B. E. CHEMICAL ENGINEERING Choice Based Credit System (CBCS) and Outcome Based Education (OBE) SEMESTER – III			
MOMENTUM TRANSFER			
Course Code	**18CH33**	CIE Marks	40
Teaching Hours/Week (L:T:P)	(3:0:0)	SEE Marks	60
Credits	03	Exam Hours	03

Course Learning Objectives: The students will

1. Understand concepts on nature of fluids, pressure concepts and measurement of pressure by various experimental methods and by mathematical relations and enhancement of problem solving skills.
2. Learn detailed explanation on types of fluids, stress and velocity relations, type of fluid flow and boundary layer relations.
3. Understand relationship between kinetic energy, potential energy, internal energy and work complex flow systems using Bernoulli's equation with application to industrial problems.
4. Understand clear concepts on Flow of incompressible fluids in conduits and thin layers and friction factor variations with velocity and friction losses using Bernoulli's Equations and they will be demonstrated experimentally.
5. Study Flow of compressible fluids, Dimensional analysis, Dimensional homogeneity and various dimensionless numbers and their applications.
6. Understand principles and working of various types of pumps, transportation and metering of fluids using various experimental techniques and applications to industry.

Module-1

FLUID STATICS AND ITS APPLICATIONS:

Concept of unit operations, Concept of momentum transfer, Nature of fluids and pressure concept, variation of pressure with height – hydrostatic equilibrium, Barometric equation, Measurement of fluid pressure – manometers, Continuous gravity decanter, Centrifugal decanter.

FLUID FLOW PHENOMENA:

Type of fluids – shear stress and velocity gradient relation, Newtonian and Non- Newtonian fluids, Viscosity of gases and liquids. Types of flow – laminar and turbulent flow, Reynolds stress, Eddy viscosity. Flow in boundary layers, Reynolds number, and Boundary layer separation and wake formation.

Module-2

BASIC EQUATIONS OF FLUID FLOW:

Average velocity, Mass velocity, Continuity equation, Euler and Bernoulli equations Modified equations for real fluids with correction factors, Pump work in Bernoulli equation, Angular momentum equation.

FLOW OF INCOMPRESSIBLE FLUIDS IN CONDUITS AND THIN LAYERS:

Laminar flow through circular and non-circular conduits, Hagen Poiseuille equation, Laminar flow of Non-Newtonian liquids, Turbulent flow in pipes and closed channels.

Module-3

FLOW OF INCOMPRESSIBLE FLUIDS IN CONDUITS AND THIN LAYERS:

Friction factor chart, friction from changes in velocity or direction, Form friction losses in Bernoulli equation. Flow of fluids in thin layers.

FLOW OF COMPRESSIBLE FLUIDS:

Continuity equation, Concept of Mach number, Total energy balance, Velocity of sound, Ideal gas equations. Flow through variable-area conduits, Adiabatic frictional flow, Isothermal frictional flow (elementary treatment only).

Module-4

TRANSPORTATION AND METERING OF FLUIDS:

Pipes, Fittings and valves, Measurement of fluid and gas flow rates by orifice meter, rotameter and pitot tube. Elementary concept of target meter, vortex-shedding meters, turbine meters, positive displacement meters, magnetic meters, coriolis meters and thermal meters. Flow through open channel-weirs and notches.

Module-5

PUMPS:

Performance and Characteristics of pumps-positive displacement and centrifugal pumps, Fans, compressors, and blowers.

DIMENSIONAL ANALYSIS:

Dimensional homogeneity, Rayleigh's and Buckingham Π- methods, Significance of different dimensionless

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numbers, Elementary treatment of similitude between model and prototype.

Course Outcomes: On completion of this course the students will be able to

- Recall the concepts of fluid statics and dynamics and able to measure pressure difference.
- Explain the fundamental equations of fluid flow.
- Understand the various equations for incompressible and compressible fluids in conduits.
- Demonstrate the knowledge of fluid flow principles in various types of flow measurements. transportation and metering equipment of fluids using experimental techniques and applications to industry.
- Develop functional relationships using dimensional analysis and similitude to solve technical problems.
- Design appropriate flow systems and flow measuring instruments.

QUESTION PAPER PATTERN:

- The question paper will have ten questions.
- Each full Question consisting of 20 marks
- There will be 2 full questions (with a maximum of four sub questions) from each module.
- Each full question will have sub questions covering all the topics under a module.
- The students will have to answer 5 full questions, selecting one full question from each module.

TEXT BOOKS:

1. McCabe, W.L., *et.al.*, **"Unit Operations in Chemical Engineering"**, 5th edn., McGraw Hill, New York 1993
2. Kumar K.L., **"Engineering Fluid Mechanics"**, Eurasia Publishing House (p) Ltd., New Delhi, 3rd edn. 1984
3. Dr R K Bansal., "**A Text Book of Fluid Mechanics**" 1st edn., Laxmi Publications (P) Ltd., New Delhi. 2005.

REFERENCE BOOKS:

1. Coulson J.H. and Richardson J.F., **"Chemical Engineering"**, Vol-I, 5th edn., Asian Books (p) Ltd., New Delhi, 1998
2. Badger W.L. and Banchero J.T., **"Introduction to Chemical Engineering"**, Tata McGraw Hill, New York, 1997

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Properties of Fluids

▶ 1.1 INTRODUCTION

Fluid mechanics is that branch of science which deals with the behaviour of the fluids (liquids or gases) at rest as well as in motion. Thus this branch of science deals with the static, kinematics and dynamic aspects of fluids. The study of fluids at rest is called fluid statics. The study of fluids in motion, where pressure forces are not considered, is called fluid kinematics and if the pressure forces are also considered for the fluids in motion, that branch of science is called fluid dynamics.

▶ 1.2 PROPERTIES OF FLUIDS

1.2.1 Density or Mass Density. Density or mass density of a fluid is defined as the ratio of the mass of a fluid to its volume. Thus mass per unit volume of a fluid is called density. It is denoted the symbol ρ (rho). The unit of mass density in SI unit is kg per cubic metre, *i.e.*, kg/m^3. The density of liquids may be considered as constant while that of gases changes with the variation of pressure and temperature.

Mathematically, mass density is written as

$$\rho = \frac{\text{Mass of fluid}}{\text{Volume of fluid}}.$$

The value of density of water is 1 gm/cm^3 or 1000 kg/m^3.

1.2.2 Specific Weight or Weight Density. Specific weight or weight density of a fluid is the ratio between the weight of a fluid to its volume. Thus weight per unit volume of a fluid is called weight density and it is denoted by the symbol *w*.

Thus mathematically, $w = \dfrac{\text{Weight of fluid}}{\text{Volume of fluid}} = \dfrac{(\text{Mass of fluid}) \times \text{Acceleration due to gravity}}{\text{Volume of fluid}}$

$$= \frac{\text{Mass of fluid} \times g}{\text{Volume of fluid}}$$

$$= \rho \times g \qquad \left\{\because \frac{\text{Mass of fluid}}{\text{Volume of fluid}} = \rho\right\}$$

$$\therefore \qquad w = \rho g \qquad \ldots(1.1)$$

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The value of specific weight or weight density (w) for water is 9.81×1000 Newton/m^3 in SI units.

1.2.3 Specific Volume. Specific volume of a fluid is defined as the volume of a fluid occupied by a unit mass or volume per unit mass of a fluid is called specific volume. Mathematically, it is expressed as

$$\text{Specific volume} = \frac{\text{Volume of fluid}}{\text{Mass of fluid}} = \frac{1}{\dfrac{\text{Mass of fluid}}{\text{Volume}}} = \frac{1}{\rho}$$

Thus specific volume is the reciprocal of mass density. It is expressed as m^3/kg. It is commonly applied to gases.

1.2.4 Specific Gravity. Specific gravity is defined as the ratio of the weight density (or density) of a fluid to the weight density (or density) of a standard fluid. For liquids, the standard fluid is taken water and for gases, the standard fluid is taken air. Specific gravity is also called relative density. It is dimensionless quantity and is denoted by the symbol S.

Mathematically, $$S(\text{for liquids}) = \frac{\text{Weight density (density) of liquid}}{\text{Weight density (density) of water}}$$

$$S(\text{for gases}) = \frac{\text{Weight density (density) of gas}}{\text{Weight density (density) of air}}$$

Thus weight density of a liquid $= S \times$ Weight density of water

$$= S \times 1000 \times 9.81 \text{ N/m}^3$$

The density of a liquid $= S \times$ Density of water

$$= S \times 1000 \text{ kg/m}^3. \qquad \text{...(1.1}A\text{)}$$

If the specific gravity of a fluid is known, then the density of the fluid will be equal to specific gravity of fluid multiplied by the density of water. For example the specific gravity of mercury is 13.6, hence density of mercury $= 13.6 \times 1000 = 13600$ kg/m^3.

Problem 1.1 *Calculate the specific weight, density and specific gravity of one litre of a liquid which weighs 7 N.*

Solution. Given :

$$\text{Volume} = 1 \text{ litre} = \frac{1}{1000} \text{ m}^3 \quad \left(\because \ 1 \text{ litre} = \frac{1}{1000} \text{ m}^3 \text{ or } 1 \text{ litre} = 1000 \text{ cm}^3\right)$$

Weight = 7 N

(*i*) Specific weight (w) $$= \frac{\text{Weight}}{\text{Volume}} = \frac{7 \text{ N}}{\left(\dfrac{1}{1000}\right) \text{m}^3} = \mathbf{7000 \ N/m^3. \ Ans.}$$

(*ii*) Density (ρ) $$= \frac{w}{g} = \frac{7000}{9.81} \text{ kg/m}^3 = \mathbf{713.5 \ kg/m^3. \ Ans.}$$

(*iii*) Specific gravity $$= \frac{\text{Density of liquid}}{\text{Density of water}} = \frac{713.5}{1000} \quad \{\because \ \text{Density of water} = 1000 \text{ kg/m}^3\}$$

$= \mathbf{0.7135. \ Ans.}$

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Problem 1.2 *Calculate the density, specific weight and weight of one litre of petrol of specific gravity = 0.7*

Solution. Given : Volume = 1 litre = $1 \times 1000\ cm^3 = \frac{1000}{10^6}\ m^3 = 0.001\ m^3$

Sp. gravity $S = 0.7$

(*i*) *Density* (ρ)

Using equation (1.1 *A*),

Density (ρ) $= S \times 1000\ kg/m^3 = 0.7 \times 1000 =$ **700 kg/m³. Ans.**

(*ii*) *Specific weight* (w)

Using equation (1.1), $w = \rho \times g = 700 \times 9.81\ N/m^3 =$ **6867 N/m³. Ans.**

(*iii*) *Weight* (W)

We know that specific weight $= \frac{\text{Weight}}{\text{Volume}}$

or $w = \frac{W}{0.001}$ or $6867 = \frac{W}{0.001}$

$\therefore$ $W = 6867 \times 0.001 =$ **6.867 N. Ans.**

Problem 1.2A. *10 m³ of mercury weighs 136 × 10⁴ N. Calculate its specific weight mass density, specific volume and specific gravity.* (VTU Aug., 2002)

Solution. Given :

Volume = 10 m³ ; Weight = 136×10^4 N

(*i*) Specific weight (w) $= \frac{\text{Weight}}{\text{Volume}} = \frac{136 \times 10^4}{10} =$ **136000 N/m³. Ans.**

(*ii*) Mass density (ρ) $= \frac{w}{g} = \frac{136000}{9.81} =$ **13863.4 kg/m³. Ans.**

(*iii*) Specific volume $= \frac{1}{\rho} = \frac{1}{13863.4} =$ **72.13 × 10⁻⁶ m³/kg. Ans.**

(*iv*) Specific gravity $= \frac{\text{Density of mercury}}{\text{Density of water}} = \frac{13863.4}{1000} =$ **13.86. Ans.**

▶ 1.3 VISCOSITY

Viscosity is defined as the property of a fluid which offers resistance to the movement of one layer of fluid over another adjacent layer of the fluid. When two layers of a fluid, a distance '*dy*' apart, move one over the other at different velocities, say *u* and *u* + *du* as shown in Fig. 1.1, the viscosity together with relative velocity causes a shear stress acting between the fluid layers.

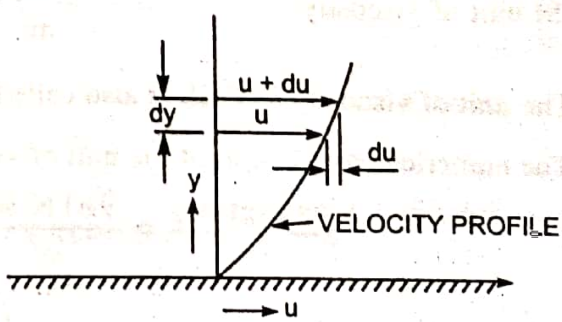

Fig. 1.1 *Velocity variation near a solid boundary.*

The top layer causes a shear stress on the adjacent lower layer while the lower layer causes a shear stress on the adjacent top layer. This shear

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