s = ma_s \qquad ...(i)$$

In regions of flow where net frictional forces are negligible, there is no pump or turbine, and there is no heat transfer along the streamline, the significant forces acting in the s-direction are the pressure (acting on both sides) and the component of the weight of the particle in the s-direction (Fig.) Therefore, equation (i) becomes

CHAPTER - 5
FLOW THROUGH PIPES

5.1 FLOW TYPES OF FLOW-REYNOLDS' EXPERIMENT

Reynolds related the inertia to viscous forces and arrived at a dimensionless parameter.

$$\text{Re or } N_R = \frac{\text{Inertia force}}{\text{Viscous force}} = \frac{F_i}{F_v} \text{ Re or } N_R = \frac{\text{Inertia force}}{\text{Viscous force}} = \frac{F_i}{F_v}$$

According to Newton's second law of motion the inertia force T_i is given b

F_i = mass × acceleration

= ρ × volume × acceleration

= $\rho \times L^3 \times (L/T^2) = (\rho L^2 V^2)$

Similarly viscous force F_v is given by Newton's law of viscosity as

$F_v = \tau \times$ area

$$= \mu \frac{\partial v}{\partial y} \times L^2 = (\mu VL)$$

$$\therefore \text{ Re or } N_R = \frac{(\rho L^2 V^2)}{\mu VL} = \frac{\rho VL}{\mu}$$

This dimensionless parameter is called Reynolds number, in which ρ and μ are respectively the mass density and viscosity of the flowing fluid, V is the characteristic (or representative) velocity of flow and L is the characteristic linear dimension. In the case of flow through pipes the characteristic linear dimension L is taken as the diameter D of the pipe and the characteristic velocity is taken as the average velocity V of flow of fluid. Thus Reynolds number becomes $(\rho DV/\mu)$ or (VD/ν) where $(\mu/\rho) = \nu$, is kinematic viscosity of the flowing fluid. The Reynolds number is therefore a very useful parameter in predicting whether the flow is laminar or turbulent. One may predict that the flow will be laminar if Reynolds number is less than 2000 and turbulent if it is greater than 4000.

5.2 LAWS OF FLUID FRICTION

1. Law of fluid friction for laminar flow

The frictional resistance in the laminar flow is as follows

(i) Proportional to the velocity of flow

(ii) Independent of the pressure

(iii) Proportional to the area of surface in contact

(iv) Independent of the nature of the surface in contact

(v) Greatly affected by variation of the temperature of the flowing fluid.

2. Laws of fluid friction for turbulent flow

The frictional resistance in the case of turbulent flow is as follow

(i) Proportional to velocity where the index n varies form 1.72 to 2.0

(ii) Independent of the pressure

(iii) Proportional to the density of the flowing fluid

(iv) Slightly affected by the variation of the temperature of the flowing fluid

(v) Proportional to area of surface in contact

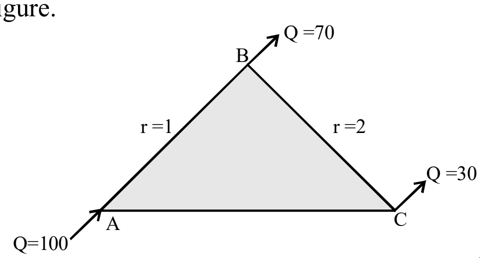
(vi) Dependent on the nature of the surface in contact

GATE QUESTIONS

1. Water is pumped at a steady uniform flow rate of 0.01 m^3/s through a horizontal smooth circular pipe of 100 mm diameter. Given that the Reynolds number is 800 and g is 9.81 m/s^2, the head loss (in meter, up to one decimal place) per km length due to friction would be ____

[GATE - 2017]

2. A triangular pipe network is shown in the figure.



The head loss in each pipe is given by $h_f = rQ^{1.8}$, with the variables expressed in a consistent set of units. The value of r for the pipe AB is 1 and for the pipe BC is 2. If the discharge supplied at the point A(i.e, 100) is equally divided between the pipes AB and AC, the value of r (up to two decimal places) for the pipe AC should be ____

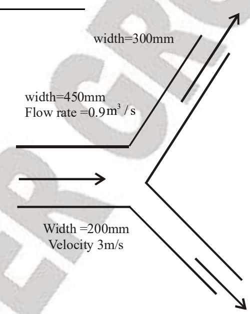
[GATE - 2017]

3. For steady flow of a viscous incompressible fluid through a circular pipe of constant diameter, the average velocity in the fully developed region is constant. Which one of the following statements about the average velocity in the developing region is TRUE ?

[GATE - 2017]

(a) It increases until the flow is fully developed.
(b) It is constant and is equal to the average velocity in the fully developed region
(c) It decreases until the flow is fully developed.
(d) It is constant but is always lower than the average velocity in the fully developed region.

4. A channel of width 450mm branches into sub-channels having width 300mm and 200mm as shown in figure .If the volumetric flow rate (taking unit depth) of an incompressible flow through the main channel is $0.9 m^3/s$ and the velocity in the sub-channel of width 200mm is 3m/s , the velocity in the sub channel of width 300mm is________



[GATE - 2016]

5. For steady incompressible flow through a closed-conduit of uniform cross-section, the direction of flow will always be

[GATE - 2015]

(a) From higher to lower elevation
(b) From higher to lower pressure
(c) From higher to lower velocity
(d) From higher to lower piezometric head

6. Two reservoirs are connected through a 930 m long, 0.3 m diameter pipe, which has a gate valve. The pipe entrance is sharp (loss coefficient = 0.5) and the valve is half-open (loss coefficient = 5.5), The head difference between the two reservoirs is 20 m. Assume the friction factor for the pipe as 0.03 and $g = 10 m/s^2$. The discharge in the pipe accounting for all minor and major losses is ___ m^3/s.

[GATE - 2015]

7. A pipe of 0.7 m diameter has a length of 6 km and connects two reservoirs *A* and *B*. The water level in reservoir *A* is at an elevation 30 m above the water level in reservoir *B*. Halfway along the pipe line, there is a branch through

ESE CONV QUESTIONS

1. An oil density 917kg/m^3 is being pumped in a 15cm diameter horizontal plane. The discharge is measured as 800 litre /minute .The drop in pressure in a stretch of 800m of pipeline is measured as 95kPa.Estimate the absolute viscosity of the fluid .

[ME ESE - 2015]

Solution.

$\rho = 917 kg/m^3$, $D = 15cm = 0.15m$, $Q = 800L/min = 0.0133m^3/s$

$$Q = \frac{\pi}{4} D^2 \times V$$

$$0.0133 = \frac{\pi}{4}(0.15)^2 \times V$$

$$\therefore V = 0.75262 m/s$$

$$P_2 - P_1 = \frac{32\mu VL}{D^2}$$

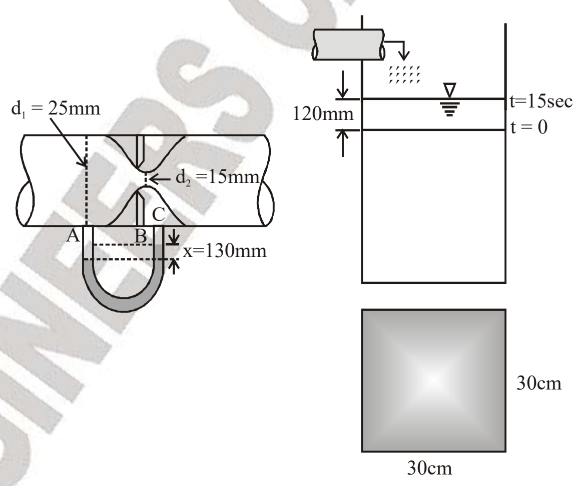
$$95 \times 10^3 = \frac{32 \times \mu \times 0.75262 \times 800}{0.15^2}$$

$$\therefore \mu = 0.11094 Ns/m^2$$

2. In a laboratory experiment, an orifice of diameter 15 mm is installed in a 25 mm diameter pipe and two pressure tappings, one before and one after the orifice, are connected to a vertical mercury manometer. The discharge is obtained by measuring the rise of water level in a 30 cm × 30 cm square tank collecting the outflow from the pipe. For a particular experiment, the difference in manometer readings was 130 mm of Hg and the rise of water level was 120 mm in 15 seconds. Estimate the coefficient of discharge.

[CE ESE - 2014]

Solution.



$$\text{Discharge of pipe, } Q = \frac{\text{Volume stored in tank}}{\text{Time of storage}} = \frac{0.30 \times 0.30 \times 0.120}{15} = 7.2 \times 10^{-4} m^3/s$$

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CHAPTER - 6
BOUNDARY LAYER THEORY

6.1 INTRODUCTION
When a real fluid flows past a solid boundary, a layer of fluid which comes in contact with the boundary surface adheres to it on account of viscosity. Since this layer of fluid cannot slip away from the boundary surface it attains the same velocity that of the boundary. In other words, at the boundary surface there is no relative motion between the fluid and the boundary. This condition is known as no slip condition. Thus at the boundary surface the layer of fluid undergoes retardation. This retarded layer of fluid further causes retardation for the adjacent layers of the fluid, thereby developing a small region in the immediate vicinity of the boundary surface in which the velocity of flowing fluid increase gradually from zero at the boundary surface to the velocity of the main stream. This region is known as boundary layer. In the boundary layer region since there is a larger variation of velocity in a relatively small distance, there exists a fairly large velocity gradient ($\partial v/\partial y$) normal to the boundary surface. As such in this region of boundary layer even if the fluid has small viscosity, the corresponding shear stress $\tau = \mu\ (\partial v/\partial y)$, is of appreciable magnitude. The flow may thus be considered to have two regions, one close to the boundary in the boundary layer zone in which due to larger velocity gradient appreciable viscous forces are produced and hence in this region the effect of viscosity is mostly confined and second outside the boundary layer zone in which the viscous forces are negligible and hence the flow may be treated as non-ciscous or inviscid. The concept of boundary layer was first introduced by L. Prandtl in 1904 and since then it has been applied to several fluid flow problems.

6.1.1 Following Boundary Conditions May Be Noted
Essential Boundary condition

1. at $x = 0$ (leading edge) , thickness of boundary layer = 0i.e, $\delta = 0$
2. at $y = 0$, $u = 0$
3. at $y = \delta$, $u = V_2$ = Free stream velocity = constant
4. at $y = \delta$, $\frac{du}{dy} = 0$

Desirable Boundary conditions

At $y = \delta$, $\frac{du}{dy} = 0, \frac{d^2u}{dy^2} = 0$

(i) When a fluid flows a past a flat plate, the velocity at leading edge is zero and retardation of fluid increases as more and more of the plate is exposed to flow. Hence boundary layer thickness increase as distance from leading edge increases
(ii) Upto certain distance from the leading edge, flow in boundary layer is laminar irrespective of the fact that flow of approaching stream in laminar or turbulent
(iii) As the depth of laminar boundary layer increases, it cannot dissipate the effect of instability in flow and hence transition to turbulent boundary layer is more
(iv) Thus thickness of turbulent boundary layer is more
(v) Change of boundary layer from Laminar to turbulent is affected by
(a) Roughness of plate
(b) Plate curvature

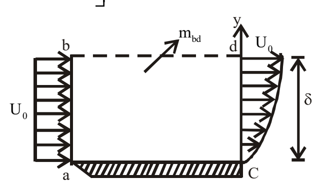
GATE QUESTIONS

1. For a steady incompressible laminar flow between two infinite parallel stationary plates, the shear stress variation is

[GATE - 2017]

(a) Linear with zero value at the plates
(b) Linear with zero value at the centre
(c) Quadratic with zero value at the plates
(d) Quadratic with zero value at the centre

2. A steady laminar boundary layer is formed over a flat plate as shown in the figure .The free stream velocity of the fluid is U_0 .The velocity profile at the inlet a-b is uniform , while that at a downstream location c-d is given by $u = U_0\left[2\left(\frac{y}{\delta}\right)-\left(\frac{y}{\delta}\right)^2\right]$



The ratio of the mass flow rate, m b, leaving through the horizontal section b-d to that entering through the vertical section a-b is_______

[GATE - 2016]

3. A fluid (Prandtl number , Pr = 1) at 500K flows over a flat plate of 1.5m length , maintained at 300K.The velocity of the fluid is 10m/s. Assuming kinematic viscosity , v = $30\times10\text{-}6m^2/s$, the thermal boundary layer thickness (in mm) at 0.5m from the leading edge is________

[GATE - 2016]

4. An incompressible fluid flows over a flat plate with zero pressure gradient. The boundary layer thickness is 1 mm at a location where the Reynolds number is 1000. If the velocity of the fluid alone is increased by a factor of 4, then the boundary layer thickness at the same location, in mm will be

[GATE - 2012]

(a) 4	(b) 2
(c) 0.5	(d) 0.25

Linked Statement for Q.5 & Q.6

An automobile with projected area 2.6 m^2 is running on a road with a speed of 120 km per hour. The mass density and the kinematic viscosity of air are 1.2 kg/m^3 and 1.5×10^{-5} m^2/s, respectively. The drag coefficient is 0.30.

5. The drag force on the automobile is

[GATE - 2008]

(a) 620 N	(b) 600 N
(c) 580 N	(d) 520 N

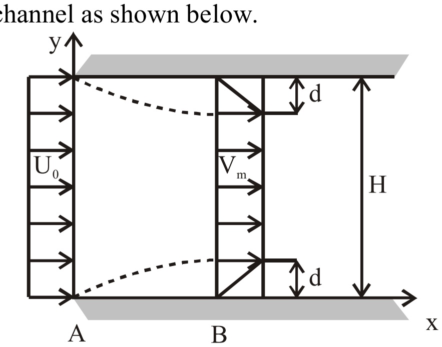
6. The metric horse power required to overcome the drag force is

[GATE - 2008]

(a) 33.23	(b) 31.23
(c) 23.23	(d) 20.23

Common data for Q. 6 & Q. 7

Consider a steady incompressible flow through a channel as shown below.



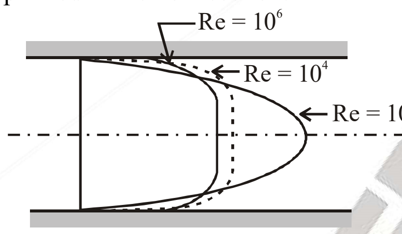
The velocity profile is uniform with a value of U_0 at the inlet section A. The velocity profile at section B downstream is

CHAPTER - 7
TURBULENT FLOW IN PIPES

7.1 INTRODUCTION

As stated earlier if Reynolds number is greater than 4000 the flow is turbulent. The velocity distribution in turbulent flow is relatively uniform and the velocity profile of turbulent flow is much flatter than the corresponding laminar flow parabola for the same mean velocity.

In the case of turbulent flow the velocity fluctuations influence the mean motion in such a way that an additional shear (or frictional) resistance to flow is caused. This shear stress produced in turbulent flow is in addition to the viscous shear stress and it is termed as turbulent shear stress which may be evaluated as explained in the next section.



(i) Velocity distribution in laminar and turbulent flow

7.2 RELATION BETWEEN SHEAR AND PRESSURE GRADIENTS IN LAMINAR FLOW

Consider a free body of fluid having the form of an elementary parallelopiped of length δ_x, width is δ_z, thickness δy .

The magnitudes of shear stresses on the layers abcd and a′b′c′d′ will be different. Thus if τ represents the shear stress on the layer abcd then the shear stress on the layer a′b′c′d′ is equal to $\left(\tau + \frac{\partial \tau}{\partial y}\delta y\right)$.

For two – dimensional steady flow there will be no shear stresses on the vertical faces abb′a′ and cdd′c′. Thus the only forces acting on the parallelepiped in the direction of flow x will be the pressure and shear forces. The net shear force acting on the parallelepiped.

$$= \left[\left(\tau + \frac{\partial \tau}{\partial y}\delta y\right)\delta x \delta z - \tau \delta x \delta z\right] = \frac{\partial \tau}{\partial y}\delta x \delta y \delta z$$

If the pressure intensity on face add′a′ is p, and since there exists a pressure gradient in the direction of flow, the pressure intensity on the face bcc′b′ will be $\left(p + \frac{\partial p}{\partial x}\delta x\right)$. The net pressure force acting on the parallelopiped.

$$= \left[p\delta y \delta z - \left(p + \frac{\partial p}{\partial x}\delta x\right)\delta y \delta z\right] = -\left(\frac{\partial p}{\delta x}\right)\delta x \delta y \delta z$$

For steady and uniform flow, there being no acceleration in the direction of motion, the sum of these forces in the x-direction must be equal to zero. Thus

GATE QUESTIONS

1. Consider fluid flow between two infinite horizontal plates which are parallel (the gap between them being 50mm) .The top plate is sliding parallel to the stationary bottom plate at a speed of 3m/s. The flow between the plates is solely due to the motion of the top plate .The force per unit area (magnitude) required to maintain the bottom plate stationary is __________N/m^2 .Viscosity of the fluid μ = 0.44kg/m-s and density ρ = $888 kg/m^3$

[GATE - 2016]

2. With reference to a standard Cartesian (x, y) plane, the parabolic velocity distribution profile of fully developed laminar flow in x-direction between two parallel, stationary and identical plates that are separated by distance, h, is given by the expression

$$u = -\frac{h^2}{8\mu}\frac{dp}{dx}\left[1-4\left(\frac{y}{h}\right)^2\right]$$

In this equation, the y = 0 axis lies equidistant between the plates at a distance h/2 from the two plates, p is the pressure variable and μ is the dynamic viscosity term. The maximum and average velocities are, respectively

[GATE - 2014]

(a) $u_{max} = -\frac{h^2}{8\mu}\frac{dp}{dx}$ and $u_{average} = \frac{2}{3}u_{max}$

(b) $u_{max} = \frac{h^2}{8\mu}\frac{dp}{dx}$ and $u_{average} = \frac{2}{3}u_{max}$

(c) $u_{max} = -\frac{h^2}{8\mu}\frac{dp}{dx}$ and $u_{average} = \frac{3}{8}u_{max}$

(d) $u_{max} = \frac{h^2}{8\mu}\frac{dp}{dx}$ and $u_{average} = \frac{3}{8}u_{max}$

3. Consider the turbulent flow of a fluid through a circular pipe of diameter, D. Identify the correct pair of statements.

I. The fluid is well-mixed

II. The fluid is unmixed

III. $Re_D < 2300$

IV. $Re_D > 2300$

[GATE - 2014]

(a) I and III (b) II and IV

(c) II and III (d) I and IV

4. Water flows through a pipe having an inner radius of 10 mm at the rate of 36 kg/hr at 25°C. The viscosity of water at 25°C is 0.001 kg/ms. The Reynolds number of the flow is _____.

[GATE - 2014]

5. For a fully developed flow of water in a pipe having diameter 10 cm, velocity 0.1 m/s and kinematic viscosity 10^{-5} m^2/s, the value of Darcy friction factor is ____.

[GATE - 2014]

6. In a simple concentric shaft-bearing arrangement, the lubricant flows in the 2 mm gap between the shaft and the bearing. The flow may be assumed to be a plane Couette flow with zero pressure gradient. The diameter of the shaft is 100 mm and its tangential speed is 10 m/s. The dynamic viscosity of the lubricant is 0.1 kg/m.s. The frictional resisting force (in newton) per 100 mm length of the bearing is ______.

[GATE - 2014]

7. Consider laminar flow of water over a flat plate of length 1 m. If the boundary layer thickness at a distance of 0.25 m from the leading edge of the plate is 8 mm, the boundary layer thickness (in mm), at a distance of 0.75 m, is _____.

[GATE - 2014]

8. The maximum velocity of a one-dimensional incompressible fully developed viscous flow, between two fixed parallel plates, is 6 ms^{-1}. The mean velocity (in ms^{-1}) of the flow is

[GATE - 2013]

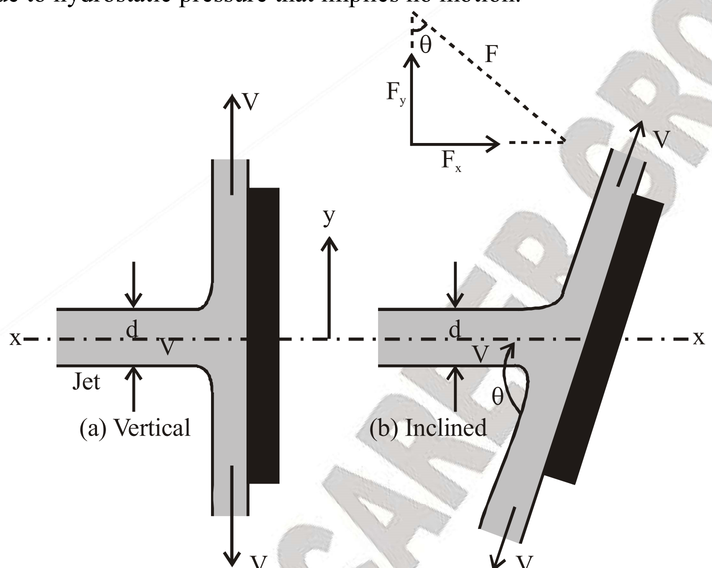
(a) 2 (b) 3

(c) 4 (d) 5

CHAPTER - 8
FLUID MACHINERY

9.1 IMPACT OF JETS

A jet of fluid emerging from a nozzle has some velocity and hence it possesses a certain amount of kinetic energy. If this jet strikes an obstruction placed in its path, it mil exert a force on the obstruction. This impressed force is known as impact of the jet and it is designated as hydrodynamic force, in order to distinguish it from the forces due to hydrostatic pressure. Since a dynamic force is exerted by virtue of fluid motion, it always involves a change of momentum, unlike a force due to hydrostatic pressure that implies no motion.



Fluid jet striking stationary flat plate

9.2 FORCE EXERTED BY FLUID JET ON STATIONARY FLAT PLATE

1. Flat Plate Normal to the Jet

Let a jet of diameter d and velocity V issue from a nozzle and strike a flat plate as shown in figure below. The plate is held stationary and perpendicular to the centre line of the Jet. The jet after striking the plate will leave it tangentially i.e., the jet will get deflected through 90°. If the plate is quite smooth the friction between the jet and the plate may be neglected. Further if there is no energy loss in the flow because of impact of the fluid jet, and the difference in elevation between the incoming and outgoing jets is neglected; the application of Bernoulli's equation indicates that the jet will move on and off the plate with the same velocity V. However, if some energy loss occurs the velocity of the fluid leaving the plate will be slightly less than V.

The quantity of fluid striking the plate $Q = (\pi d^2/4) \times V = aV$, where a is the area of cross-section of the jet. Thus the mass of fluid issued by the jet per second is $m = \rho Q = \rho aV$; where ρ represents the mass density of the fluid. Since p = (w/g), where TV is the specific weight of the fluid, the mass m may also be expressed as m = (waV/g).

GATE QUESTIONS

1. If a centrifugal pump has an impeller speed of N (in rpm), discharge Q(in m^3/s) and the total head H(in m), the expression for the specific speed N_s of the pump is given by

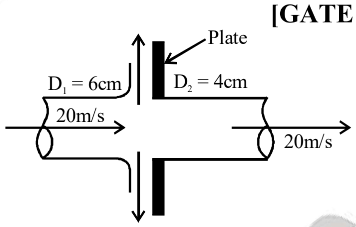
[GATE - 2017]

(a) $N_s = \frac{NQ^{0.5}}{H^{0.5}}$ (b) $N_s = \frac{NQ^{0.5}}{H}$

(c) $N_s = \frac{NQ^{0.5}}{H^{0.75}}$ (d) $N_s = \frac{NQ}{H^{0.75}}$

2. A 60mm-diameter water jet strikes a plate containing a hole of 40mm diameter as shown in the figure. Part of the jet passes through the hole horizontally, and the remaining is deflected vertically. The density of water is $1000 kg/m^3$. If velocities are as indicated in the figure, the magnitude of horizontal force (in N) required to hold the plate is

[GATE - 2017]



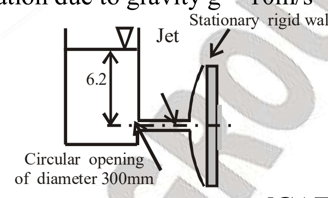
3. A penstock of 1m diameter and 5km length is used to supply water from a reservoir to an impulse turbine .A nozzle of 15cm diameter is fixed at the end of the penstock .The elevation difference between the turbine and water level in the reservoir is 500m .Consider the head loss due to friction as 5% of the velocity head available at the jet .Assume unit weight of water = 10kN $/m^3$ and acceleration due to gravity (g) = $10 m/s^2$ .If the overall efficiency is 80% , power generated (expressed in kW and rounded to nearest integer) is ___________

[GATE - 2016]

4. The water jet exiting from a stationary tank through a circular opening of diameter 300mm impinges on a rigid wall as shown in figure .Neglect all minor losses and assume the water level in the tank to remain constant .The net horizontal force experienced by the wall is ________.kN.

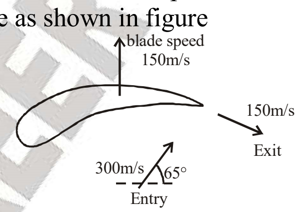
Density of water is $1000 kg/m^3$

Acceleration due to gravity g = $10 m/s^2$



[GATE - 2016]

5. The blade and fluid particles for an axial turbine are as shown in figure



The magnitude of absolute velocity at entry is 300m/s at an angle of 65° to the axial direction while the magnitude of the absolute velocity at exist is 150m/s .The exit velocity vector has a component in the downward direction .Given that the axial (horizontal) velocity is the same at entry and exit, the specific work (in kJ /kg) is _________.

[GATE - 2016]

6. A horizontal jet of water with its cross sectional area of 0.0028 m^2 hits a fixed vertical plate with a velocity of 5 m/s. After impact the jet splits symmetrically in a plane parallel to the plane of the plate. The force of impact (n N) of the jet on the plate is

[GATE - 2014]

(a) 90 (b) 80

(c) 70 (d) 60

7. A horizontal nozzle of 30 mm diameter discharges a steady jet of water into the atmosphere at a rate of 15 litres per second. The diameter of inlet to the nozzle is 100mm. The jet

CHAPTER - 9
DIMENSIONAL ANALYSIS &MODEL STUDIES

10.1 INTRODUCTION
1.Dimensional analysis is a mathematical technique for solving engineering problems. It makes uses of the dimensions of variables on which the problem depends.
2.A physical phenomenon can be expressed by an equation giving relationship between different quantities. Such quantities are dimensional and non-dimensional .
3.Dimensional analysis helps in determining a systematic arrangement of the variables in the physical relationship, combining dimensional variables to form non-dimensional paramaters.
4. It has becomes an important tool for analyzing fluid flow problems.

10.2 SYSTEMS OF DIMENSIONS
1. The various physical quantities can be expressed in terms of fundamental quantities.
2. The fundamental (or primary) quantities are: mass (M), length (L), time (T), and temperature (θ).
3. The quantities which are expressed in terms of the fundamental-quantities are called derived (or secondary) quantities, e.g. velocity, area, acceleration etc.
4. The expression for a derived quantity in terms of the primary quantities is called the dimension of the physical quantity.
5. The two common system of dimensioning a physical quantity are; M-L-T and F-L-T system of units where F is force. The dimensions of various quantities used in both the system are given in table on the next page.

10.3 DIMENSIONAL HOMOGENEITY
1. Dimensional homogeneity states that every term in an equation when reduced to fundamental dimensions must contain identical powers of each dimension.
2. A dimensionally homogenous equation is independent of the fundamental units of measurement if the units there in are consistent.
3. Let us consider the velocity equation,

$$V = \sqrt{2gh}$$

$$[LT^{-1}] = [2 \times LT^{-2} \times L]^{1/2} = [L^2T^{-2}]^{1/2} = [LT^{-1}]$$

Similarly, $h_f = \dfrac{4flv^2}{2gd}$

$$[L] = \frac{[L][LT^{-1}]^2}{[LT^{-2}][L]} = [L]$$

Dimensional homogeneity is bases on the Fourier's principle of homogeneity.

Table: Dimensions of Various Physical Quantities

Physical quantity	Symbol	Dimensions	
		M-L-T system	F-L-T system
1. Fundamental Quantities			
Mass	M	M	$FL^{-1}T^2$
Length	L	L	L

GATE QUESTIONS

1. The drag force, F_D, on a sphere kept in a uniform flow field depends on the diameter of the sphere D, flow velocity V; fluid density ρ; and dynamic viscosityμ. Which of the following options represents the non dimensional parameters which could be used to analyze this problem?

[GATE - 2015]

(a) $\frac{F_D}{V_D}$ and $\frac{\mu}{\rho VD}$
(b) $\frac{F_D}{\rho VD^2}$ and $\frac{\rho VD}{\mu}$
(c) $\frac{F_D}{\rho V^2D^2}$ and $\frac{\rho VD}{\mu}$
(d) $\frac{F_D}{\rho V^3D^3}$ and $\frac{\mu}{\rho VD}$

2. The relationship between the length scale ratio (L_f) and the velocity scale ratio (V_f) in hydraulic models, in which Froude dynamic similarity is maintained, is

[GATE - 2015]

(a) $V_r = L_r$
(b) $L_r = \sqrt{V_r}$
(c) $V_r = L_r^{1.5}$
(d) $V_r = \sqrt{L_r}$

3. Group-I contain dimensionless parameter and Group-II contains ratio.

Group-I
A. Match number
B. Reynold number
C. Weber number
D. Froude number

Group-II
(i) Ratio of internal force and gravity force.
(ii) Ratio of fluid velocity and velocity of sound.
(iii) Ratio of inertial force and viscous force.
(iii) Ratio of inertial force and surface tension force.

Correct match of the dimensionless parameter in Group-I with Group-II is

[GATE - 2013]

Code:
(a) A-iii, B-ii, C-iv, D-i
(b) A-iii, B-iv, C-ii, D-i
(c) A-ii, B-iii, C-iv, D-i
(d) A-iii, B-iii, C-ii, D-iv

4. A phenomenon is modeled using n dimensional variables k primary dimensions. The number of non-dimensional variables is

[GATE - 2010]

(a) k
(b) n
(c) n – k
(d) n + k

5. A river reach of 2.0 km long with maximum flood discharge of 10000 m^3/s is to be physically modeled in the laboratory where maximum available discharge is 0.20 m^3/s. For a geometrically similar model based on equality of Froude number , the length of the river reach (m) in the model is

[GATE - 2008]

(a) 26.4
(b) 25.0
(c) 20.5
(d) 18.0

6. A 1:50 scale model of a spillway is to be tested in the laboratory. The discharge in the prototype is 1000 m^3/s. The discharge to be maintained in the model test is

[GATE - 2007]

(a) 0.057 m^3/s
(b) 0.08 m^3/s
(c) 0.57 m^3/s
(d) 5.7 m^3/s

7. The flow of glycerin (kinematic viscosity ν = $5 \times 10^{-4} m^2/s$) as the flowing fluid. If both gravity and viscosity are important, what should be the length scale (i.e., ratio of prototype to model dimensions) for maintaining dynamic similarity?

[GATE - 2006]

(a) 1
(b) 22
(c) 63
(d) 500

8. The height of a hydraulic jump in the stilling pool of 1 : 25 scale model was observed to be 10 cm. The corresponding prototype height of the jump is

[GATE - 2004]

(a) Not determinable from the data given
(b) 2.5 m
(c) 0.5 m
(d) 0.1 m

ESE CONV QUESTIONS

1. Estimate for 1: 20 model of a spillway (i) prototype velocity corresponding to a model velocity 2 m/sec. (ii) prototype discharge per unit width corresponding to a model discharge per unit width of 0.3 m^3/sec/m, (iii) pressure head in the prototype corresponding to a model head of 5 cm of mercury at a point and (iv) the energy dissipated per second in the model corresponding to a prototype value of 1.5 kW.

[CE ESE - 2015]

Solution.

Length ratio, $L_r = \frac{L_m}{L_p} = \frac{1}{20}$

(i) Prototype velocity for model velocity of 2 m/sec

Velocity ratio $V_r = \sqrt{L_r}$

$\Rightarrow \frac{V_m}{V_p} = \sqrt{\frac{1}{20}}$

$\Rightarrow V_P = V_m\sqrt{20} = 2\sqrt{20}$

(ii) Prototype discharge per unit width for model discharge per unit width of 0.3 m^3/s/m.

Discharge intensity ratio, $q_r = \frac{V_r A_r}{L_r} = \frac{\sqrt{L_r} \times L_r^2}{L_r} = L_r^{3/2}$

$\frac{q_m}{q_p} = \left(\frac{1}{20}\right)^{3/2}$

$q_p = q_m(20)^{3/2} = 0.3 \times (20)^{3/2}$

$q_p = 26.83\ m^3/s/m$

(iii) Prototype pressure head for model pressure head of 5 cm of Hg.

$\left(\frac{p}{\rho g}\right)_r = L_r$

$\Rightarrow \frac{(\rho/\rho g)_m}{(p/\rho g)_p} = \frac{1}{20}$

$\Rightarrow (p/\rho g)_p = 20 \times (p/\rho g)_m = 20 \times 5 = 100$ cm of Hg

(iv) Energy dissipated per second in model for 1.5 kW. Energy dissipated in prototype.

Energy dissipated/sec. = Work done/sec. + Power

$P_r = F_r V_r$

$= \rho_r L_r^3 \times g_r \times \sqrt{L_r}$

$= L_r^{7/2}$ $(\because \rho_r = 1 \text{ and } g_r = 1)$

$\Rightarrow \frac{P_m}{P_P} = \left(\frac{1}{20}\right)^{7/2}$

$\Rightarrow P_m = 1.5 \times \left(\frac{1}{20}\right)^{7/2}$

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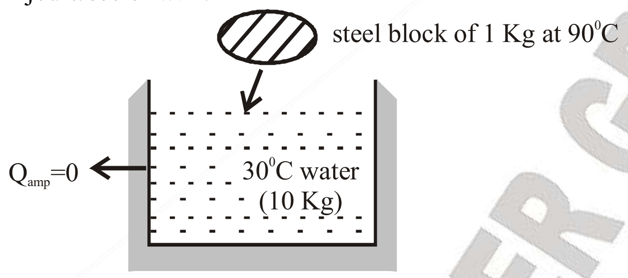
CONTENTS

CHAPTER - 1
BASIC CONCEPT

1.1 INTRODUCTION
The main difference between thermodynamic analysis and heat transfer analysis of a problem is that in thermodynamic we deal with system in equilibrium i.e., to bring a system from one equilibrium state how much heat is require is the main criteria in thermodynamic analysis.
But in heat transfer analysis we deal with how fast the change of state occurs by calculating the rate of heat transfer in joule/sec or watt.



In the above figure, a steel block which is at 90ºC is put in water at 30ºC.
Here we can use thermodynamic approach to find the equilibrium temperature T_e i.e.
Heat lost by steel = Heat gained by water

$$m_s \times c_{ps} (T_{si} - T_e) = m_w \times c_{pw} (T_e - T_{wi})$$

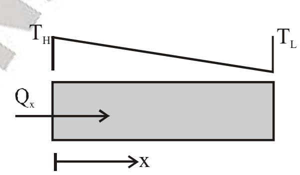
Where, m_s and m_w are mass of steel block and mass of water
c_{ps} and c_{pw} are specific heat of steel block and water
Tsi and Twi are initial temperature of steel block and water

$$1\times c_{ps}\times (90 - T_e) = 10\times c_{pw} \times (T_e - 30)$$

From the above equation T_e (equilibrium tamp.) can be easily found out with given value of specific heat of steel block and water.

1.2 MODES OF HEAT TRANSFER
The heat transfer generally takes place under three different controlling laws as Conduction, Convection and Radiation all three has been discusses below in detail.

1.3 CONDUCTION
In such case heat transfer takes place between the molecules of a stationery medium like solid, liquid and gas. The conduction phenomenon can be easily understand by Fourier law of conduction.



GATE QUESTIONS

1. As the temperature increases, the thermal conductivity of a gas

[GATE - 2014]

(a)Increases
(b)Decreases
(c)Remains constant
(d)Increases upto a certain temperature and then decreases

2. One dimensional unsteady state heat transfer equation doe a sphere with heat generation at the rate of 'q' can be written

[GATE - 2004]

(a) $\frac{1}{r}\frac{\partial}{\partial r}\left(r\frac{\partial T}{\partial r}\right)+\frac{q}{k}=\frac{1}{\alpha}\frac{\partial T}{\partial t}$

(b) $\frac{1}{r^2}\frac{\partial}{\partial r}\left(r^2\frac{\partial T}{\partial r}\right)+\frac{q}{k}=\frac{1}{\alpha}\frac{\partial T}{\partial t}$

(c) $\frac{\partial^2 T}{\partial r^2}+\frac{q}{k}=\frac{1}{\alpha}\frac{\partial T}{\partial t}$

(d) $\frac{\partial^2}{\partial r^2}(rT)+\frac{q}{k}=\frac{1}{\alpha}\frac{\partial T}{\partial t}$

3. In descending order of magnitude, the thermal conductivity (a) Pure iron (b) Liquid water (c) saturated water vapour (d) Pure aluminium can be arranged as

[GATE - 2001]

(a) abcd (b) bcad
(c) dabc (d) dcba

4. For a given heat flow and for the same thickness, the temp, drop across the material will be maximum for

[GATE - 1996]

(a) Copper (b) Steel
(c) Glass wool (d) Refractory brick

5. Match the property with their units

Property
A. Bulk modulus
B. Thermal conductivity
C. Heat transfer coefficient
D. Heat flow rate

Units
(i) W/s
(ii) N/m^2
(iii) N/m^3
(iv) W
(v) W/mK
(vi) W/m^2K

[GATE - 1991]

Codes:
(a) A-i, B-ii, C-vi, D-v
(b) A-ii, B-v, C-vi, D-i
(c) A-ii, B-vi, C-iv, D-i
(d) A-i, B-v, C-ii, D-ii

6. Thermal conductivity is lower for

[GATE - 1990]

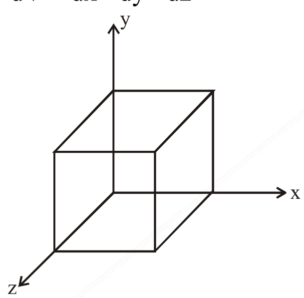
(a) Wood
(b) Air
(c) Water at 100°C
(d) Steam at 1 bar

CHAPTER - 2
STEADY STATE CONDUCTION THROUGH A PLANE WALL

2.1 INTRODUCTION
The objective of conduction analysis is:
1. To calculate the temperature distribution and temperature gradient means variation of temperature with time and distance.
2. To calculate heat transfer rate through geometry.

2.2 HEAT DIFFUSION EQUATION IN CARTESIAN COORDINATE SYSTEM
Consider an infinitesimal volume element through which heat flow rate exist and which is oriented in a three dimensional co-ordinate system. The sides dx, dy and dz have been taken parallel to the x, y and z respectively. The volume for element will be:

$$dV = dx \times dy \times dz$$



1. Accumulation of Heat in x-direction
By using Taylor series expansion we get,

$$Q_x - Q_{x+dx} = Q_x - \left[Q_x + \frac{-\partial}{\partial x}\left(Q_x\right)dx\right]$$

$$Q_x - Q_{x+dx} = -\frac{\partial}{\partial x}\left(Q_x\right)dx$$

$$Q_x - Q_{x+dx} = -\frac{\partial}{\partial x}\left(-k_x A_x \frac{dT}{dx}\right)dx$$

$$Q_x - Q_{x+dx} = \frac{\partial}{\partial x}\left(k_x dydz \frac{dT}{dx}\right)dx$$

$$\left(\because A_x = dy \times dz\right)$$

$$Q_x - Q_{x+dx} = \frac{\partial}{\partial x}\left(k_x \frac{dT}{dx}\right)dxdydz$$

$$Q_x - Q_{x+dx} = \frac{\partial}{\partial x}\left(k_x \frac{dT}{dx}\right)dV$$

CHAPTER - 3
CONDUCTION ANALYSIS THROUGH A HOLLOW CYLINDER

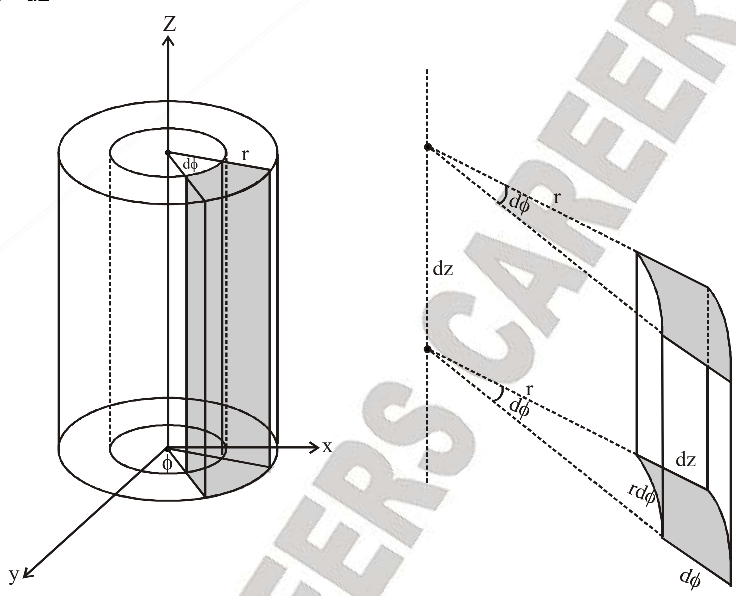
3.1 INTRODUCTION

In power stations, process industries and oil refineries the cylindrical metal tubes are essential element. Almost in all thermodynamic applications the cylindrical tubes are used. Evidently, in tubes, pipes and insulation used to cover pipe has the radial heat transfer rate through is quite important.

3.2 HEAT DIFFUSION EQUATION IN CYLINDRICAL COORDINATE SYSTEM

As we know tubes and pipes have cylindrical geometry. Thus, it is more convenient to consider cylindrical co-ordinates. The general heat equation can be setup by considering an infinitesimal cylindrical volume element. The volume for element will be:

$$dV = dr_o \times r_o d\phi \times dz$$



1. Accumulation of Heat in Radial Direction (z – ϕ plane)

$$Q_{ro} - Q_{r_o+dr_o} = Q_{r_o} - \left[Q_{r_o} + \frac{\partial}{\partial r_o}\left(Q_{r_o}\right)dr_o\right]$$

$$Q_{r_o} - Q_{r_o+dr_o} = -\frac{\partial}{\partial r_o}\left(Q_{r_o}\right)dr_o$$

$$Q_{r_o} - Q_{r_o+dr_o} = -\frac{\partial}{\partial r_o}\left(-k_{r_o} A_{r_o} \frac{dT}{dr_o}\right)dr_o$$

GATE QUESTIONS

1. A plastic sleeve of outer radius r_0 = 1mm covers a wire (radius r = 0.5mm) carrying electric current .Thermal conductivity of the plastic is 0.15W/m–K. The heat transfer coefficient on the outer surface of the sleeve exposed to air is 25W/m^2–K. Due to the addition of the plastic cover, the heat transfer from the wise to the ambient will

[GATE - 2016]

(a) Increase (b) Remain the same
(c) Decrease (d) Be zero

2. Consider the radiation heat exchange inside an annulus between two very long concentric cylinders .The radius of the outer cylinder is R_0 and that of the inner cylinder is R_i. The radiation view factor of the outer cylinder into itself is

[GATE - 2016]

(a) $1-\sqrt{\dfrac{R_i}{R_0}}$ (b) $\sqrt{1-\dfrac{R_i}{R_0}}$
(c) $1-\left(\dfrac{R_i}{R_0}\right)$ (d) $1-\dfrac{R_i}{R_0}$

3. A hollow cylinder has length L, inner radius r_1, outer radius r_2, and thermal conductivity k. The thermal resistance of the cylinder for radial conduction is

[GATE - 2016]

(a) $\dfrac{In(r_2/r_1)}{2\pi kL}$ (b) $\dfrac{In(r_1/r_2)}{2\pi kL}$
(c) $\dfrac{2\pi kL}{In(r_2/r_1)}$ (d) $\dfrac{2\pi kL}{In(r_1/r_2)}$

4. Consider a long cylindrical tube of and outer radii, r_1 and r_0, respectively, length L and thermal conductivity k. Its inner and outer surfaces are maintained at T_1 and T_0, respectively ($T_1 > T_0$). Assuming one-dimensional steady state heat conduction in the radial direction , the thermal resistance in the wall of the tube is

[GATE - 2014]

(a) $\dfrac{1}{2\pi kL}\ln\left(\dfrac{r_1}{r_0}\right)$
(b) $\dfrac{L}{2\pi r_i k}$
(c) $\dfrac{1}{2\pi kL}\ln\left(\dfrac{r_0}{r_i}\right)$
(d) $\dfrac{L}{4\pi kL}\ln\left(\dfrac{r_0}{r_i}\right)$

5. If q_w = 5000 and the convection heat transfer coefficient at the pipe outlet is 1000W/m^{2}K , the temperature is °C at the inner surface of the pipe at the outlet is

[GATE - 2013]

(a) 71 (b) 76
(c) 79 (d) 81

6. If q_w = 2500 heat , c_p = 4.18kJ/kgK enters a pipe at rate 0.01kg/s and a temperature of 20°C , the pipe , of diameter 50mm and length 3m, is subjected to a wall heat flux q_w in W/m^2

[GATE - 2013]

(a) 42 (b) 62
(c) 74 (d) 104

7. A hollow enclosure is formed between two infinitely long concentric cylinders of radii 1m and 2m, respectively. Radiative heat exchange takes place between the inner surface of the larger cylinder (surface -2) and the outer surface of the smaller cylinder (surface-1). The radiating surface are diffuse and the medium in the enclosure is non-participating ,The fraction of the thermal radiation leaving the larger surface and striking itself is

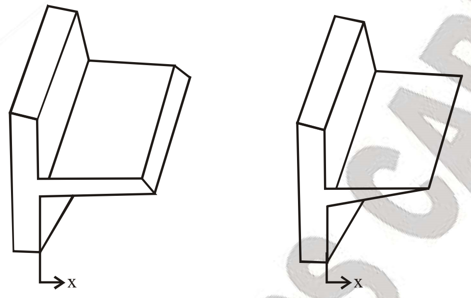
CHAPTER - 5
EXTENDED SURFACES (FINS)

5.1 INTRODUCTION

In many engineering applications the cooling of surface is mandatory to increase the working period of material whereas in compressors the surface cooling is required to reduce work input. It can be done by using suitable convective heat transfer coefficient (h) which leads to maximum heat transfer rate. The convective coefficient (h) is function of geometry, fluid properties and the flow rate. The optimum value of h can be determined from these parameters. As we know heat transfer rate is through convection is $Q = h\ A\ (T_s - T_a)$. In actual practice mostly engineering applications are in contact with atmospheric air only. In summer or hot weather conditions the temperature of hot gases will increase and temperature difference will starting decrease which leads to decrease in heat transfer rate due to convection. The possible effort to increase surface area will increase heat transfer rate. Thus, concept of fins introduced by the attachment of extended surfaces with surface area which is exposed to the surroundings.
The most commonly fins are discussed below

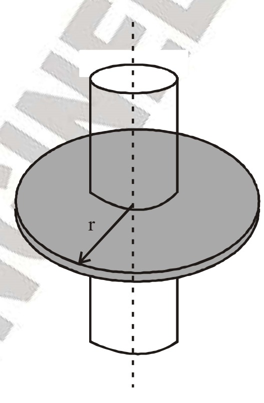
5.1.1 Straight Fin

It is an extended surface attached to the plane wall, the cross-sectional area of the fin may be uniform or it may vary with distance from the wall.



5.1.2 Annular Fins

These types of fins are usually attached circumferentially to a cylindrical surface and their cross-sectional area varies with radius from the centre line of the cylinder.



GATE QUESTIONS

1. Which one of the following configuration has the highest fin effectiveness?

[GATE - 2012]

(a) Thin, closely spaced fins
(b) Thin, widely spaced fins
(c) Thick, widely spaced fins
(d) Thick, closely spaced fins

2. A fin has 5mm diameter and 100mm length. The thermal conductivity of fin material is $400 Wm^{-1}K^{-1}$.One end of the fin is maintained at 130°C and its remaining surface is exposed to ambient air at 30°C .if the convective heat transfer coefficient is $40\ Wm^{-2}K^{-1}$, the heat loss (in W) from the fin is

[GATE - 2010]

(a) 0.08 (b) 5.0
(c) 7.0 (d) 7.8

SOLUTIONS

Sol. 1. (a)

Fin effectiveness,

$$\in = \frac{\text{heat transfer with fin}}{\text{heat transfer without fin}}$$

i.e., for so long fin

$$\in = \sqrt{\frac{Pk}{hA}} P\uparrow \& A\downarrow$$

And this is highest with thin closely spaced fins

Sol. 2. (b)

$$\sqrt{\frac{hP}{KA}}$$

$P = \pi d$

$$A = \frac{\pi}{4}d^2$$

$$\frac{P}{A} = \frac{4}{d}$$

$$m = \sqrt{\frac{4h}{Kd}} = \sqrt{\frac{4\times 40}{400\times 5\times 10^{-3}}} = 8.94$$

mL = 8.94×0.1 = 0.894

i.e., fin of so long

So the fin is insulated tip

$$Q_{f_{in}} = mAK(t_0 - t_a)\tan h(mL)$$

$$8.94\times\frac{\pi}{4}(5\times 10^{-3})^2\times 400\times 100\times \tanh(8.94\times 0.1)$$

=5.008W

CHAPTER - 6
UNSTEADY STATE CONDUCTION HEAT TRANSFER

6.1 INTRODUCTION

Unsteady or transient means time dependent. Unsteady state conduction refers to the heat transfer and temperature distribution varies continuously with time at any point of the system. Undoubtedly, the heat transfer and temperature varies with time or we can say both are time dependent. In industries heating, Cooling and drying processes all are time dependent. For example: Quenching of steel, where temperature gradually decreases until rod and quenching medium attain the same temperature. An increase or decrease in temperature at any instant continues until steady state temperature distribution is attained.
Further, change in temperature during unsteady state may follow a periodic or non-periodic variation as discussed below in detail.

6.1.1 Periodic Variation

In this case temperature changes in repeated cycles and condition repeated after some fixed time interval. In cylinder of I.C engine the temperature variations are considered to be periodic because during each cycle a definite variation temperature occurs with respect to the crank angle and its keeps on changing as long as engine is running. Temperature variation in building during full day period of 24 hrs can be also considered as period variations.

6.1.2 Non-Periodic Variation

In such case the temperature changes with time as non linear function. This variation is irregular and nor in repeated cycles. Heating of an ingot in a furnace is suitable example and here one medium is surrounded or influenced by another medium of given thermal state.

6.2 LUMPED PARAMETER ANALYSIS

It is the useful to many of the transient heat transfer problems which presumes that the solid posses very infinitely large thermal conductivity. The, internal conduction resistance is very small and heat transfer to or from the solid is mainly controlled by convective resistance. It means temperature gradient within the solid is negligible and varies with time only. $T = f(t)$
Consider a body of mass m, volume V, densityρ, specific heat C_p which is at an initial temperature of T_i is suddenly exposed to surrounding fluid (a thermal reservoir) which is at temperature of T_{sr}. The transient response of the solid can be determined by applying energy consevation:

$$\dot{E}_{in} - \dot{E}_{out} + \dot{Q}_{gen} = mc_p \frac{dT}{dt}$$

Here, $\dot{E}_{in} = \dot{Q}_{gen} = 0$

$$\dot{E}_{out} = -mc_p \frac{dT}{dt}$$

$$hA_s\left(T - T_{sr}\right) = -mc_p \frac{dT}{dt}$$

Upon rearranging, integrate above relation with temperature T and time t and we get,

$$\int_{T_s}^{T} \frac{dT}{\left(T - T_{sr}\right)} = -\frac{hA_s}{mc_p}\int_0^t dt$$

GATE QUESTIONS

1. A cylindrical steel rod , 0.01m in diameter and 0.2m in length is first heated to 750°C , and then immersed in a water both at 100°C .The heat transfer coefficient is $250 W/m^2 – K$. The density , specific heat and thermal conductivity of steel are ρ = $7801 kg/m^3$, c = 473 J/kg –K and k = 43 W/m-K , respectively. The time required for the rod to reach 300°C is _______seconds.

[GATE - 2016]

2. Two cylindrical shafts A and B at the same initial temperature are simultaneously placed in a furnace .The surfaces of the shafts remain at the furnace gas temperature at all times after they are introduced into the furnace .The temperature variation in the axial direction of the shafts can be assumed to be negligible .The data related to shafts A and B is given in the following table

Quantity	Shaft A	Shaft B
Diameter (m)	0.4	0.1
Thermal conductivity	40	20
Volumetric heat caspacity (j/m^3-K)	2×10^6	2×10^7

The temperature at the centerline of the shaft A reaches 400°C after two hours .The time required (in hours) for the centerline of the shaft B to attain the temperature of 400°C is_______.

[GATE - 2016]

3. Biot number signifies the ratio of

[GATE - 2014]

(a)Convective resistance in the fluid to conductive resistance in the solid
(b)Conductive resistance in the solid to convective resistance in the fluid
(c)Inertia force to viscous force in the fluid
(d)Buoyancy force to viscous force in the fluid

4. A steel ball of diameter 60mm is initially in thermal equilibrium at 1030°C in a furnace .It is suddenly removed from the furnace and cooled in ambient air at 30°C , with convective heat transfer coefficient h = $20 W/m^2K$.The thermo 0physical properties of steel are : density ρ = $7800 kg/m^2$, conductivity k = 40 W/mK and specific heat c =600J/kgK. The time required in seconds to cool the steel ball in air from 1030°C to 430°C is

[GATE - 2013]

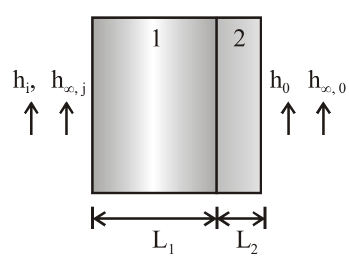
(a) 519 (b) 931
(c) 1195 (d) 2144

5. Which one of the following configurations has the highest , fin effectiveness ?

[GATE - 2012]

(a) Thin, closely spaced fins
(b) Thin, widely spaced fins
(c) Thick, widely spaced fins
(d) Thick, closely spaced fins

6. Consider steady –state heat conduction across the thickness in a plane composite wall (as shown in the figure) exposed to convection conditions on both sides
Given : $h_i = 20 W/m^2K$; $h_0 = 50 W/m^2K$; T_∞ = 20°C; $T_{\infty,\ 0}$ = -2°C; k_1 = 20W/mK; k_2 = 50W/mK; L_1 = 0.30 m and L_2 = 0.15m .Assuming negligible contact resistance between the wall surfaces , the interface temperature , T(in °C), of the two walls will be



[GATE - 2009]

CHAPTER - 7
HEAT EXCHANGERS

7.1 INTRODUCTION

It is an effective equipment designed for heat transfer between two different or same fluid placed at different temperatures i.e. a hot fluid and coolant. It is a device which can be used for either heating or cooling of fluid. The heat exchanger may be used for boiling and condensation purposes where latent heat or phase change plays vital role. Some of the industrial applications of heat exchangers are:

1. Steam Power Plant
In power plants the heat exchangers are used in the form of:
(i) Boilers
(ii) Super heaters
(iii) Condensers
(iv) Economizer

2. Heat Engine
In heat engines the heat exchangers are used in the form of:
(i) Radiator
(ii) Oil coolers

3. Refrigerating Unit
In refrigerating unit the heat exchangers are used in the form of:
(i) Evaporator
(ii) Condenser

4. Gas Turbine Unit
In gas turbine units the heat exchangers are used in the form of:
(i) Intercooler
(ii) Regenerator

7.1.1 Nature of heat exchange process

The heat exchange between two fluids depends upon nature of heat exchange process. The commonly used processes are Direct Contact, Regeneration and Recuperation. Some of useful details for these processes are discussed below:

1. Direct Contact
The direct contact are also called as open heat exchangers where heat transfer takes place between hot and cold fluid due to physical mixing there is simultaneously transfer of heat and mass. Such units are limited to use where mixing is harmless and desired. Examples: Cooling Tower and jet condenser in steam power plants.

(i) Regeneration
In this method the hot fluid is passed through a certain medium called matrix and it accumulates the heat from hot fluid during heating period. The stored heat then subsequently passes to clod

GATE QUESTIONS

1. For a heat exchanger , ΔT_{max} is the maximum temperature difference and ΔT_{min} is the minimum temperature difference between the two fluids. LMTD is the log mean temperature difference. C_{min} and C_{max} are the minimum and the maximum heat capacity rates. The maximum possible heat transfer (Q_{max}) between the two fluids is

[GATE - 2016]

(a) C_{min}LMTD
(b) $C_{min\Delta T}max$
(c) $C_{max}\Delta T_{max}$
(d) $C_{max}\Delta T_{min}$

2. Consider a parallel –flow heat exchanger with Area A_p and a counter flow heat exchanger with area A_c. In both the heat exchangers , the hot stream flowing at 1kg /s cools from 80°C to 50°C .For the cold stream in both the heat exchangers ,the flow rate and the inlet temperature are 2kg/s and 10°C , respectively .The hot and cold streams in both the heat exchangers are of the same fluid .Also, both the heat exchangers have the small overall heat transfer coefficient. The ratio A_c/A_p is ________.

[GATE - 2016]

3. In a counter flow heat exchanger , hot fluid enters at 60°C and cold fluid leaves at 30°C. Mass flow rate of the hot fluid is 1kg/s and that the cold fluid is 2kg/s. Specific heat of the hot fluid is 10kJ/kgK and that of the cold fluid is 5kJ/kgK.The log mean Temperature difference (LMTD) for the heat exchanger in °C is

[GATE - 2015]

(a) 15
(b) 30
(c) 35
(d) 45

4. Hot oil is cooled from 80 to 50°C in an oil cooler which uses air as the coolant .The air temperature rises from 30 to 40°C .The designer uses a LMTD value of 26°C .The type of heat exchanger is

[GATE - 2015]

(a) Parallel flow
(b) Double pipe
(c) Counter flow
(d) Cross flow

5. A double pipe counter flow heat exchanger transfers heat between two water streams .Tube side water at 19 litre/s is heated from 10°C to 38°C .Shell side water a at 25 litre/s is entering at 46°C .Assume constant properties of water , density is 1000 kg /m^3 and specific heat is 4186J/kg-K. The LMTD (in °C) is _______.

[GATE - 2014]

6. In a concentric counter flow heat exchanger , water flows through the inner tube at 25°C and leaves at 42°C .The engine oil enters at 100°C and flows in the annular flow passage .The exit temperature of the engine oil is 50°C .Mass flow rate of water and the engine oil are 1.5kg/s and 1kg/s , respectively .The specific heat of water and oil are 4178 J/kg. K and 2130 J/kg .K, respectively .The effectiveness of this heat exchanger is _______.

[GATE - 2014]

7. In a heat exchanger , it is observed that $\Delta T_1 = \Delta T_2$, where ΔT_1 is the temperature difference between the two single phase fluid streams at one end and ΔT_2 is the temperature difference at the other end .This heat exchanger is

[GATE - 2014]

(a) A condenser
(b) An evaporator
(c) A counter flow heat exchanger
(d) A parallel flow heat exchanger

8. Water (Cp = 4.18kJ/kg.K) at 80°C enters a counter flow heat exchanger with a mass flow rate of 0.5kg/s.Air (Cp = 1kJ/kg.K)enters at 30°C with a mass flow rate of 2.09kg/s .if the effectiveness of the heat exchanger is 0.8, the LMTD (in °C) is

CHAPTER - 8
THERMAL RADIATION

8.1 INTRODUCTION

In Thermal radiation the heat transfer takes place between two bodies without any medium or physical contact between them unlike conduction and convection. Thermal radiations occur most effectively in the vacuum because energy released by radiating surface is not continuous but in the form of discrete packets of energy called photons. These photons are propaGATEd through space as rays and the movement of set of photons can be described as electromagnetic waves and travels with speed of light ($c = 3 \times 10^8$m/sec) without changing their frequency in straight paths. When these photons reach at receiving body then reconverts into thermal energy and it may partly absorb, reflect and transmit as per condition receiving body. The magnitude of absorption, transmission and reflection purely depends upon the nature of surface of the receiving body only.

8.2 CHARACTERISTICS OF THERMAL RADIATION

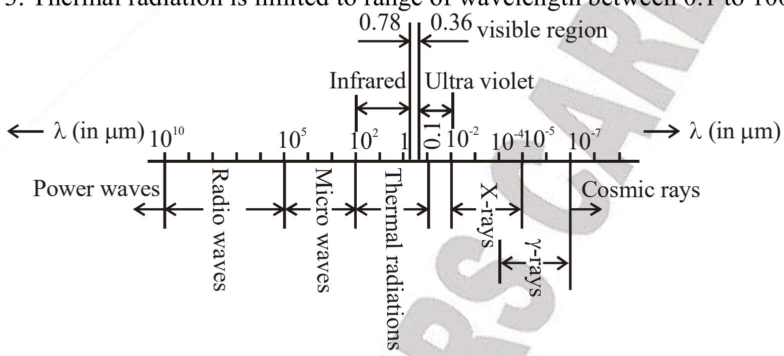
Some of the characteristics of thermal radiations are discussed below:

1. The amount of emit of thermal radiations (energy) completely depends upon the nature of surface and its absolute temperature. Each surface emits radiations above 0 K temperatures.

2. A high temperature body will have high frequency photons which lead to shorter wavelength.

Speed of light (c) = wavelength (λ) × Frequency (f)

3. Thermal radiation is limited to range of wavelength between 0.1 to 100 micron (μm).



Electromagnetic wave spectrum

Thermal radiation consists of entire visible and infrared and some part of ultraviolet from spectrum of electromagnetic waves.

4. Thermal radiation shows characteristics similar to the visible light and also follows the optical laws.

5. The heat exchange by radiation gets enhanced at elevated temperatures of the source and the surrounding unlike conduction and convection in which heat transfer primarily on the basis of temperature gradient only within the same body.

6. Thermal radiation is a volume phenomenon because all solid, liquid and gases emit, absorb and transmitted though entire volume due to continuous motion electron, atom and molecules above absolute zero temperature.

7. Thermal radiation for opaque objects like: metals, wood and rock is considered as surface (phenomenon because radiation emitted by interior region can never reach the surface and radiation incident on such bodies is usually absorbed within few microns from the surface.

GATE QUESTIONS

1. Consider the radiation heat exchange inside an annulus between two very long concentric cylinders .The radius of the outer cylinder is R_0 and that of the inner cylinder is R_{21} .The radiation view factor of the outer cylinder onto itself is

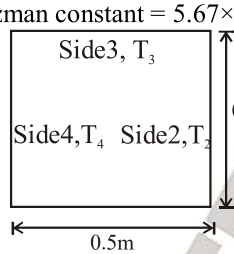
[GATE - 2016]

(a) $1-\sqrt{\frac{R_1}{R_0}}$ (b) $\sqrt{1-\frac{R_1}{R_0}}$

(c) $1-\left(\frac{R_1}{R_0}\right)^{1/3}$ (d) $1-\frac{R_1}{R_0}$

2. An infinitely long furnace of 0.5m ×0.4m cross-section is shown in the figure below .Consider all surfaces of the furnace to be black.The top and bottom walls are maintained at temperature $T_1 = T_3$= 927°C while the side walls are at temperature $T_2 = T_4$ = 527° .The view factor , F_{1-2} is 0.26 .The net radiation heat loss or gain on side 1 is W/m

Stefan –Boltzman constant = 5.67×10^{-8} W/m^2-K^4



[GATE - 2016]

3. Two large parallel plates having a gap of 10mm in between them are maintained at temperatures T_1=1000K and T_2 = 400K.Given emissivity values , $\varepsilon_1 = 0.5$, $\varepsilon_2 = 0.25$ and Stefan –Boltzmann constant $\sigma = 5.67\times10^{-8}$W/m^2-K.the heat transfer between the plates (in kW/m^2) is __________ **[GATE - 2016]**

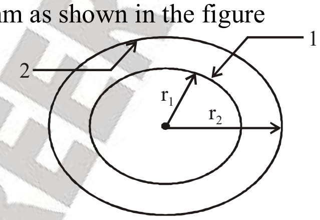
4. Two infinite parallel plates are place at a certain distance apart .An infinite radiation shield is inserted between the plates without touching any of them to reduce heat exchange between the plates .Assume that the emissivities of plates and radiation shield are equal .The ratio of the net heat exchange between the plates with and without the shield is

[GATE - 2014]

(a) 1/2 (b) 1/3

(c) 1/ 4 (d) 1/8

5. A solid sphere of radius r1 = 20mm is placed concentrically inside a hollow sphere of radius r_2 = 30mm as shown in the figure



The view factor F_{21} for radiation heat transfer

[GATE - 2014]

(a) $\frac{2}{3}$ (b) $\frac{4}{9}$

(c) $\frac{8}{27}$ (d) $\frac{9}{4}$

6. A hemispherical furnace of 1m radius has the inner surface (emissivity , ε =1) of its roof maintained at 800K, while its floor (ε =0.5) is kept at 600K.Stefan –Boltzmann constant is 5.668×10^{-8}W/m^2.K^4 .The net radiative heat transfer (in kW) from the roof to the floor is ________.

[GATE - 2014]

7. Two large diffuse gray parallel plates , separated by a small distance , have surface temperature of 400K and 300K .If the emissivities of the surfaces are 0.8 and the Stefan –Boltzmann constant is $5.67\times^{10-}8$ W/m^{3}K^4 , the net radiation the two plates is

[GATE - 2013]

(a) 0.66 (b) 0.79

CHAPTER - 9
CONVECTION HEAT TRANSFER

9.1 INTRODUCTION

In any convection heat transfer problem it is required to obtain, the convection heat transfer coefficient h for a given boundary conditions prevailing between the solid surface and the surrounding moving fluid. And hence to obtain the convention heat transfer rate between solid and fluid from Newton's low of cooling.

i.e. $q_{conv} = hA\,\Delta T \rightarrow (T_{\omega} - T_{\infty})$

Wall/surface temperature   free stream

Two types

- Forced convection
  (Velocity of fluid is evident)
- Free convection
  No velocity is evident but the flow of fluid occurs naturally due to buoughly forces arising out of desity charges of fluid

9.1.1 Force Convection

Forced convection

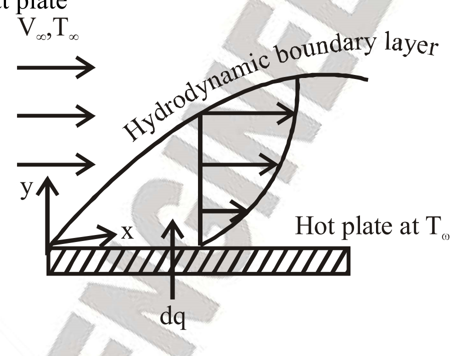
- Flow over flat plates
- Flow through pipes or ditcts (internal flow)

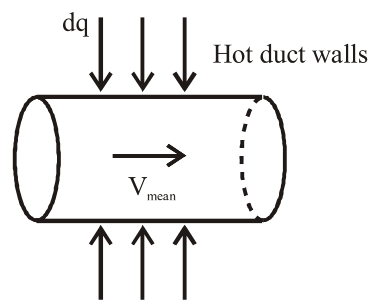
In any forced convection heat transfer,

$$h = f(\vec{V}, D, \rho, \mu, C_p, k)$$

$\vec{D}$ = Charactersitic dimension of body

For flat plate





GATE QUESTIONS

1. Grash of number signifies the ratio of **[GATE - 2016]**

(a) Inertia force to viscous force
(b) Buoyancy force to viscous force
(c) Buoyancy force to inertia force
(d) Inertial force to surface tension force

2. Match List-I with List-II

List-I
A. Biot number
B. Grash of number
C. Prandtl number
D. Reynold's number

List-B
(i) Ratio of buoyancy to viscous force
(ii) Rate of inertia force to viscous force
(iii) Ratio of momentum to thermal diffusivities
(iv) Ratio of internal thermal resistance to boundary layer thermal resistances

[GATE - 2014]

Codes :
(a) A-iv, B-i, C-iii, D-ii
(b) A-iv, B-iii, C-i, D-ii
(c) A-iii, B-ii, C-i, D-iv
(d) A-ii, B-i, C-iii, D-iv

3. For laminar force convection over a flat plate if the free stream velocity increases by a factor of 2, the average heat transfer coefficient **[GATE - 2014]**

(a) Remains same
(b) Decreases by a factor of $\sqrt{2}$
(c) Rises by a factor of $\sqrt{2}$
(d) Rises by a factor of 4

4. Water flows through a tube of diameter 25mm at an average velocity of 1.0m/s. The properties of water are ρ = 1000kg/m^3, $\mu = 7.25\times10^{-4}$N.s/m^2 , k = 0.625W/m, K, Pr = 4.85. Using $Nu = 0.023Re^{0.8}\,Pr^{0.4,}$ the convective heat transfer coefficient (in W/m^2.K) is ______ **[GATE - 2014]**

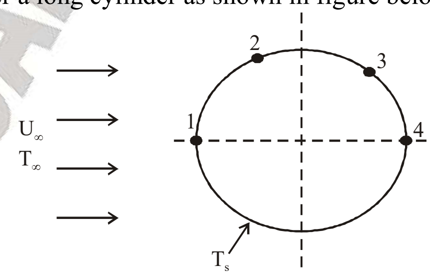
5. The non-dimensional fluid temperature profile near the surface of a convectively cooled flat plate is given by

$$\frac{T_w - T}{T_w - T_\infty} = a + b\frac{y}{L} + c\left(\frac{y}{L}\right)^2,$$

where y is measured perpendicular to the plate, L is the plate length , and a , b and c are arbitrary constants .T_w and T_∞ are wall and ambient temperatures ,respectively .if the thermal conductivity of the fluid is k and the wall heat flux is q" , the Nusselt number Nu = $\frac{q"}{T_w - T_\infty}\frac{L}{K}$ is equal to **[GATE - 2014]**

(a) a
(b) b
(c) 2c
(d) (b+2c)

6. Consider a two dimensional laminar flow over a long cylinder as shown in figure below



The free stream velocity is U_∞ and the free stream temperature T_∞ is lower than the cylinder surface temperature T_s .The local heat transfer coefficient is minimum at point **[GATE - 2014]**

(a)1
(b) 2
(c) 3
(d) 4

7. The ratios of the laminar hydrodynamic boundary layer thickness to thermal boundary layer thickness of flows of two fluids P and Q on a flat plate are ½ and 2 respectively .The Reynolds number based on the plate length for both the flows is 10^4 .The Prandtl and Nusselt

ESE CONV QUESTIONS

1. A refrigerator is placed near a partition wall of a room such that there is only a 4 cm gap between the wall and the refrigerator surface facing the wall. The refrigerator surface is of 1.6 m height and 0.8 m breadth and has a temperature of 22^0C. The wall temperature is 30^0C. Calculate the rate of heat gain by the refrigerator surface.
Assume the properties of air at 26^0C
$\nu = 1.684\times 10^{-5}$ m^2/s, k = 0.26 W/mK,
$\alpha = 2.21 \times 10^{-5}$ m^2/s, Pr = 0.7
Use the equation,

$$Nu = 0.42\ Ra_w^{0.25}\ Pr^{0.012}\left(\frac{L}{W}\right)^{-0.3}$$

(where Ra is the Rayleigh number)

[ESE - 2015]

Solution.

$$Nu = 0.42\ Ra_w^{0.25}\ Pr^{0.012}\left(\frac{L}{W}\right)^{-0.3}$$

$$Ra_L = \frac{gL^3\beta\Delta T}{\nu\alpha} = \frac{9.81(1.6)^3 \times 1\times 8}{1.684\times10^{-5}\times 299\times 2.21\times10^{-5}}$$

$$Ra_L = 0.288877284\times10^{10}$$

$$Nu = 0.42\times(288772840)^{0.25}\times(0.7)^{0.012}\times\left(\frac{1.6}{0.8}\right)^{-0.3}$$

$$Nu = 0.42\times231.84365\times0.99573\times0.81225$$

$$Nu = 78.75$$

$$\frac{hL}{k} = 78.752$$

$$h = 12.797 W/m^2 - K$$

$$\dot{q} = hA(T_s - T_\infty) = 12.797\times(1.6\times0.8)\times8$$

$$\dot{q} = 131.0425 W$$

2. Air at a temperature of 30^0C flows over a flat of length 2 m, which is maintained at 150^0C. The air flows with a velocity of 12 m/s. Find the local heat transfer coefficient at a distance of 0.5 m from the leading edge, and at the trailing edge. What is the type of flow at these two sections ? At what length, does the flow pattern change ?
The properties of air at the mean temperature of 90^0C are
C_p = 1.01 kJ/kg^{0}C, ρ = 0.962 kg/m^3
$\mu = 2.131 \times 10^{-5}$ kg/m –s, k = 0.031 W/mK
Use the equations:
Nu = 0.332 $Re^{0.5}Pr^{0.33}$ for laminar flow and
Nu = 0.0296 $Re^{0.8}Pr^{0.33}$ for turbulent flow