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ME 400 GRADUATION PROJECT

MEASUREMENT OF FLUID PROPERTIES

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ACKNOWLEDGEMENT

Actually it sound like the easiest part of the project at first. But as I make a review of the last 5 years in my mind, with its all particular moments happy and sad, I do not know where to begin indeed. I suppose it should be the best to start submitting my sincere gratitude to numerous loyal friends.

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ABSTRACT

The aim of this projects is examine the measurement of fluid properties. Properties of fluid are density, viscosity, pressure, velocity, discharge, venturi tube, flow nozzle, orifice meter. To measure these properties we will use some calculations, experimental operations and special devices.

In chapter one information Historical Background, SI units Properties Fluid and Development of Fluid Mechanics are explained briefly.These properties are; Compressible and Incompressible Fluids, Compressibility of Liquids, Viscosity, Surface Tension, Density and Ideal Fluid are examined.

In chapter two, Types of Flow Models are explained. In this chapter following subjects are contained; Laminar and Turbulent Flow, Steady Flow and Uniform Flow, One Dimensional, Two Dimensional and Three Dimensional Flow fields are examined.

In chapter three, fluid metrology is the science, associated with fluid-flow projects, which examines and measures flow properties such as density, viscosity, pressure, velocity, discharge. Some basic methodologies of flow measurements will be described in this chapter, including several techniques to measure the properties just listed.

In chapter four, this chapter is continue of third chapter and it is described the subjects below; venturi tube, flow nozzle, orifice meter and measurement of mass flow.

CHAPTER 1

1. 1 INTRODUCTION

In chapter one information Historical Background, SI units Properties Fluid and Development of Fluid Mechanics are explained briefly. These properties are; Compressible and Incompressible Fluids, Compressibility of Liquids, Viscosity, Surface Tension, Density and Ideal Fluid are examined.

Fluid mechanics is the branch of engineering that examines the nature and properties of fluids, both in motion and at rest. Fluid mechanics is concerned, for example, about the existence and distribution of static pressure in fluids at rest, or with the transportation of fluid mass and associated properties of momentum and energy for fluids in motion. Flow phenomena and fluid properties are affected by the action of applied forces due to physical, gravitational, thermal and other environmental conditions.

In practice, the treatment of fluid mechanics can be divided into two broad categories: internal flow systems and external flow systems. Internal flow systems are those where fluid flows through confined spaces, such as pipes and open channels. External flow systems are those where confining boundaries are at relatively larger or infinite distances, such as the atmosphere through which airplanes, missiles and space vehicles travel, or the ocean water through which submarines and torpedoes move.

The study of fluid mechanics is essential for the production and distribution of fluids necessary for the sustenance of our daily lives, as well as for design of equipment that controls fluid flow for reasons of the general public' s health and safety. Table 1.1 lists some of the applications of fluid mechanics as practiced by other disciplines in science and engineering to solve actual problems. This list is by no means exhaustive, but is offered to suggest the many areas of inquiry, which are appropriately examined from the perspective of fluid mechanics.

Table 1.1 Applications Of Fluid Mechanics In Branches Of Science

Aeronautics / Astronautics

Aircraft and missile aerodynamics

Cooling system

Control hydraulics

Civil Engineering

Pipe and channel flow

Surface and ground water hydrology

Wind and water structure loads

Coastline flows

Water and waste-water treatment

Physics

Magnetohydodynamics: fusion devices

Superconductivity

Astrophysics

Solar wind

Comet tails

Mathematics

Solution and differential equation

Boundary conditions

Nonlinear differential equations

Computational fluid dynamics

Dynamics analogies

Mechanical / Nuclear Engineering

Pumps and compressor

Impulse and reaction turbines

Heat exchangers

Process control

Cooling system

Heating, ventilation and air-conditioning

Chemical / Petroleum Engineering

Material transport

Filtering

Heat transfer

Mixing

Multiphase flows

Biophysics

Cellular mass

Heat transfer

Locomotion

Blood flow

Geophysics

Meteorology

Oceanography

Space

1.2 HISTORICAL BACKGROUND

As the human race evolved, its survival depended on learning how to use the common fluids, water and air. Archaeological investigations in the Nile and Indus Valleys have discovered, for example, irrigation systems, which are clear manifestations of the commercial usage of water by ancient cultures. The Romans are known to have built aqueducts for water supply in the fourth century B.C. although their writings indicate that they did not fully comprehend the actual behavior of fluid flows. Historical records show how people learned to use the force of wind for transportation in sailboats; the flight of birds inspired humans to invent flying machines.

More specifically, many scholars and scientists have contributed to the understanding of fluids. Archimedes (287-217 B.C.) observed the flotation of his body while taking a bath and reasoned out the principle of buoyancy. Newton (1642-1727) developed the resistance law, known as Newton's law of viscosity, and discovered contraction of water jets. Bernoulli (1700-1782) developed the energy equation for in viscid fluids. Euler (1707-1783) formulated the fundamental differential equations for ideal fluid flows. Theoretical developments by such scientists as Bernoulli and Euler established a sound foundation for the science of hydrodynamics; however, they did not thoroughly grasp the effects of viscosity. As a result, it was impossible to apply the concepts of hydrodynamics to real flow problems. Consequently, the field of experimental hydraulics flourished along with hydrodynamics during the 18th century.

1.3 SI UNITS

The most commonly used base and supplementary SI units used in elementary fluid mechanics are given in Table 1.2. Some derived SI units having special names are listed in Table 1.3. Other derived SI units appear in the text at appropriate places. The liter L and the milliliter ml are related to the cubic meter m^3 and the cubic millimeter mm^3 respectively, as follows:

$$1\ L = 10^3\ ml = 10^{-3}\ m^3 = 10^6\ mm^3$$

$$1\ ml = 10^{-3}\ L = 10^{-6}\ m^3 = 10^3\ mm^3$$

Some base level units are either too small or too large for normal working situations. Under these circumstances, either a higher or a lower unit than the base unit is needed.

Table 1.4 presents some normal working SI units, as well as some other, less-used SI units. For ease of identification, working units have been typeset in bold.

Table 1.2 SI UNITS

Quantity	*Unit*	*Symbol*
Length	metre	m
Mass	kilogram	kg
Time	second	s
Thermodynamic temperature	kelvin	K
Temperature interval in degrees celsius	degrees celsius	°C
Plane angle	radian	rad

Table 1.3 DERIVED SI UNITS

Quantity	*Unit Name*	*Symbol*	*Expression in terms of other units*
Force	newton	N	$kg\ m\ s^{-2}$
Pressure, stress, modulus	pascal	Pa	$N\ m^{-2}$
Energy, energy transfer	joule	J	N m
Power	watt	W	$J\ s^{-1}$
Frequency	hertz	Hz	s^{-1}

Table 1.4 WORKING—AND OTHER—SI UNITS

Metre	*Kilogram*	*Second*	*Newton*	*Joule*	*Watt*
km	**kg**	ks	**kN**	**kJ**	**kW**
m	g	s	N	J	W
mm	mg	ms	mN	mJ	mW

Radian	*Velocity*	*Pressure*	*Dynamic Viscosity*	*Kinematic Viscosity*
krad	km s^{-1}	**kPa**	kPa s	$km^2\ s^{-1}$
rad	**m s^{-1}**	Pa	Pa s	$m^2\ s^{-1}$
mrad	mm s^{-1}	mPa	**mPa s**	**$mm^2\ s^{-1}$**

1.5 PROPERTIES OF FLUID

Fluid mechanics is the science of the mechanics of liquids and gases and is based on the same fundamental principles that are employed in the mechanics of solids. Fluid mechanics is a more difficult subject, however, because with solids one deals with separate and tangible elements, while with fluids there are not separate elements to be distinguished.

1.5.1 DEVELOPMENT OF FLUID MECHANICS

Fluid mechanics may be divided into three branches: fluid static's is the study of the mechanics of fluids at rest; kinematics deals with velocities and streamlines without considering forces or energy; and hydrodynamics is concerned with the relations between velocities and accelerations and the forces exerted by or upon fluids in motion

Classical hydrodynamics is largely a subject in mathematics, since it deals with an imaginary ideal fluid that is completely frictionless. The results of such studies, without consideration of all the properties of real fluids, are of limited practical value. Consequently, in the past, engineers turned to experiments, and from these developed empirical formulas, which supplied answers to practical problems. This subject was called hydraulics.

Empirical hydraulics was confined largely to water and was limited in scope. With developments in aeronautics, chemical engineering, and the petroleum industry, the need arose for a broader treatment. This has led to the combining of classical hydrodynamics with the study of real fluids, and this new science is called fluid mechanic. In modern fluid mechanics the basic principles of hydrodynamics are combined with the experimental techniques of hydraulics. The experimental data can be used to verify theory or to provide information supplementary to mathematical analysis. The end product is a unified body of basic principles of fluid mechanics that can be applied to the solution of fluid-flow problems of engineering significance.

1.5.2 COMPRESSIBLE AND INCOMPRESSIBLE FLUIDS

Fluid mechanics deals with both incompressible and compressible fluids that is, with fluids of either constant or variable density. Although there is no such thing in reality as an incompressible fluid, this term is applied where the change in density with pressure is so small as to be negligible. This is usually the case with liquids. Gases, too, may be considered incompressible when the pressure variation is small compared with the absolute pressure.

Liquids are ordinarily considered incompressible fluids, yet sound waves, which are really pressure waves, travel through them. This is evidence of the elasticity of liquids. In problems involving water hammer, it is necessary to consider the compressibility of the liquid.

The flow of air in a ventilating system is a case where a gas may be treated as incompressible, for the pressure variation is so small that the change in density is of no importance. But for a gas or steam flowing at high velocity through a long pipeline, the drop in pressure may be so great that change in density cannot be ignored. For an airplane frying at speeds below 250 mph (100 m/s), the air may be considered to be of constant density. But as an object moving through the air approaches the velocity of sound, which is of the order of 700 mph (300 m/s) the pressure and density of the air adjacent to the body become materially different from those of the air at some distance away, and the air must then be treated as a compressible fluid.

1.5.3 COMPRESSIBILITY OF LIQUIDS

The compressibility of a liquid is inversely proportional to its volume modulus of elasticity, also known as the bulk modulus. This modulus. Is defined as

$E_v = -vdp/dv = -(v/dv)dp$, Where v is specific volume, and ρ is unit pressure. As v/dv is a dimensionless ratio, the units of Ev and p are the same. The bulk modulus is analogous to the modulus of elasticity for solids; however, for fluids it is defined on a volume basis rather than in terms of the familiar one-dimensional stress-strain relation for solid bodies.

Table 1.5 Bulk Modulus Of Water

Pressure, psia	Temperature, °F				
	32	68°	120°	200°	300°
15	292,000	320,000	332,000	308,000	
1,500	300,000	330,000	342,000	319,000	248,000
4,500	317,000	348,000	362,000	338,000	271,000
15,000	380,000	410,000	426,000	405,000	350,000

In most engineering problems the bulk modulus at or near atmospheric pressure is the one of interest. The bulk modulus is a property of the fluid and is a function of temperature and pressure. In Table 1.5 are shown a few values of the bulk modulus for water. At any temperature it can be noted that the value of $\gamma = \rho g$ increases continuously with pressure, but at any one pressure the value of Ev is a maximum at about 50°C. Thus water has a minimum compressibility at about 50°C.

The volume modulus of mild steel is about 170,000 MN/m^2. Taking a typical value for the volume modulus of cold water to be 2,200 MN/m^2, it is seen that water is about 80 times as compressible as steel. The compressibility of liquids covers a wide range. Mercury for example, is approximately 8 percent as compressible as water, while the compressibility of nitric acid is nearly six times greater than that of water.

Table 1.5 shows that at any one temperature the bulk modulus does not vary a great deal for a moderate range in pressure, and thus as an approximation one may use

$$\frac{v_1 - v_2}{v_1} = \frac{p_2 - p_1}{Ev} \qquad \frac{\Delta v}{v_1} = -\frac{\Delta p}{Ev}$$

Where Ev is the mean value of the modulus for the pressure range.

1.5.4 IDEAL FLUID

An ideal fluid may be defined, as one in which there is no friction. That is, its viscosity is zero. Thus the internal forces at any internal section are always normal to the section, even during motion. Hence the forces are purely pressure forces. Such a fluid does not exist in reality.

In a real fluid, either liquid or gas, tangential or shearing forces always come into being whenever motion takes place, thus giving rise to fluid friction, because these forces oppose the movement of one particle past another. These friction forces are due to a property of the fluid called viscosity.

1.5.5 VISCOSITY

The viscosity of a fluid is a measure of its resistance to shear or angular deformation. The friction forces in fluid flow result from the cohesion and momentum interchange between molecules in the fluid. As the temperature increases, the viscosities of all liquids decrease, while the viscosities of all gases increase. This is because the force of cohesion, which diminishes with temperature, predominates with liquids, while with gases the predominating factor is the interchange of molecules between the layers of different velocities. Thus a rapidly moving molecule shifting into a slower-moving layer tends to speed up the latter. And a slow-moving molecule entering a faster-moving layer tends to slow it down. This molecular interchange sets up a shear, or produces a friction. Force between adjacent layers. Increased molecular activity at higher temperatures causes the viscosity of gases to increase with temperature.

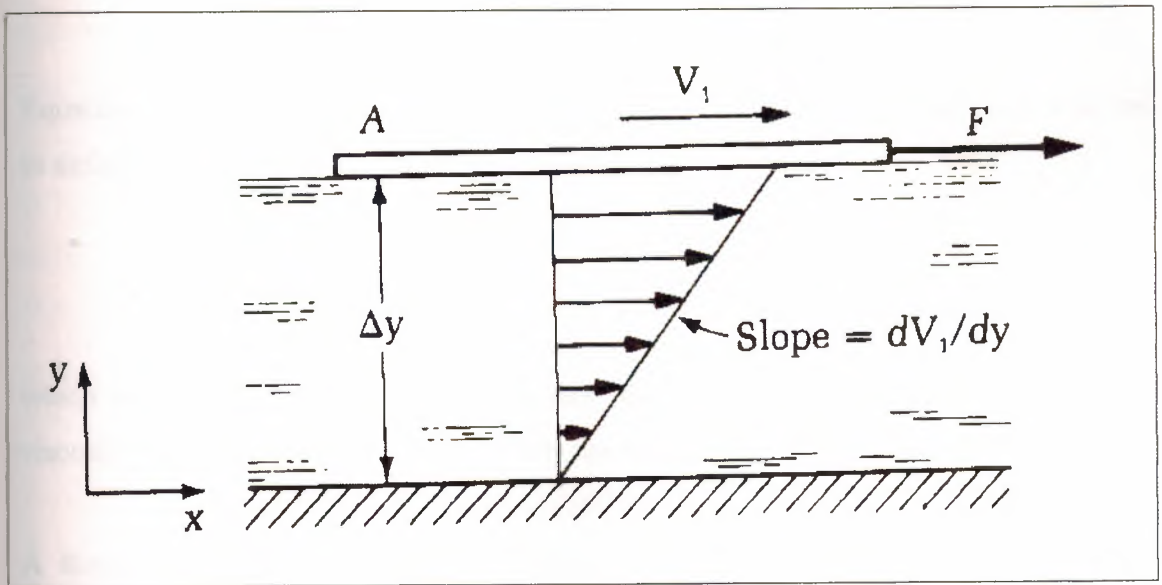

Figure 1.1 Shear Stress Applied To A Fluid

Consider two parallel plates (Fig. 1.1), sufficiently large so that edge conditions may be neglected, placed a small distance Y apart, the space between being filled with the fluid. The lower surface is assumed to be stationary, while the upper one is moved parallel to it with a velocity U by the application of a force F corresponding to some area A of the moving plate. Such a condition is approximated, for instance, in the clearance space of a flooded journal bearing (any radial load being neglected).

Particles of the fluid in contact with each plate will adhere to it, and if the distance Y is not too great or the velocity U too high, the velocity gradient will be a straight line. The action is much as if the fluid were made up of a series of thin sheets, each of which would slip a little relative to the next. Experiment has shown that for a large class of fluids

$$F \approx \frac{AU}{Y}$$

It may be seen from similar triangles in Fig. 1.4 that U/Y can be replaced by the velocity gradient du/dy if a constant of proportionality μ is now introduced, the shearing stress τ between any two thin sheets of fluid may be expressed by

$$\tau = \frac{F}{A} = \mu\frac{U}{Y} = \mu\frac{du}{dy}$$

Equation (1.8) is called Newton's equation of viscosity, and in transposed form it serves to define the proportionality constant

$$\mu = \frac{\tau}{du / dy}$$

which is called the coefficient of viscosity, the absolute viscosity, and the dynamic viscosity (since it involves force1 or simply the viscosity of the fluid.

A further distinction among various kinds of fluids and solids will be clarified by reference to Fig. 1.1. In the case of a solid, shear stress is proportional to the magnitude of the deformation; but

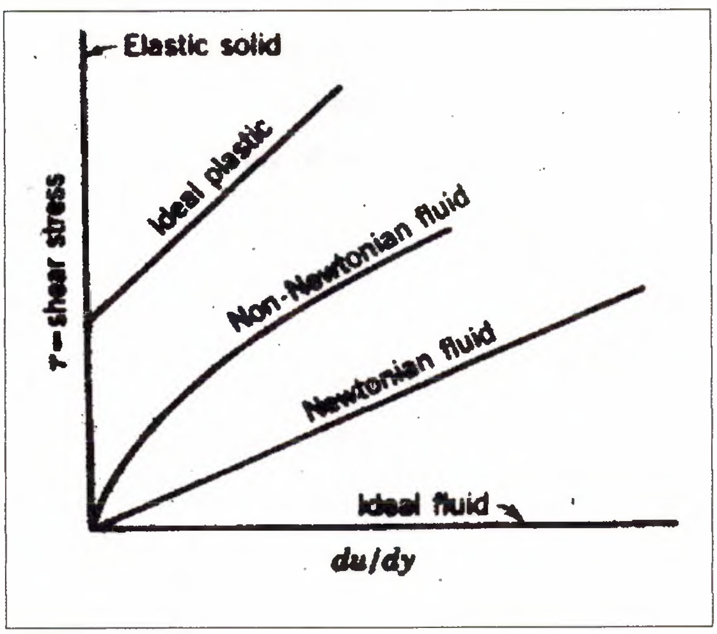

Figure 1.2 The Theological Diagram For Newtonian And Non-Newtonian Time Independent Fluid

A fluid for which the constant of proportionality (i.e., the viscosity) does not change with rate of deformation is said to be a Newtonian fluid and can be represented by a straight line in Fig. 1.2. The viscosity determines the slope of this line. The ideal fluid, with no viscosity, is represented by the horizontal axis, while the true elastic solid is represented by the vertical axis. A straight line intersecting the vertical axis at the yield stress can show a plastic, which sustains a certain amount of stress before suffering a plastic flow. There are certain non-Newtonian fluids in which μ varies with the rate of deformation. These are relatively uncommon; hence the remainder of this text will be restricted to the common fluids, which obey Newton's law.

In SI unit,

$$\text{Dimensions of } \mu = \frac{N/m^2}{s^{-1}} = \frac{N*s}{m^2}$$

A widely used unit for viscosity in the metric system is the poise (P), after Poiseuille, who was one of the first investigators of viscosity. The poise = 0.10 N s / m^2. The centipoises (cP) (= 0.01 P = m N s / m^2) are frequently a more convenient unit. It has a further advantage in that the viscosity of water at 68.4°F is 1 cP. Thus the value of the viscosity in centipoises is an indication of the viscosity of the fluid relative to that of water at 68.4°F.

In many problems involving viscosity there frequently appears the value of viscosity divided by density. This is defined as kinematics viscosity v, so called because force is not involved, the only dimensions being length and time, as in kinematics. Thus

$$v = \frac{\mu}{\rho}$$

In the English system, kinematics viscosity is usually measured in cm^2/s, also called the stoke (St) after G.G. Stokes. The centistokes (0.01 St) is of ten a more convenient unit.

The absolute viscosity of all fluids is practically independent of pressure for the range that is ordinarily encountered in engineering work.

1.5.6 SURFACE TENSION

Capillarity

Liquids have cohesion and adhesion, both of which are forms of molecular attraction. Cohesion enables a liquid to resist tensile stress; while adhesion enables it to adhere to another body. The attraction between molecules forms an imaginary film capable of resisting tension at the interface between two immiscible liquids or at the interface between a liquid and a gas. The liquid property that creates this capability is known as surface tension. The surface tension of liquids covers a wide range. Typical values of the surface tension of water are presented in Table 1.6. Capillarity is due to both cohesion and adhesion. When the former is of less effect than the latter, the liquid will wet a solid surface with which it is in contact and rise at the point of contact; if cohesion predominates, the liquid surface will be depressed at the point of contact.

Capillary rise (or depression) in a tube is depicted in Fig. 1.1. From free-body considerations, assuming the meniscus is spherical and equating the lifting force created by surface tension to the gravity force,

$$2\pi r\sigma\cos\theta = mg = \rho\pi r^2 hg$$

or

$$h = \frac{2\sigma\cos\theta}{\pi g r}$$

or

$$\sigma = \frac{\rho g r h}{2\cos\theta}$$

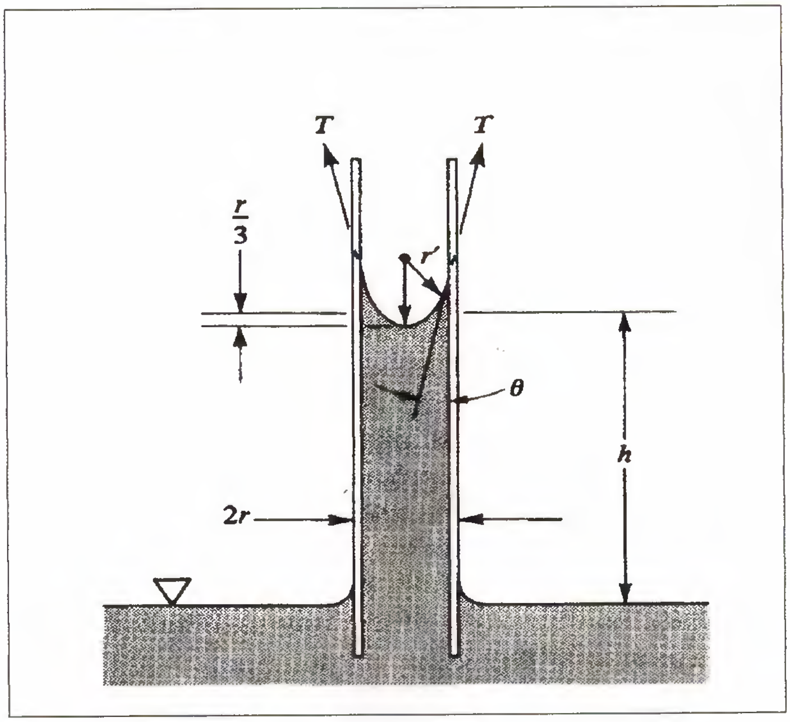

Figure 1.4 Capillary Rise Of A Wetting Liquid

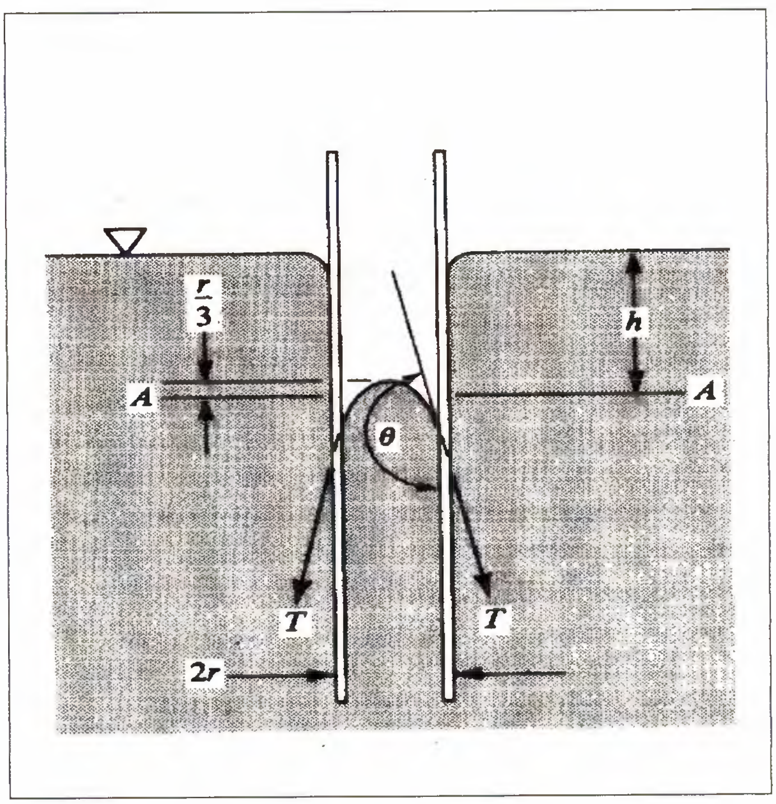

Figure 1.5 Capillary Depressions For A Nonwetting Liquid

Where σ = surface tension in units of force per unit length

γ = Specific weight of liquid

r = Radius of tube

h = Capillary rise

Table 1.6 Surface Tension Of Water

SI units		
	Surface tension, σ	
°C	mN/m = dyn/cm	N/m
0	75.6	0.0756
10	74.2	0.0742
20	72.8	0.0728
30	71.2	0.0712
40	69.6	0.0696
60	66.2	0.0662
80	62.6	0.0626
100	58.9	0.0589

This expression can be used to compute the approximate capillary rise or depression in a tube. If the tube is clean, $\theta = 0°$ (or water and about 140° for mercury. For tube diameters larger than $\frac{1}{2}$ in (12 mm), capillary effects are negligible. If mercury is in contact with water, the surface-tension effect is slightly less than when in contact with air.

Surface tension decreases slightly with increasing temperature. Surface-tension effects are generally negligible in most engineering situations; however, they may be important in problems involving capillary rise, the formation of drops and bubbles, the breakup of liquid jets, and in hydraulic model studies where the model is small.

1.5.7 DENSITY, SPECIFIC WEIGHT, SPECIFIC VOLUME, AND SPECIFIC GRA VITY

The density ρ of a fluid is its mass per unit volume, white the specific weight γ is its weight per unit volume. In the English engineers, or gravitational, system density ρ will be in kg/m^3 in SI units, which may also be expressed as units of (N)(s^2) /m^4 in SI units.

Specific weight γ represents the force exerted by gravity on a unit volume of fluid and therefore must have the units of force per unit volume, such as N/m^3 in SI units.

Density and specific weight of a fluid are related as follows:

$$\rho = \frac{\gamma}{g} \quad \text{Or} \quad \gamma = \rho g$$

Since the physical equations are dimensionally homogeneous, the dimensions of density are

In SI unit,

$$\text{Dimensions of } \rho = \frac{N/m^3}{m/s^2} = \frac{Nm^3}{m/s^2} = \frac{mass}{volume} = \frac{kg}{m^3}$$

It should be noted that density ρ is absolute since it depends or mass which is independent of location. Specific weight γ, on the other hand, is not absolute for it depends on the value of the gravitational acceleration g, which varies with location, primarily latitude and elevation above mean sea level.

Specific volume v is the volume occupied by a unit mass of fluid. It is commonly applied to gases and is usually expressed in m^3/kg in SI units. Specific volume is the reciprocal of density. Thus

$$v = \frac{1}{\rho}$$

Specific gravity s of a liquid is the ratio of its density to that of pure water at a standard temperature. Physicists use 4°C as the standard, but engineers often use 6O°F. In the metric system the density of water at 4°C is 1.00 g/cm^3, equivalent to 1000 kg/m^3, and hence the specific gravity (which is dimensionless) has the same numerical value for a liquid in that system as its density expressed in g/cm^3 or in Mg/m^3.

The specific gravity of a gas is the ratio of its density to that of either hydrogen or air at some specified temperature and pressure, but there is no general agreement on these standards, and so they must be stated in any given case.

Since the density of a fluid varies with temperature, specific gravities must be determined and specified at particular temperatures.

Example 1.1. The specific weight of water at ordinary pressure and temperature is 62.4 Ib/ft^3 (9.81 kN/m^3). The specific gravity of mercury is 13.55. Compute the density of water and the specific weight and density of mercury.

$$\rho_{water} = \frac{\gamma_{water}}{g} = \frac{9{,}81 kN/m^3}{9{,}81 m/s^2} = 1{,}00 Mg/m^3 = 1{,}00 g/cm^3$$

$$\gamma_{mercury} = s_{mercury}\gamma_{mercury} = 13{,}55(9{,}81) = 133 kN/m^3$$

$$\rho_{mercury} = s_{mercury}\gamma_{mercury} = 13{,}55(1{,}00) = 13{,}55 Mg/m^3$$

SUMMARY

In this chapter, we mentioned about historical backround which is including; histories and inventors of Newton, Bernoulli and reynolds Number. After these subjects, we explained SI units.

Properties of fluids are explaned briefly which is include the following subjects;

Development of fluid mechanics
Compressible and Incomperssible fluids
Compresibility of liquids
Ideal fluid
Viscosty
Surface tension
Densty, specific weight, specific volume and specific gravity.

CHAPTER 2

TYPES OF FLOW MODELS

2.1 INTRODUCTION

In chapter two, Types of Flow Models are explained. In this chapter following subjects are contained; Laminar and Turbulent Flow, Steady Flow and Uniform Flow, One Dimensional, Two Dimensional and Three Dimensional Flow fields are examined.

2.2 LAMINAR AND TURBULENT FLOW

In this chapter we deal only with velocities and accelerations and their distribution in space without consideration of any forces involved. That there are two distinctly different types of fluid flow was demonstrated by Osborne Reynolds in 1883. He injected a fine, threadlike stream of colored liquid having the same density as water at the entrance to a large glass tube through which water was flowing from a tank. A valve at the discharge end permitted him to vary the flow. When the velocity in the tube was small, this colored liquid was visible as a straight line throughout the length of the tube, thus showing that the particles of water moved in parallel straight lines. As the velocity of the water was gradually increased by opening the valve further, there was a point at which the flow changed. The line would first become wavy, and then at a short distance from the entrance it would break into numerous vortices beyond which the color would be uniformly diffused so that no streamlines could be distinguished. Later observations have shown that in this latter type of flow the velocities are continuously subject to irregular fluctuations.

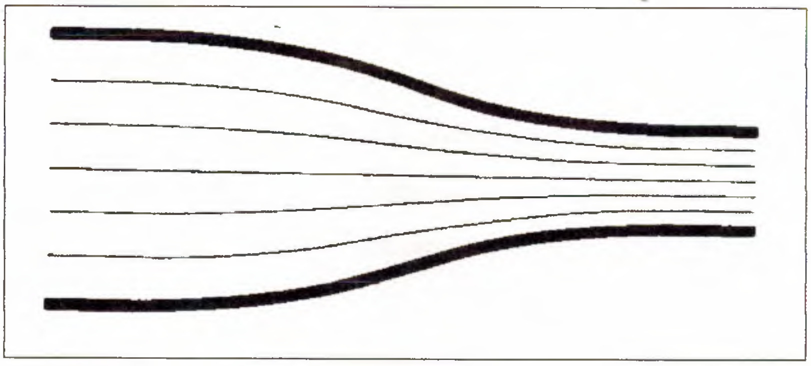

Figure 2.1 Laminar Flow

The first type is known as laminar, streamline, or viscous flow. The significance of these terms is that the fluid appears to move by the sliding of laminations of infinitesimal thickness relative to adjacent layers; that the particles move in definite and observable paths or streamlines, as in Fig. 2.1; and also that the flow is characteristic of a viscous fluid or is one in which viscosity plays a significant part.

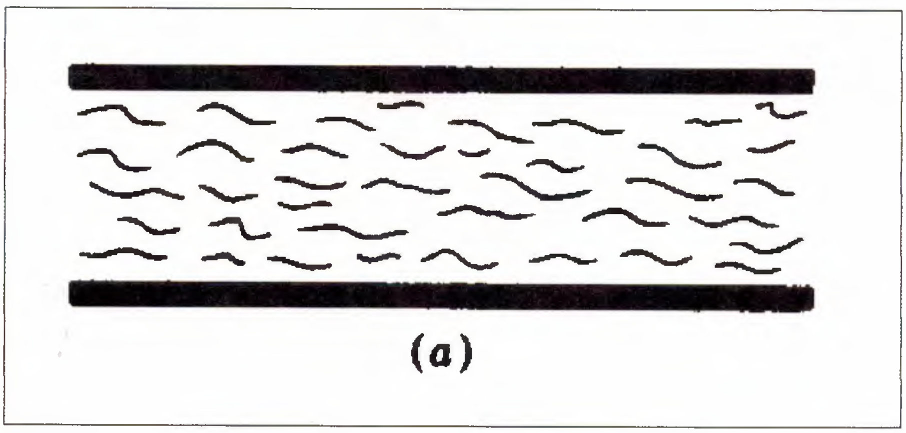

Figure 2.2 A) Turbulent Flow

The second type is known as turbulent flow and is illustrated in Fig. 2.2, where (a) represents the irregular motion of a large number of particles during a very brief time interval, while (b) shows the erratic path followed by a single particle during a longer time interval. A distinguishing characteristic of turbulence is its irregularity, they're being no definite frequency, as in wave action, and no observable pattern, as in the case of eddies.

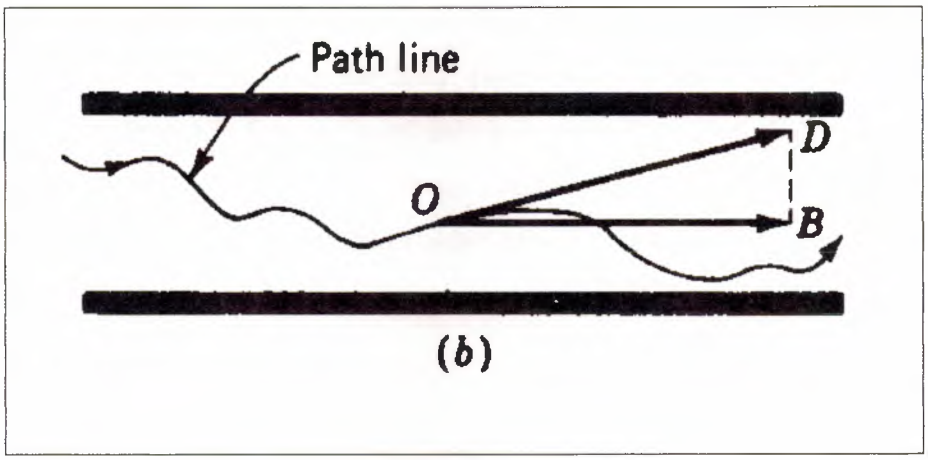

Figure 2.2 B) Turbulent Flow

Large eddies and swirls and irregular movements of large bodies of fluid, which can be traced to obvious sources of disturbance, do not constitute turbulence, but may be described as disturbed low. By contrast, turbulence may be found in what appears to be a very smoothly flowing stream and one in which there is no apparent source of disturbance. The fluctuations of velocity are comparatively small and can often be detected only by special instrumentation.

At a certain instant a particle at O in Fig. 2.2 b may be moving with the velocity AD, but in turbulent flow OD will vary continuously both in direction and in magnitude. Fluctuations of velocity are accompanied by fluctuations in pressure, which is the reason why manometers or pressure gages attached to a pipe in which fluid is flowing usually show pulsations. In this type of flow an individual particle will follow a very irregular and erratic path, and no two particles may have identical or even similar motions. Thus a rigid mathematical treatment of turbulent flow is impossible, and instead statistical means of evaluation must be employed.

2.3 STEADY FLOW AND UNIFORM FLOW

A steady flow is one in which all conditions at any point in a stream remain constant with respect to time, but the conditions may be different at different points. A truly uniform flow is one in which the velocity is the same in both magnitude and direction at a given instant at every point in the fluid. Both of these definitions must be modified somewhat, for true steady flow is found only in laminar flow. In turbulent flow there are continual fluctuations in velocity and pressure at every point, as has been explained. But if the values fluctuate equally on both sides of a constant average value, the flow is called steady flow. However, a more exact definition for this cage would be mean steady flow.

Likewise, this strict definition of uniform flow can have little meaning for the flow of a real fluid where the velocity varies across a section, as in Fig. 2.2 b. But

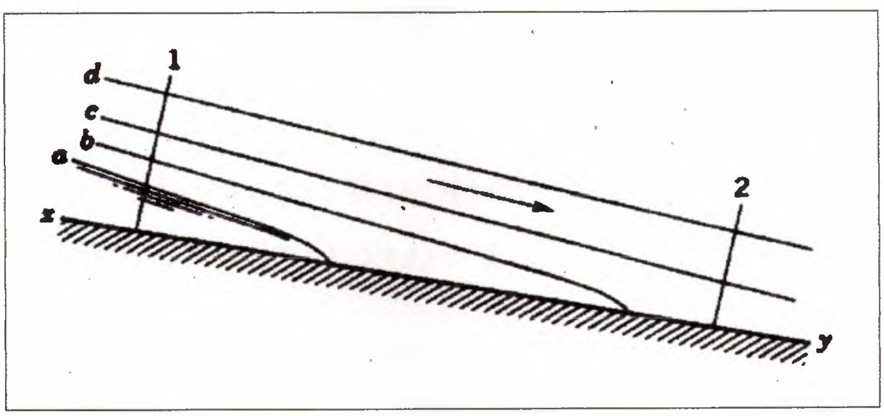

FIGURE 2.3 Steady Flow And Uniform Flow

when the size and shape of cross section are constant along the length of channel under consideration, the flow is said to be uniform. Steady (or unsteady) and uniform (or nonuniform) flow can exist independently of each other, so that any of four combinations is possible. Thus the flow of liquid at a constant rate in a long straight pipe of constant diameter is steady uniform flow, the flow of liquid at a constant rate through a conical pipe is steady nonuniform flow, while at a changing rate of flow these cases become unsteady uniform and unsteady nonuniform flow, respectively.

Unsteady flow may be a transient phenomenon, which in time becomes either steady flow or zero flow. An example may be seen in Fig. 2.3, where (a) denotes the surface of a stream that has just been admitted to the bed of a canal by the sudden opening of a gate. After a time the water surface will be at (b), later at (c), and finally reaches equilibrium at (d). The unsteady flow has then become me a steady flow. Another example of transient phenomenon is when a valve is closed at the discharge end of a pipeline, thus causing the velocity in the pipe to decrease to zero. In the meantime there will be fluctuations in both velocity and pressure within the pipe.

Unsteady flow may also include periodic motion such as that of waves on beaches, tidal motion in estuaries, and other oscillations. The difference between such cases and that of mean steady flow is that the deviations from the mean are very much greater and the time scale is also much longer.

2.4 ONE-DIMENSIONAL, TWO-DIMENSIONAL AND THREE-DIMENSIONAL FLOW FIELDS

A flow field is classified as one, two or three-dimensional depending on space coordinates required to specify the velocity field. Fluid flow is generally three-dimensional in character, which presents varying degrees of complexities and difficulties in nature during the analysis of different types of problems, The continuity, momentum and energy equations that describe flow phenomena in three dimensions are difficult to solve for lack of enough initial and boundary conditions, or because of analytical obstacles.

To circumvent these difficult situations and to be able to find satisfactory solutions for the flow problems, certain simplifying assumptions are introduced into the flow equations. These assumptions usually involve a reduction of the flow complexities and the number of coordinate dimensions, A three-dimensional flow problem can be reduced to either a two- or a one-dimensional problem if the flow system allows the properties of interest to exist in two directions or one, respectively. For example, flow between two nonparallel plates is treated as a two-dimensional case although the actual flow is three-dimensional. However, if there is no net flow in the third direction, and if the flow properties are assumed to remain constant in that direction, assumption of two-dimensionality is valid for all practical purposes.

Similarly, flow in pipes, rivers and artificial channels are assumed to be one-dimensional and the analysis of flow parameters is carried out accordingly. Given that the actual flow phenomena in all modes of transport are three-dimensional, however, the assumption of one-dimensional flow provides us only with information of gross quantities, such as total discharge and head lass in the main macroscopic flow direction; it does not give us detailed information about the flow properties on a microscopic basis. In the following chapters, it will be of increasing importance to recognize the fact that, whenever high accuracy is desirable for numerical solutions, the equations derived on the basis of one-dimensional flow analyses, i.e., based on the concept of finite control volumes, require further refinements for variations across the flow cross-sections. Circumstances sometimes dictate that a solution be immediately available for a critical flow problem, with the understanding that an approximate solution is better than none at all. Therefore, reduction of flow complexities and attainment of accurate solutions to a high degree of precision usually have relative importance and the proper method depends on the design problem at hand.

2.5 REYNOLDS NUMBER

The behavior of fluid, particularly with regard to energy losses, is quite dependent on whether the flow is laminar or turbulent. For this reason I want to have means of predicting the type of flow without actually observing it.

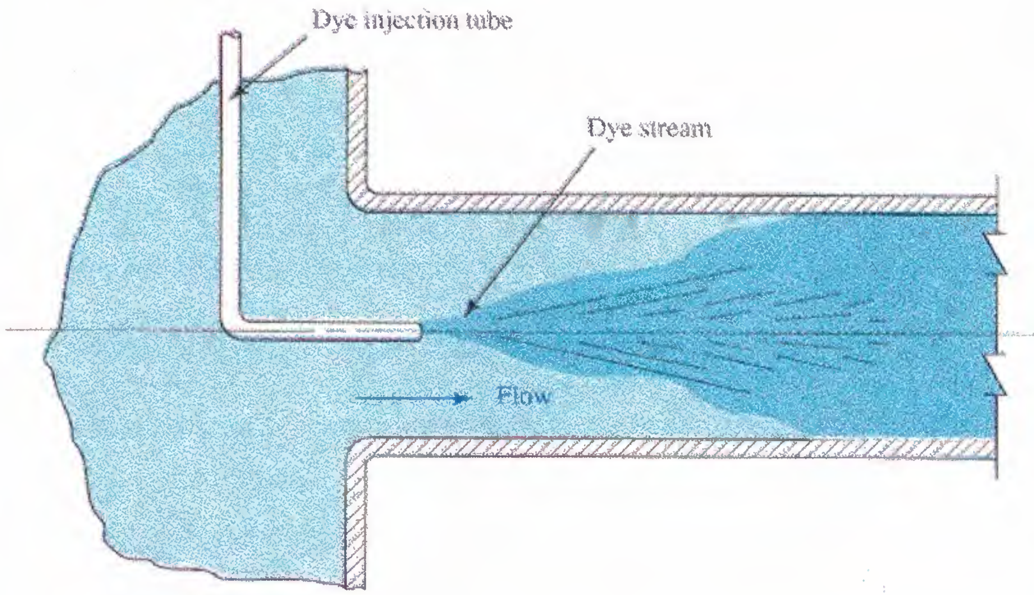

Figure 2.4 Dye Stream Mixing With Turbulent Flow

Direct observation is impossible for fluids in opaque pipes. It can be shown experimentally and verified analytically that the character of flow in a round pipe depends on four variables: fluid density ρ, fluid viscosity μ, pipe diameter D, and average velocity of flow υ. Osborne Reynolds was the first to demonstrate that laminar or turbulent flow can be predicted if the magnitude of a dimensionless number, now called Reynolds number (R_e), is known. Equation shows the basic definition of the Reynolds number.

$$\mathrm{Re} = \frac{\rho VD}{\mu} = \frac{VD}{\nu}$$

We can demonstrate that the Reynolds number is dimensionless by substituting standard SI units into equation

$$Re= (m/s). (m). (Kg/m^3). (M.s/kg)$$

Because all units can be cancelled, Re is dimensionless. However, it is essential that all terms in the equation be in consistent units in order to obtain the correct numerical value for Re. Reynolds number is one of several dimensionless numbers useful in the study of fluid mechanics and heat transfer. The process dimensional analysis can be used to determine dimensionless numbers. Reynolds number is the ratio of the inertia force on an element of fluid to the viscous force. The inertia force is developed from Newton's second law of motion, F= ma.

Flows having large Reynolds numbers, typically because of high velocity and/or low viscosity, tend to be turbulent. Those fluids having high viscosity and/or moving at low velocities will have low Reynolds numbers and will tend to be laminar. The following section gives some quantitative data with which to predict whether a given flow system will be laminar or turbulent. The formula for Reynolds number takes a different form for noncircular cross sections, open channels, and for the flow fluid around immersed bodies.

Critical Reynolds Numbers

For practical applications in pipe flow we find that if the Reynolds number for the flow is less than 2000, the flow will be laminar. Also, if the Reynolds number is greater than 4000, the flow can be assumed to be turbulent. In the range of Reynolds numbers between 2000 and 4000, it is impossible to predict which type of flow exists; therefore this range is called the critical region. Typical applications involve flows that are well within the laminar flow range or well within the turbulent flow range, so the existence of this region of uncertainty does not cause the flow to be definitely laminar or turbulent. More precise analysis is hen possible.

By carefully minimizing external disturbances, it is possible to maintain laminar flow for Reynolds numbers as high as 50 000. However, when Re is greater than about 4000 a minor disturbance of the flow stream will cause the flow to suddenly change from laminar to turbulent.

If Re < 2000, the flow is LAMİNAR.

If Re < 4000, the flow is TURBULENT.

SUMMARY

At the end of second chapter, we can summarize the subjects. Firstly of all, we mentioned about types of fluid flow, which is include the following;

Laminar and turbulent flow

Steady flow and Uniform flow

One dimensional, Two dimensional and Three dimensional flow fields are explained with figures.

Finally, we described Reynolds Number.

CHAPTER 3

MEASUREMENT OF FLUID PROPERTIES

3.1 INTRODUCTION

Fluid metrology is the science, associated with fluid-flow projects, which examines and measures flow properties such as density, viscosity, pressure, velocity, discharge. Some basic methodologies of flow measurements will be described in this chapter, including several techniques to measure the properties just listed.

Flow measurements are necessary for safe and accurate design of structures and industrial operations.

3.2 MEASUREMENT OF DENSITY

There are several available techniques to measure the density of liquids with varying degrees of accuracy. Although there are handbooks available with density figures, it is necessary at times to determine the density of a liquid by measurement, such as liquid solutions and suspensions. The most common and convenient technique used to obtain liquid density includes the use of the hydrometer, as shown in Fig. 3.1. It is an enclosed tube of known mass with a slender, graduated neck to indicate density of the liquid, relative to that of water at 4°C, based on the level of its immersion.

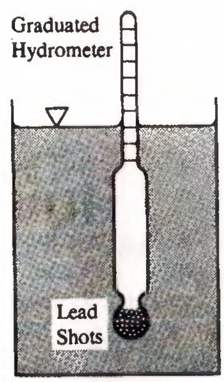

Figure 3.1 Measurement Of Liquid Density With The Help Of Graduated Hydrometer

3.3 MEASUREMENT OF VISCOSTY

The instruments or devices used to measure viscosity of liquids are known as viscosymeters or viscometers, for which Newton's law of viscosity is assumed to be applicable. The construction of a given viscometer should ensure the existence of laminar flow through the particular passage used in determining viscosity. There are three types of viscometers in common use: falling sphere, straight tube and rotational.

The device for the falling sphere viscometer consists of a tall transparent cylinder containing the given liquid of density ρ; a sphere, of known density ρ_S and diameter D, is dropped into it. According to Stokes' law, if the sphere is small enough compared to the cylinder Dc, the terminal, or fall, velocity U of the sphere is (approximately) inversely proportional to the viscosity μ of the liquid. The forces acting on the cylinder include friction drag, gravity and buoyancy forces. For Reynolds number Re: 5 0.1, friction drag for the sphere is given as

$$F_f = 3\pi\mu UD$$

The gravitational and buoyant forces acting on the cylinder are, respectively,

$$F_G = \frac{\rho_S g \pi D^3}{6} \quad \text{and} \quad F_B = \frac{\rho_S g \pi D^3}{6}$$

At terminal velocity, these three forces acting on the sphere are in equilibrium and, therefore, we write

$$F_f - F_G + F_B = 3\pi\mu UD - \frac{\rho_S g\pi D^3}{6} + \frac{\rho g\pi D^3}{6} = 0$$

The concept of a straight-tube viscometer is depicted through the Say bolt instrument, as shown in Fig. 3.2. In this case, the flow is unsteady and the liquid flows through a very small tube under a variable head, due to changing liquid level in the overhead reservoir. It is assumed that laminar flow exists throughout length L of the small tube, that the average head h_f is expended entirely through the small tube, and that the friction losses everywhere else are negligible.

Rotational viscometers are based on the concept that laminar flow can be maintained between two concentric cylinders when one of them is held stationary and the other one is allowed to rotate, as shown in Fig. 3.3. Uniform space b between their lateral surface, opening a between their lower ends, and the difference between their radii are all maintained at small magnitude.

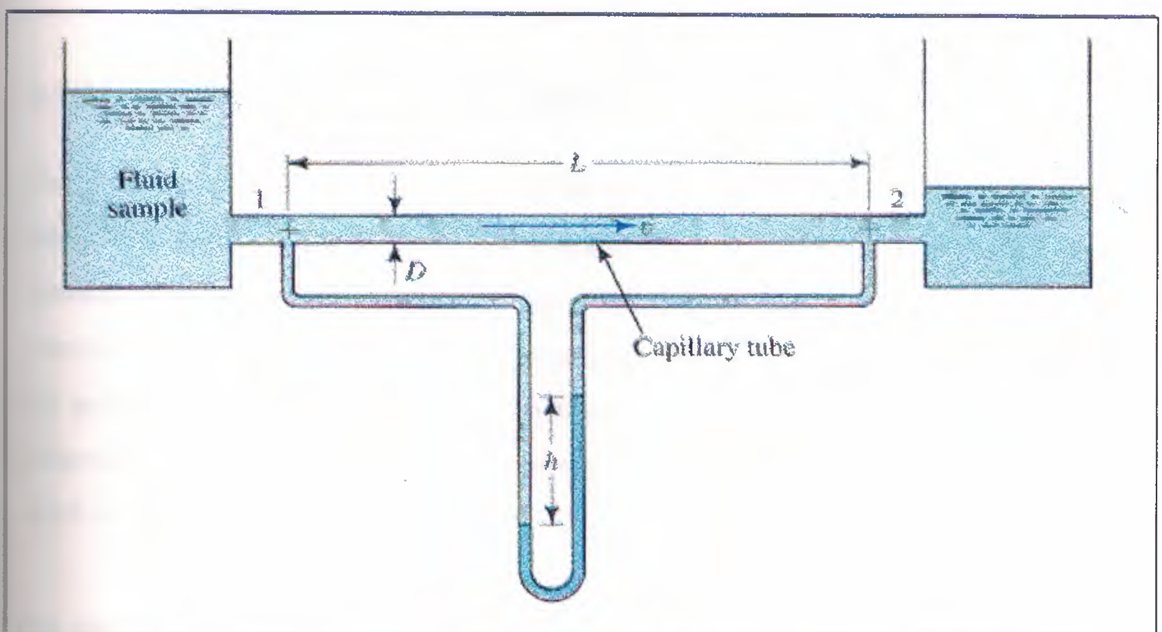

Figure 3.2 A Straight-Tube Viscometer

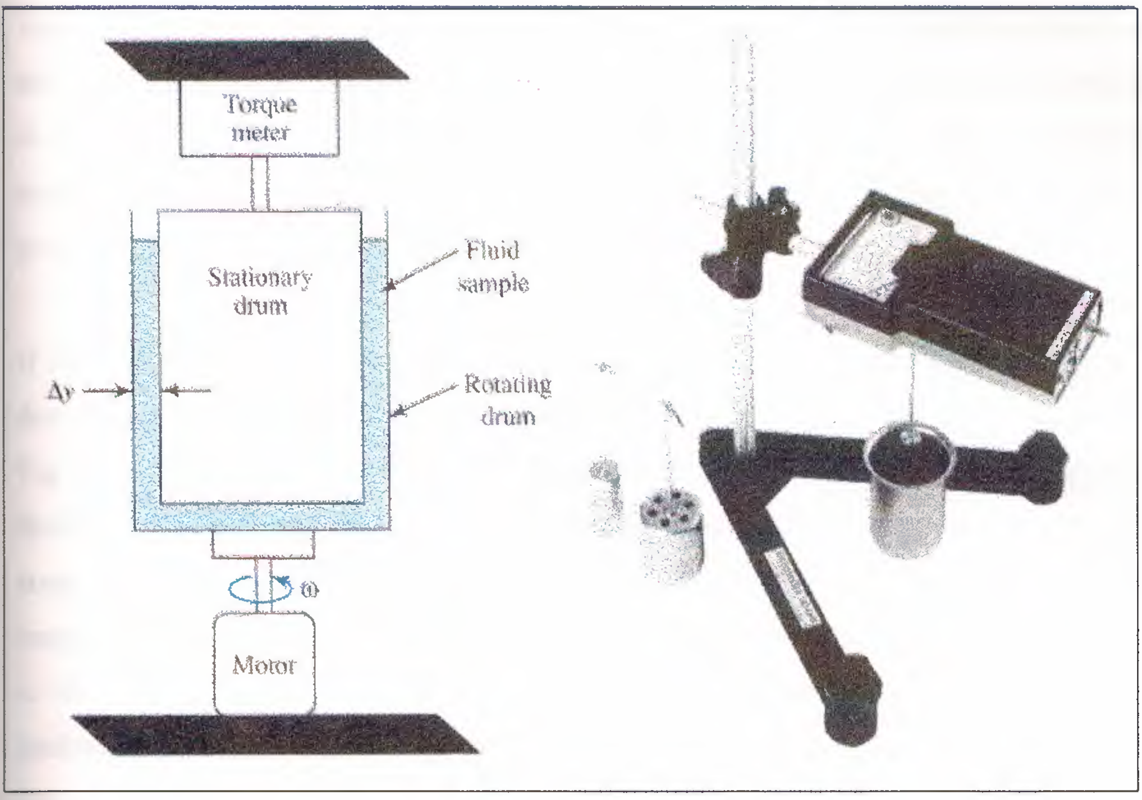

Figure 3.3 A Rotational-Type Viscometer

3.4 MEASUREMENT OF PRESSURE

The measurement of pressure in a fluid at rest is an easy task compared to pressure measurement of a flowing fluid. For a static fluid, the geometry of the piezometer opening dress not influences the accuracy of measurement. In a flowing fluid, however, orientation of the piezometer hale with respect to the direction of streamlines does affect the pressure readings. For a fluid in motion, the axis of the pressure hole should be perpendicular to the streamlines, because any deviation from the normal direction would result in erroneous pressure readings.

For example, for flow through smooth pipes, the piezometer opening should be normal to the direction of streamlines and flush with the inner surface in contact with the fluid, as shown in Fig. 3.4. The hole should be small in size, its length at least twice its diameter, quite smooth and free of burrs at edges, where some founding is permissible.

Any misalignment of the hole axis, with respect to the direction of the streamlines, or the existence of small roughness projections in the vicinity of the hole, can cause error in pressure measurement. Under these circumstances, it is advisable to use a piezometer ring, which has several openings around its circumference and is fitted in a pipeline, providing an integrated average pressure at the point under examination.

If the pipe or the conduit surface is very rough, such that pressure readings are in doubt due to flow disturbance at the piezometric opening, then a static tube, such as shown in Fig. 3.5, should be used. The end of the static-tube leg, parallel to the fluid stream and facing upstream, is completely closed. A short distance down stream from its end, the static-tube leg has radial holes, which convey fluid either to a manometer or a pressure transducer for pressure measurement purposes. It is assumed that the streamlines close to the radial holes are parallel to the axis of the static-tube leg and that the flow is undisturbed there, thus providing an accurate reading of the pressure; however, it must be remembered that the flow is disturbed

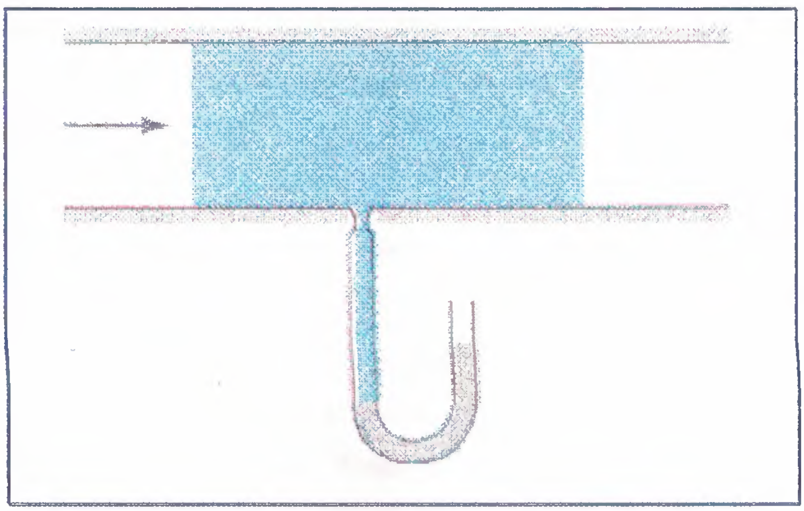

Figure 3.4 Piezometer Opening

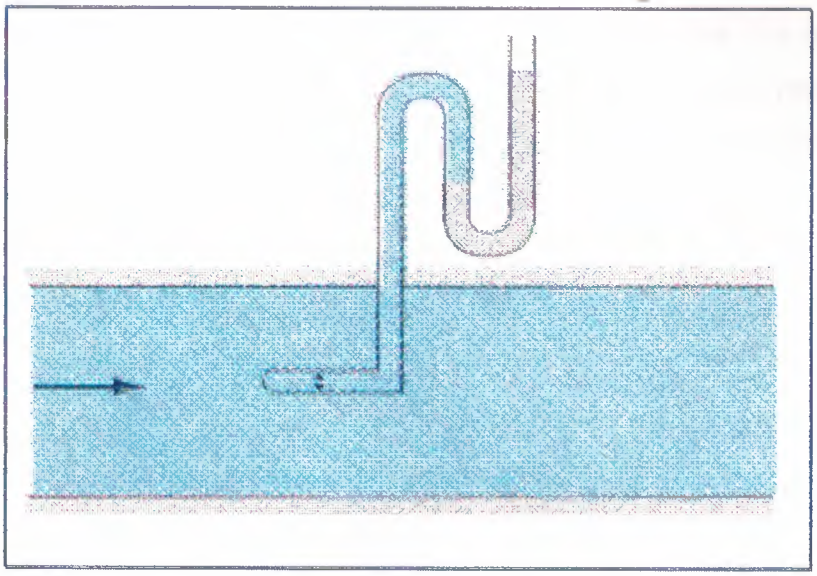

Figure 3.5 Static Tube

By both the tube end and the right-angled leg perpendicular to the direction of flow. These disturbances cause a larger velocity and a lower pressure at the static-tube holes. This error can be minimized by making the tube diameter as small as possible. A calibration of the static tube is recommended to further improve the level of confidence in its pressure measurement.

In case the flow direction in a two-dimensional flow field is uncertain, a cylinder (Fig. 3.6) with two holes connected to a differential manometer, is rotated around its axis until the differential manometer shows a zero reading. Then the flow direction is parallel to the bisector of the angle a formed by joining the center points of the two holes with the center of the cylinder. Point A is located on the bisector at the cylinder surface and represents the position of the stagnation pressure higher than the static pressure of the undisturbed flow upstream by an amount based upon the undisturbed velocity. As we travel at the cylinder surface from point A in either direction, we will reach a position on either side of point A where the pressure is equal to the static pressure of the undisturbed flow.

For an incompressible fluid it has been shown experimentally that if a is maintained equal to 78.5°, then the pressure at each hole is equal to the static pressure of the undisturbed flow, which can be measured by a separate manometer connected to either one of the holes. By rotating the cylinder and positioning one of the holes at point A, the stagnation pressure can be measured. The velocity of the undisturbed flow can then be computed by writing the Bernoulli equation between point A and the upstream position of the undisturbed flow.

From this discussion we conclude that the true static pressure at any location in a given flow field can only be measured if the flow surrounding the location of interest is never disturbed. Surely, such a stringent condition cannot be met in reality, due to the imperfections of the pressure measurement techniques. Certainly, reasonable precautions must be followed to achieve the desired accuracy of measurements. The basic concepts of simple manometers and other devices used to measure pressure of Fluids, both at rest and in motion, were described in Chapter Two. Further details about their operational characteristics will not be pursued here. However, brief accounts of the pressure transducer, inclined manometer, micro manometer and differential micro manometer are described over the next few pages for further understanding of pressure measurement.

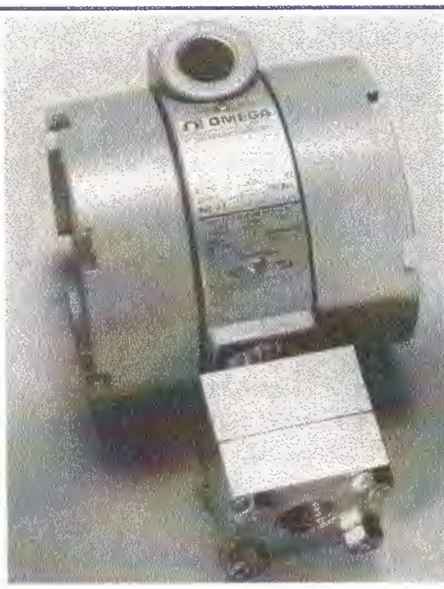

Figure 3.7a A View Of Piezoresistive Diaphragm Pressure Transducer

Figure 3.7b Side View Of A Piezoresistive Diaphragm Pressure Transducer With The End Cap Removed And Showing The Electrical Circuitry

Figure 3.7c An Excitation Source Unit

Figure 3.7d A Power Supply Regulator

Figure 3.7e An Analog Pressure Controller Along With Two Pressure Transducers Fitted With Lead Wires The Scale Indicates Pressure

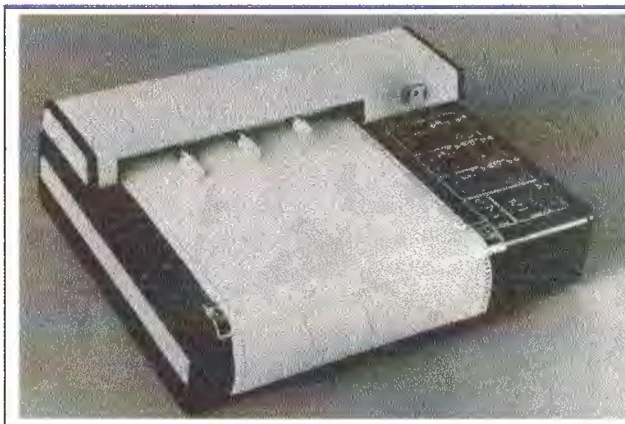

Figure 3.7f A Strip Chart Recorder

Figure 3.7g A Digital Readout Computer Interface

3.4.1 MEASUREMENT OF STATIC PRESSURE

To get an accurate measurement of static pressure in a flowing fluid, it is important that the measuring device fit the streamlines perfectly so as to create no disturbance to the flow. In a straight reach of conduit the static pressure is ordinarily measured by attaching to a pyrometer a pressure gage or a U-tube manometer. The piezometer opening in the side of the conduit should be normal to and flush with the surface. Any projection, such as (c) in Fig.3.8, will result in error. Allen and Hopper, 2 for example, found that a projection of 0.10 in (2.5 mm) will cause a 16 percent change in the local velocity head. In this case the recorded pressure is depressed below the pressure in the undisturbed fluid because the

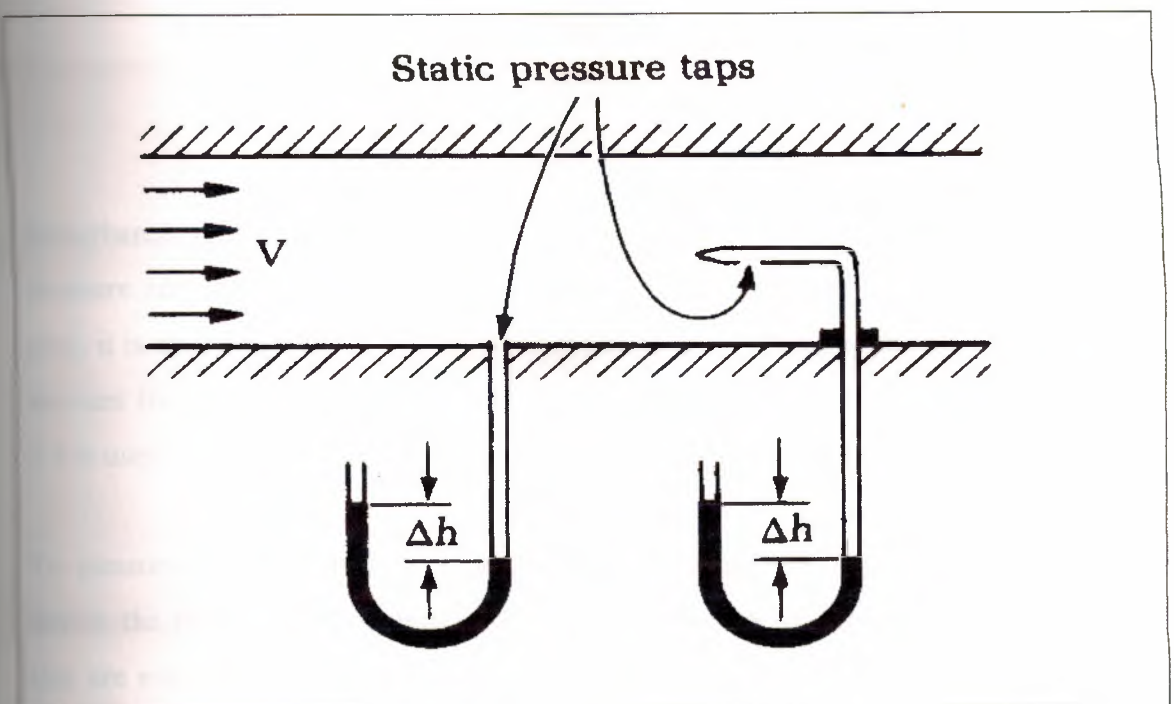

Figure 3.8 Methods For Measuring Static Pressure Of Flow

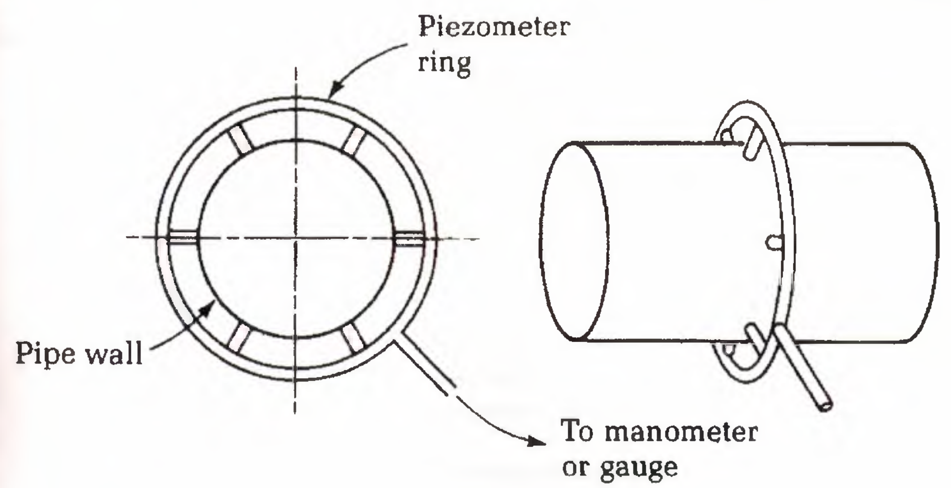

Figure 3.9 Piezometer Ring Connected To Static Pressure Taps

Disturbance of the streamline pattern increases the velocity, hence decreasing the pressure according to the Bernoulli equation. When measuring the static pressure in a pipe, it is desirable to have two or more openings around the periphery of the section to account for possible imperfections of the wall. For this purpose a piezometer ring Fig. 3.9 is used.

To measure the static pressure in a flow field, the static tube Fig. 3.10 is used. In this device the pressure is transmitted to a gage or manometer through piezometric holes that are evenly spaced around the circumference of the tube. This device will give good results if it is perfectly aligned with the flow. Actually, the mean velocity past the piezometer holes will be slightly larger than that of the undisturbed flow field; hence the pressure at the holes will generally be somewhat below the pressure of the undisturbed fluid. This error can be minimized by making the diameter of the tube as small as possible. If the direction of the flow is unknown for two-dimensional flows, a direction finding tube Fig. 3.11 may be used. This device is a cylindrical tube having two piezometer holes located as shown. Each piezometer is connected to its own measuring device. The tube may be rotated until each tube shows the same reading. Then, from symmetry, one can determine the direction of flow. It has been found that if the piezometer openings are located as shown, the recorded pressures will correspond very closely to those of the undisturbed flow.

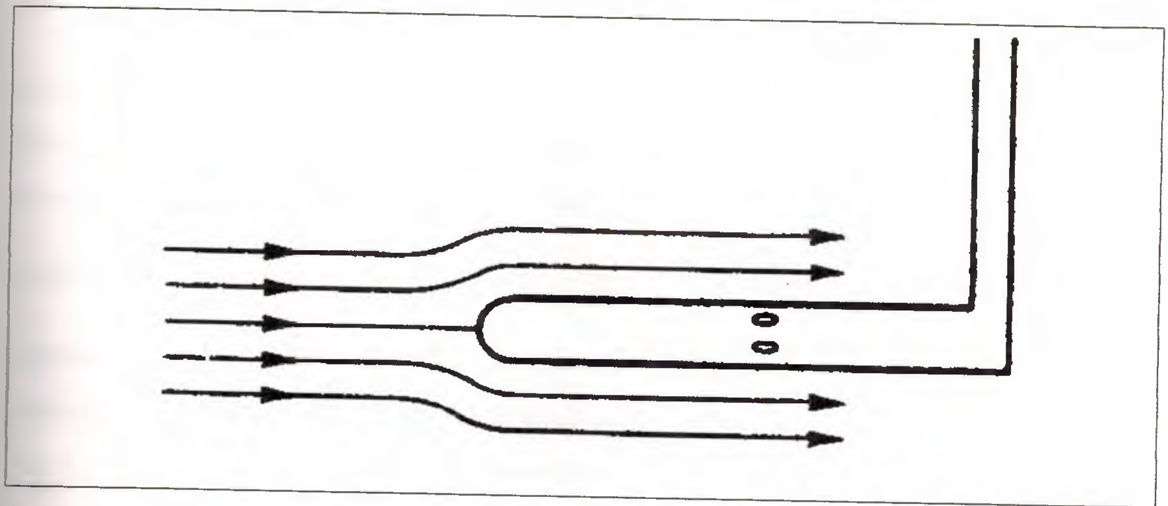

Figure 3.10 Measurement Of Stagnation Pressure With A Pitot Tube

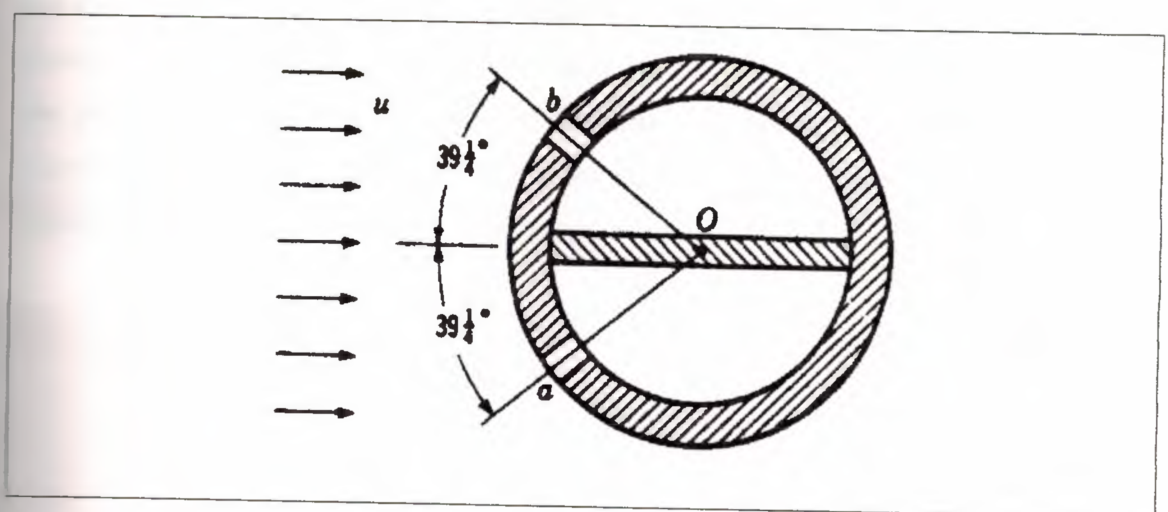

FIGURE 3.11 DIRECTION-FINDING TUBE

3.5 MEASUREMENT OF VELOCITY

3.5.1 MEASUREMENT OF VELOCITY WITH PITOT TUBES

One means of measuring the local velocity u in a flowing fluid is the pitot tube, named after Henri Pitot, whose used a bent glass tube in 1730 to measure velocities in the River Seine. It is shown that the pressure at the forward stagnation point of a stationary body in a flowing fluid is $P_S = P_0 + \frac{1}{2}\rho u^2$, where Po and u are the pressure and velocity, respectively, in the undisturbed flow upstream from t e body. If Ps - Po can be measured, the velocity at a point is determined by t is relation. The stagnation pressure can be measured by a tube facing upstream, such as (b) in Fig. 3.8 For a liquid jet or open stream with parallel streamlines, only this single tube is necessary, since the height h to which the liquid rises in the tube above the surrounding free surface is equal to the velocity head in the stream approaching the tip of the tube.

For a closed conduit under pressure it is necessary to measure the static pressure also, as shown by tube (a) in Fig. 3.8, and to subtract this from the total pitot reading to secure the differential head h. The differential pressure may be measured with any suitable manometer arrangement. The formula for the pitot tube for incompressible flow may be derived by writing the energy equation between point's-m and n of Fig. 3.8,

$$\frac{P_0}{\gamma} + \frac{u^2}{2g} = \frac{P_S}{\gamma}$$

$$u^2 = 2g\left(\frac{P_S}{\gamma} - \frac{P_0}{\gamma}\right)$$

$$u = \sqrt{2g\left(\frac{P_S}{\gamma} - \frac{P_0}{\gamma}\right)}$$

This equation gives the ideal velocity of flow at the point in the stream where the Pitot tube is located. In actuality the right-hand side of this equation must be multiplied by a factor varying from 0.98 to 0.995 to give the true velocity. This is so because the directional velocity fluctuations of turbulence cause a pitot tube to read a value somewhat higher than the temporal mean axial component of velocity.

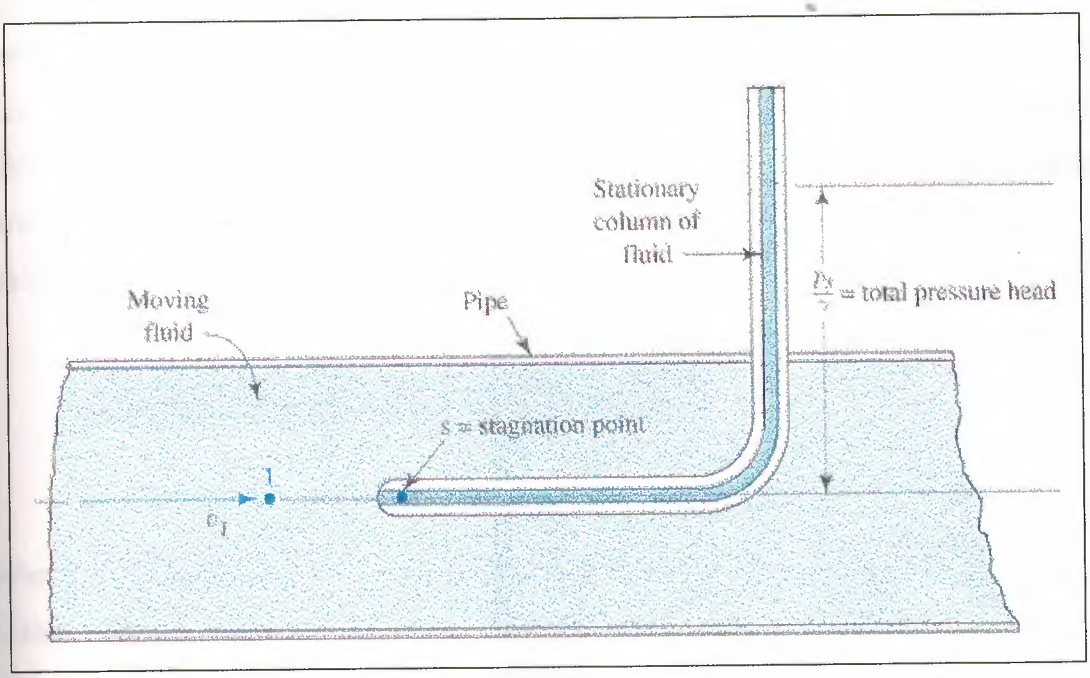

Figure 3.13 Pitot-Static Tube

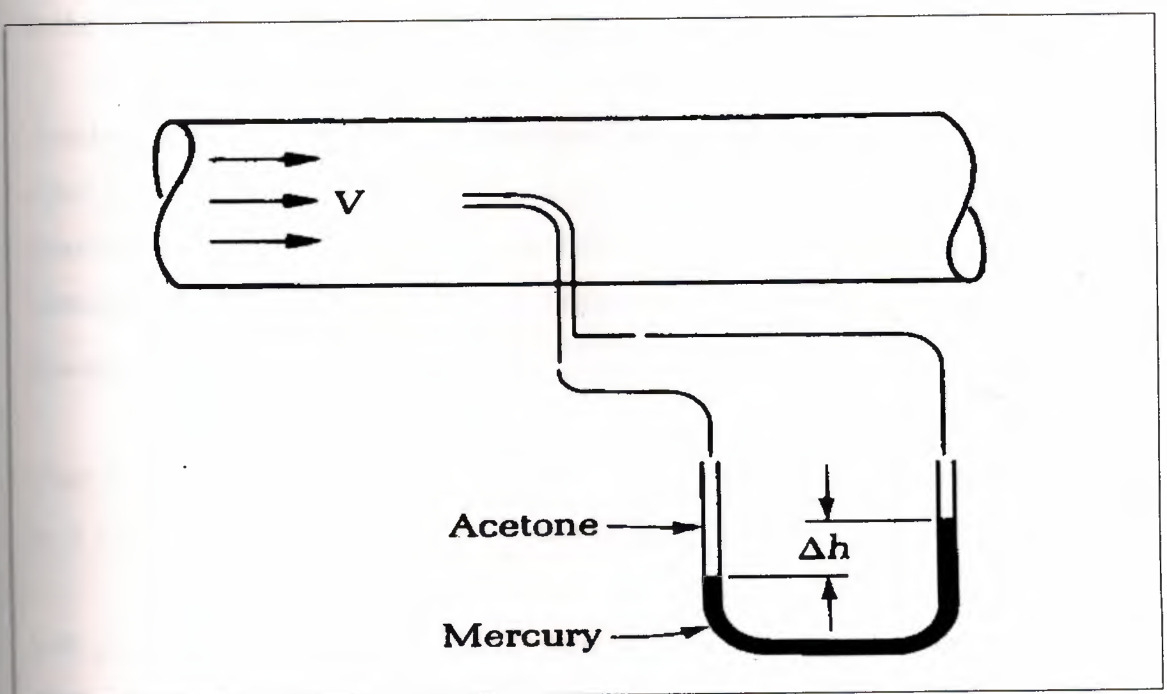

Figure 3.14 Measurement Of Velocity With A Pitot-Static Tube

Where conditions are such that it is impractical to measure static pressure at the wall, a combined pitot-static tube, as in Fig. 3.14, may be used. The static pressure is measured through two or more holes drilled through an outer tube into an annular space. Rarely are the piezometer holes located in precisely the correct position to indicate the true value of P_0/γ Hence Eq. is modified as follows:

$$u = C_1\sqrt{2g(\frac{P_S}{\gamma} - \frac{P_0}{\gamma})}$$

where C_1 a coefficient of instrument, is introduced to account for this discrepancy. Either English units or SI units may be used with this equation since C_1 is dimensionless. However, when a coefficient possesses dimensions, an equation developed for English units must be modified for application to SI units, and vice versa. A particular type of pitot-static tube with a blunt nose, the Prandtl tube, is designed so that $C_1 = 1$. For other pitot-static tubes, coefficient C_1 must be determined by calibration *in the laboratory.*

Another instrument, the pitometer, consists of two tubes, one pointing upstream and the other downstream; such as tubes (b) and (d) of Fig. 3.8 the reading for tube (d) will be considerably below the level of the static head. The equation applicable to a pitometer is identical to Eq. except that P_0/γ is replaced by the pressure head sensed by the downstream tube.

Most of these devices will give reasonably accurate results even if the tube is as much as ± 15° out of alignment with the direction of flow.

Still greater insensitivity to angularity may be obtained by guiding the flow past the pitot tube by means of a shroud, as shown in Fig. 4.2. Such an arrangement, called a Kiel probe, is used extensively in aeronautics. The stagnation-pressure measurement with this device is accurate to within 1 percent of the dynamic pressure for yaw angles up to ±54°. A disadvantage is that the static pressure must be measured independently.

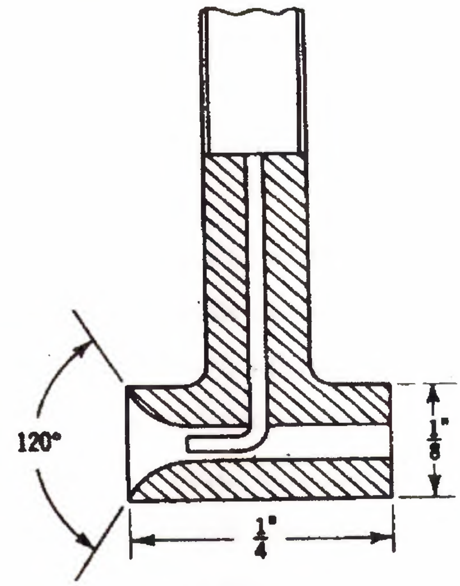

Figure 3.15 Kiel Probe

The direction-finding tube Fig. 3.10 may be used to determine velocity. The procedure is to orient it properly so that both piezometers give the same reading. This reading is the static head. Then turn the tube through $39\frac{1}{4}$ to obtain the stagnation pressure head. The difference in the two readings is the velocity head. This device has been used extensively in wind tunnels and in the investigation of hydraulic machinery.

3.5.2 MEASUREMENT OF VELOCITY BY OTHER METHODS

Other methods for measuring local velocity will be discussed in this section.

3.5.2.1 Current Meter and Rotating Anemometer

These two instruments, which are the same in principle, determine the velocity as a function of the speed at which a series of cups or vanes rotate about an axis either parallel or normal to the flow. The instrument used in water is called a current meter, and when designed for use in air, it is called an anemometer. As the force exerted depends upon the density of the fluid as well as upon its velocity, the anemometer must be so made as to operate with less friction than the current meter.

If the meter is made with cups, which move in a circular path about an axis perpendicular to the flow, it always rotate in the same direction and at the same rate regardless of the direction of the velocity, whether positive or negative, and it L even rotates when the velocity is at right angles to its plane of rotation. Thus this type is not suitable where there are eddies or other irregularities in the flow. If the meter is constructed of vanes rotating about an axis parallel to the flow, resembling a propeller, it will register the component of velocity along its axis, especially if a shielding cylinder surrounds it. It will rotate in an opposite direction for negative flow and is thus a more dependable type of meter.

3.5.2.2 Hot- Wire Anemometer

The hot-wire anemometer measures the instantaneous velocity at a point. It consists of a small sensing element that is placed in the flow field at the point where the velocity is to be measured. The sensing element is a short thin wire, which is generally of platinum or tungsten, connected to a suitable electronic circuit. The operation depends on the fact that the electrical resistance of a wire is a function of its temperature; that the temperature, in turn, depends upon the heat transfer to the surrounding fluid; and that the rate of heat transfer increases with increasing velocity of flow past the wire.

In one type of hot-wire anemometer the wire is maintained at a constant temperature by a variable voltage which changes the current through the wire. Thus, when an increase in velocity tends to cool the wire, a balancing device creates an increase in voltage to increase the current through the wire. This tends to heat up the wire to counteract the cooling and thus maintain it at constant temperature. The voltage provides a measure of the velocity of the fluid. The hot-wire anemometer is a very sensitive instrument particularly adapted to the measurement of turbulent velocity fluctuations as in Fig. 3.6

A hot-film anemometer, though similar to the hot-wire, is more rugged in that its sensing element consists of a metal film laid over a glass rod and provided with a protective coating.

3.5.2.3 Float Measurements

A crude technique for estimating the average velocity of flow in arriver or stream is to observe the velocity at which a float will travel down a stream. To get good results the reach of stream should be straight and uniform with a minimum of surface disturbances. The average velocity of flow V will generally be about (0.85: t 0.05) times the float velocity.

3.5.2.4 Photographic Methods

The camera is one of the most valuable tools in a fluid-mechanics research laboratory. In studying the motion of water, for example, a series of small spheres consisting of a mixture of benzene and carbon tetrachloride adjusted to the same specific gravity as the water can be introduced into the flow through suitable nozzles. When illuminated from the direction of the camera, these spheres will stand out in a picture. If successive exposures are taken on the same film, the velocities and the accelerations of the particles can be determined.

In the study of compressible fluids many techniques have been devised to measure optically the variations in density, as given by the interferometer, or the rate at which density changes in space, as determined in the shadowgraph and schlieren methods. From such measurements of density and density gradient it is possible to locate shock waves. Although of great importance, these photographic methods are too complex to warrant further description here.

3.6 MEASUREMENT OF DISCHARGE

There are various ways of measuring discharge in a pipe, for example, the velocity may be determined at various radii using a pitot-static tube or a pitot tube in combined with a wall piezometer. The cross section of a pipe may then be considered as series of concentric rings, each with a known velocity. The flow through these rings is summed up, as in Fig. 3.16, to determine the total flow rate.

To determine the flow in arriver or stream, a similar technique is used. The stream is divided into a number of convenient sections, and the average velocity in each section measured. A pitot tube could be used for such measurements, but a current meter is more commonly used. It has been found that the average velocity occurs at about 0.6-x depth, so the velocity is generally measured at that level. Another widely used method is to take the average of the velocities at 0.2 x depth and 0.8-x depth. This procedure for determining stream discharge is shown in Fig 3.17. A crude estimate of the flow in arriver or stream can be made by multiplying (0.85 x float velocity) times the area of the average cross section in the reach of stream over which the float measurement was made.

Devices for the direct measurement of discharge can be divided into two categories, those which measure by weight or positive displacement a certain quantity of fluid and those which employ some aspect of fluid mechanics. An, example of the first type of device is the household water meter in which a notating disk oscillates in a chamber. On each oscillation a known quantity of water passes through the meter. The second type of flow-measuring device, dependent on basic principles of fluid mechanics in combination with empirical data, will be discussed in the following sections.

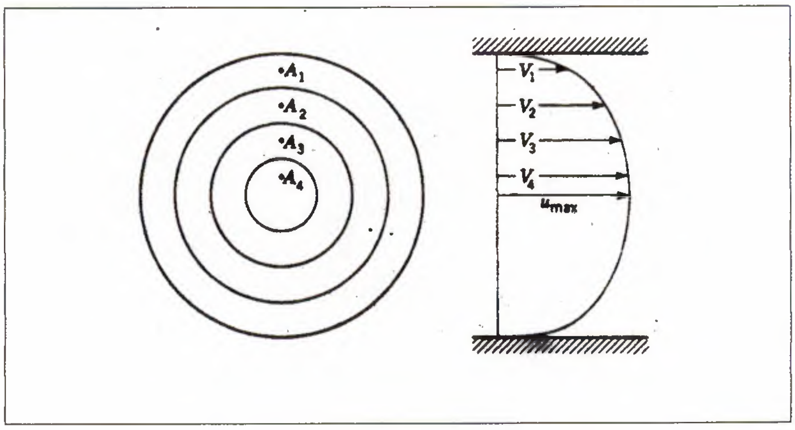

Figure 3.16 Determination Of Pipe Discharge

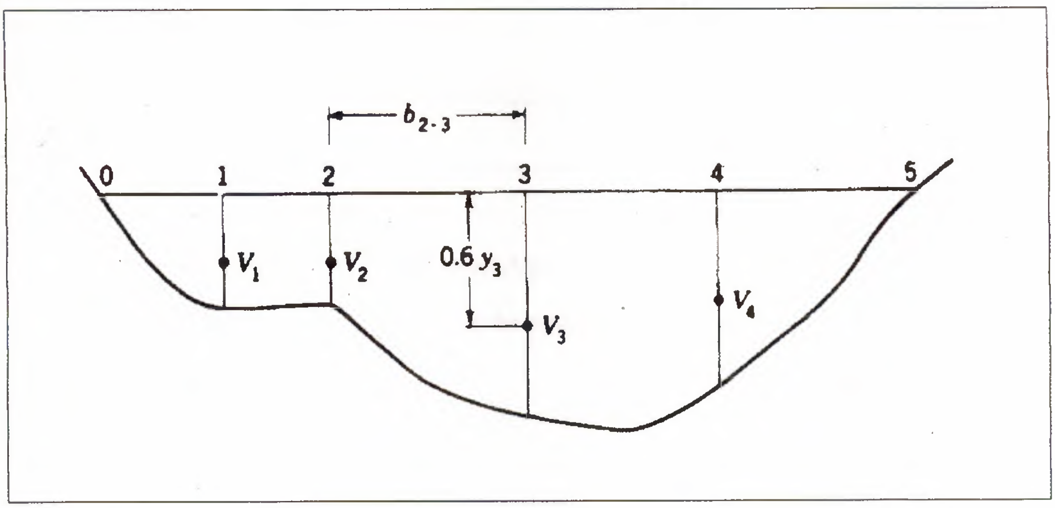

Figure 3.17 Determination Of Discharge In A Stream

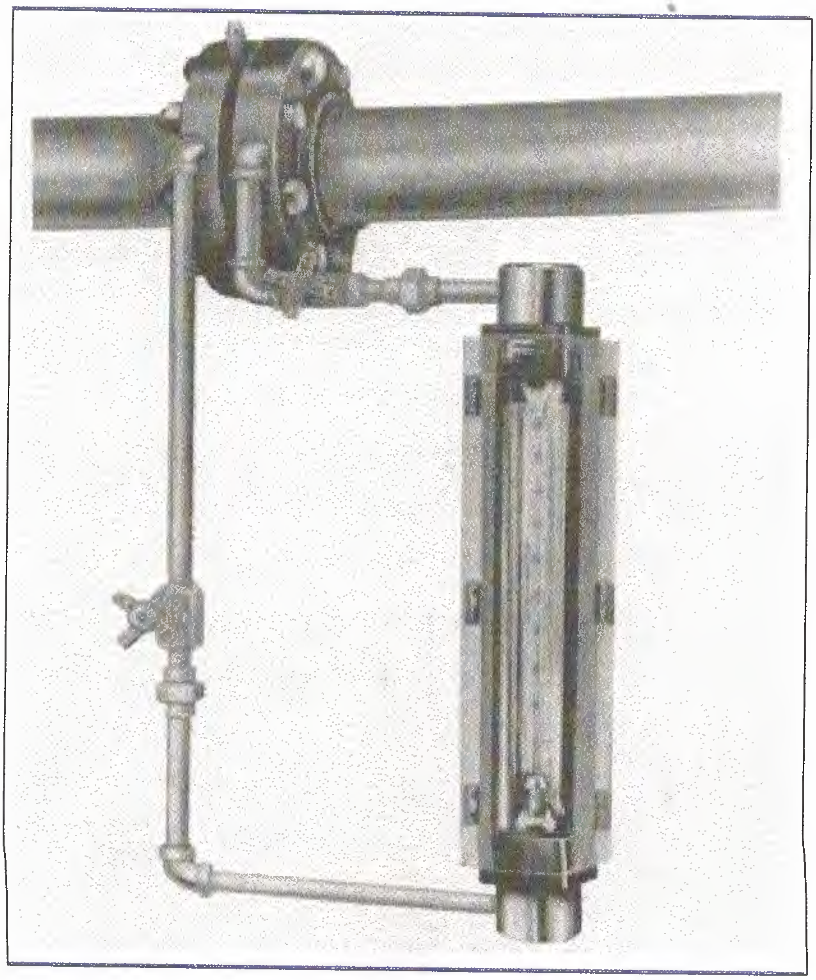

Figure 3.18 A Rotameter Assembly In Conjunction With
A Primary Orifice Plate To Measure Flow Rate In A Pipeline.

SUMMARY

At the end of third chapter, we summarize the subjects.

In this chapter, measurement types of properties of fluids are mentioned. These properties are Density, Viscosity, Pressure, Velocity and Discharge respectively. Pressure and Velocity are include following subjects;

Pressure –	Measurement of Static Pressure
Velocity –	Measurement of Velocity with Pitot Tube
	Measurement of Velocity by Other Mehods
	Current Meter and Rotating
	Hot-Wire
	Float Measurement
	Photograpic Methods

The subjects are researched and they explained by using formulas and figures.

CHAPTER 4

4.1 ORIFICES, NOZZLES, AND TUBES

Among the devices used for the measurement of discharge are orifices and nozzles. Tubes are rarely so used but are included here because their theory is the same and experiments upon tubes provide information as to entrance losses from reservoirs into pipelines. An orifice is an opening in the wall of a tank or in a plate normal to the axis of a pipe, the plate being either at the end of the pipe or in some intermediate location. An orifice is characterized by the fact that the thickness of the wall or plate is very small relative to the size of the opening. A standard orifice is one with a sharp edge as in Fig. 4.1a or an absolutely square shoulder as in Fig. 4.1b so that there is only line contact with the fluid. Those shown in Fig. 4.1c and d are not standard because the flow through them is affected by the thickness of the plate, the roughness of the surface, and for (d) the radius of curvature. Hence such orifices should be calibrated if high accuracy is desired.

A nozzle is a converging tube, as in Fig. 4.2, if it is used for liquids; but for a gas or a vapor a nozzle may first converge and then diverge again to produce supersonic flow. In addition to possible use as a flow measuring device a nozzle has other important uses, such as providing a high-velocity stream for fire fighting or for power in a steam turbine or a Pelton water wheel.

A tube is a short pipe whose length are not more than two or three diameters. There is no sharp distinction between a tube and the thick-walled orifices of Fig. 4.1c and d. A tube may be of uniform diameter, or it may diverge.

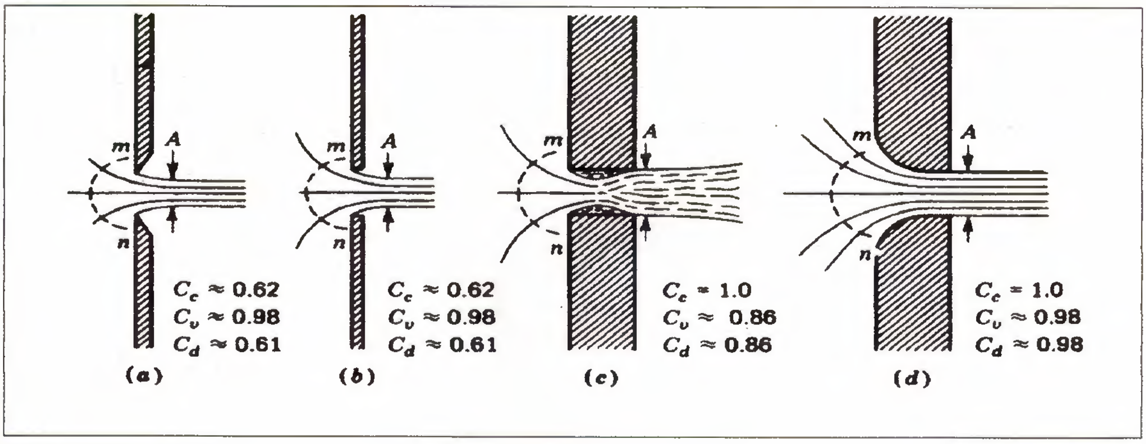

Figure 4.1 Types Of Orifice

A jet is a stream issuing from an orifice, nozzle, or tube. It is not enclosed by solid boundary walls but is surrounded by a fluid whose velocity is less than its own. The two fluids may be different or they may be of the same kind. A free jet is a stream of liquid surrounded by a gas and is therefore directly under the influence of gravity. A submerged jet is a stream of any fluid surrounded by a fluid of the same type, that is, a gas jet discharging into a gas or a liquid jet discharging into a liquid. A submerged jet is buoyed up by the surrounding fluid and is not directly under the action of gravity.

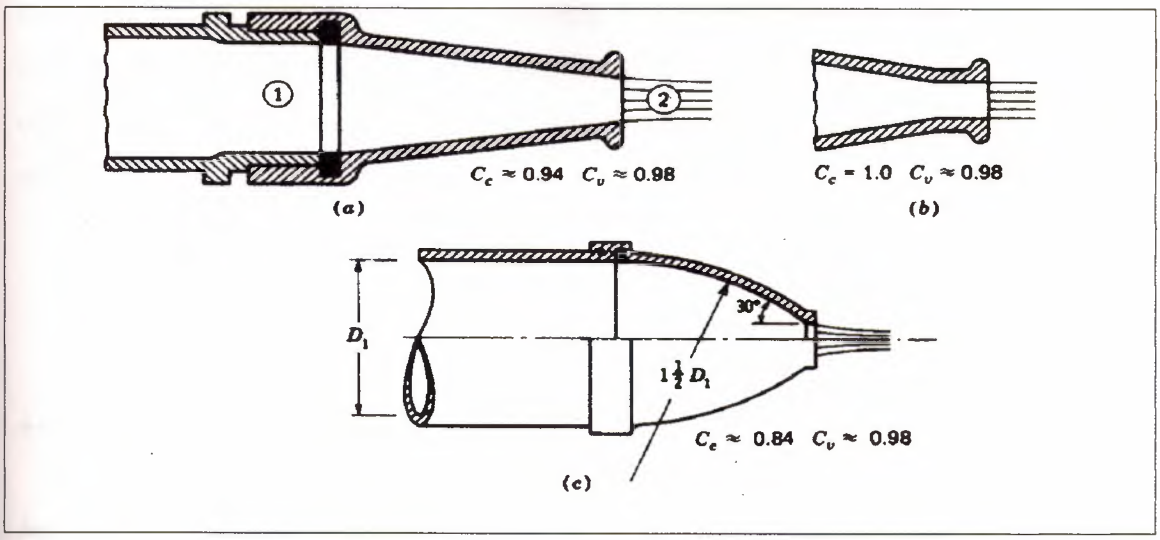

Figure 4.2 Nozzles (A) Conical Nozzle (B) Straight Nozzle

(C) Fire Nozzle

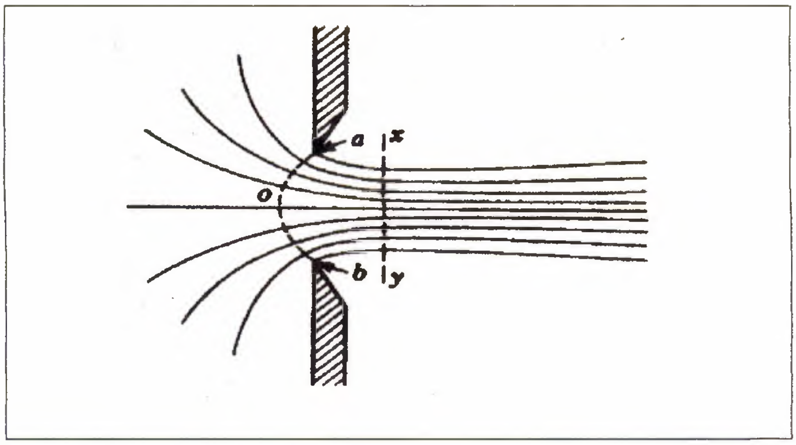

Figure 4.3 Jet Contractions

*****Jet Contraction**

Where the streamlines converge in approaching an orifice, as shown in Fig. 4.3, they continue to converge beyond the upstream section of the orifice until they reach the section by where they become parallel. Commonly this section is about O.5Do from the upstream edge of the opening, where Do is the diameter of the orifice. The section by is then a section of minimum area and is called the vena contract. Beyond the vena contract a streamlines commonly diverge because of frictional effects. In Fig. 4.1c the minimum section is referred to as a submerged vena contract an as it is surrounded by its own fluid. In Fig. 4.1 d there is no vena contract an as the rounded entry to the opening permits the streamlines to gradually converge to the cross-sectional area of the orifice.

*****Jet Velocity and Pressure**

Jet velocity is defined as the average velocity at the vena contract an in Fig. 4.1a and b and at the downstream edge of the orifices in Fig. 4.1c and d. The velocity at these sections is practically constant across the section except for a small annular region around the outside Fig. 4.4b. In all four of the jets of Fig. 4.1 the pressure is practically constant across the diameter of the jet wherever the streamlines are parallel, and this pressure must be equal to that in the medium surrounding the jet at that section. At sections mn in Fig. 4.1 where the streamlines are curved, the effective cross-sectional area of the flow (at right angles to the streamlines) is greater than at the minimum section and, hence, the average velocities at sections mn are considerably less than the jet velocities.

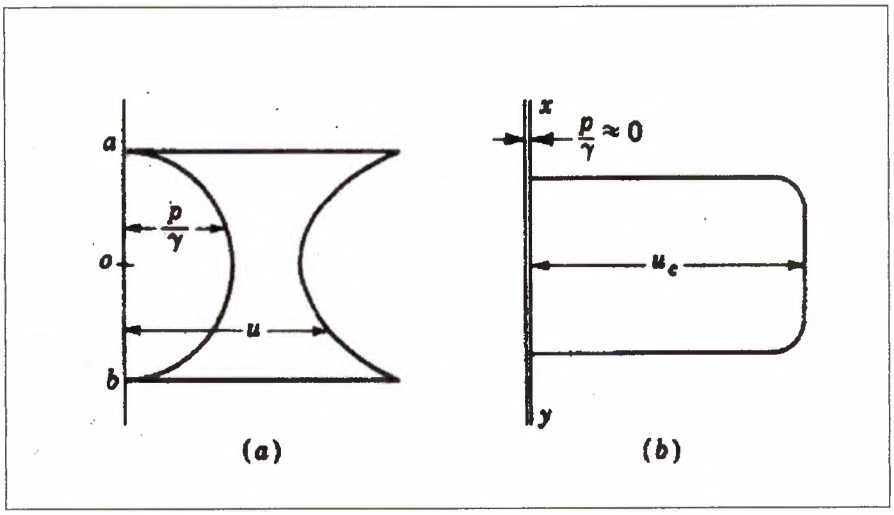

Figure 4.4 Pressures And Velocity Variation In Jet (A) At Section A0b Of Fig (B) At Vena Contract A (Section Xy) In Fig

In Fig. 4.4a the velocity and pressure distributions at section aob of Fig. 4.3 are shown. These variations are the result of the curvature of the streamlines and centrifugal effects.

Coefficient of Contraction Cc

The ratio of the area of a jet, A Fig. 4.2, to the area of the orifice or other opening, Ao, is called the coefficient of contraction. Thus A = Cc Ao

Coefficient of Velocity Cv

The velocity that would be attained in the jet if friction did not exist may be termed the ideal velocity V_I^1 it is practically the value of u_C in Fig. 4.4 Because of friction, the actual average velocity V is less than the ideal velocity, and the ratio V/V_i is called the coefficient of velocity. Thus $V = Cv\ V_i$

Coefficient of Discharge Cd

The ratio of the actual rate of discharge Q to the ideal rate of discharge Q_i (the flow that would occur if there were no friction and no contraction) is defined as the coefficient of discharge. Thus $Q = C_d\ Q_i$ By observing that $Q = A\ V$ and $Q_i = AoV_i$ it is seen

that $C_d = CcCv$

Determining the Coefficients

The coefficient of contraction can be determined by using outside calipers to. Measure the jet diameter at the vena contract a and then comparing the jet area with the orifice area. The contraction coefficient is very sensitive to small changes in the edge of the orifice or in the upstream face of the plate. Thus slightly rounding the edge of the orifice in Fig. 4.1 lb or roughening the orifice plate will increase the contraction coefficient materially.

The average velocity V of a free jet may be determined by a velocity traverse of the jet with a fine pitot tube or it may be obtained by measuring the flow rate and dividing by the cross-sectional area of the jet. The velocity may also be computed approximately from the coordinates of the trajectory of the jet, as discussed. The ideal velocity V_i is computed by the Bernoulli theorem. Thus Cv for an orifice, nozzle, or tube may be computed by dividing V by V_i

The coefficient of discharge is the one that can most readily be obtained and with a high degree of accuracy. It is also the one that is of the most practical value. For a liquid the actual Q can be determined by some standard method such as a volume or a weight measurement over a known time. For a gas one can note the change in pressure and temperature in a container of known volume from which the gas may flow. Obviously, if any two of the coefficients are measured, the third can be computed from them. Thus, in equation form

Ideal flow rate $Q_i = A_j V_j = A_0\sqrt{2g(\Delta H)}$

Actual flow rate γ

and $C_d = \dfrac{Q}{Q_i} = C_C C_V$

where ΔH is the total difference in energy head between the upstream section and the minimum section of the jet section A of Fig. 4.2. It should be recalled that the total energy head $H = z + p/\gamma + V^2/2g$. If the flow is from a tank, the velocity of approach is negligible and may be neglected. If the discharge is to the atmosphere (free jet), the downstream pressure head is zero, whereas if the jet is submerged, the downstream pressure head is equal to the depth of submergence (Fig. 4.12).

Typical values of the coefficients for orifices, nozzles, and tubes are as indicated in Figs. 4.1, 4.2, and 4.5 respectively. It is apparent from Fig. 4.5 that rounding the entrance to a tube increases the coefficient of velocity. Any device that provides a uniform diameter for a long enough distance before exit, such as the tubes of Fig. 4.5 or the nozzle tip of Fig. 4.2b, will usually create a Cc = 1.0. Although this increases the size of the jet from the given area, it also tends to produce more friction.

If the geometry of the orifice, nozzle or tube is standard such as those of Figs. 4.1,4.2, and 4.5, the coefficients should be very close to the values indicated on the figures. However, the best way to determine the coefficients of a device, particularly those of unusual shape, is by experiment in the laboratory. Also, one can make a fair estimate of the contraction by sketching the flow net. If one wishes

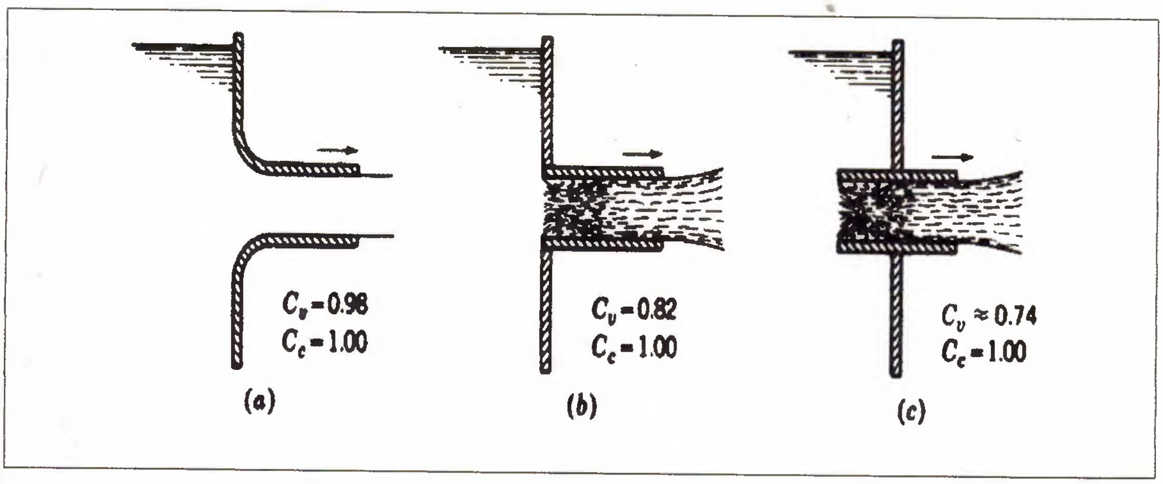

Figure 4.5 Coefficient For Tubes

to estimate. The coefficient of discharge of an orifice, nozzle, or tube it is usually best to estimate velocity and contraction coefficients separately and calculate the discharge coefficient from them.

***Borda Tube**

Tubes (b) and (c) in Fig. 4.5 are shown as flowing full, and because of the turbulence, the jets issuing from them will have a ' broomy' appearance. Because of the contraction of the jet at entrance to these tubes the local velocity in the central portion of the stream will be higher than that at exit from the tubes, and hence the pressure will be lower. If the pressure is lowered to that of the vapor pressure of the liquid, the streamlines will then no longer follow the walls. In such a cage tube (b) becomes equivalent to orifice (b) in Fig. 4.1, while tube (c) behaves as shown in Fig. 4.6. If its length is less than its diameter, the reentrant

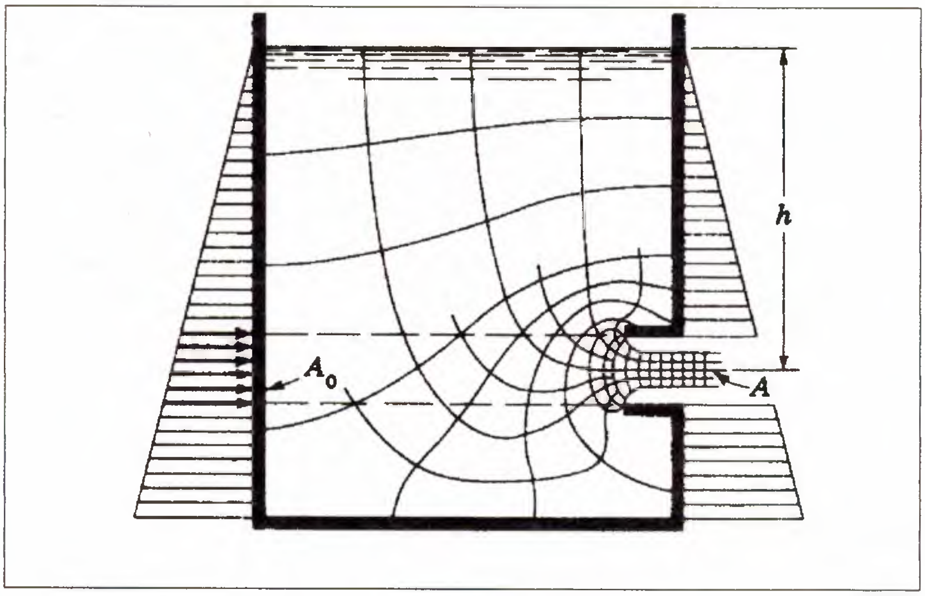

Figure 4.6 Borda Tube

tube is called a Borda mouthpiece. Because of the greater curvature of the streamlines for a reentrant tube, the contraction coefficient is lower than for any other type and the velocity coefficient is also lower Fig. 4.5c. But if the jet springs clear as in Fig. 4.6, the velocity coefficient is as high as for a sharp-edged orifice.

The Borda mouthpiece is of interest because it is one device for which the contraction coefficient can be very simply calculated. For all other orifices and tubes there is a reduction of the pressure on the walls adjacent to the opening, but the exact pressure values are unknown. But for the reentrant tube, the velocity along the wall of the tank is almost zero at all points, and hence the pressure is essentially hydrostatic. In the case of a Borda tube the only unbalanced pressure is that on an equal area Ao opposite to the tube Fig. 4.6, and its value is γ hAo. The time rate of change of momentum due to the flow out of the tube is $\rho Q V = \gamma A V^2 / g$ where A is the area of the jet. Equating force to time rate of change of momentum, $\gamma hAo = \gamma A V^2 / g$ and thus, $V^2 = ghAj A$. Ideally, $V^2 = 2gh$, and thus, ideally, Cc = Ai Ao = 0.5. The actual values of the coefficients for a Borda tube are Cc = 0.52, C. = 0.98, and Cd = 0.51.

***Head Loss**

The relationship between the head loss and the coefficient of velocity of an orifice, nozzle, or tube may be found by comparing the ideal energy equation with the actual (or real) energy equation between points 1 and 2 in Fig. 4.2a. The ideal energy equation is

$$Z_1 + \frac{P_1}{\gamma} + \frac{V_1^2}{2g} = Z_2 + \frac{P_2}{\gamma} + \frac{V_2^2}{2g}$$

In the case of a free jet, P2 = O while for the most general case of a submerged jet P_2= O. From continuity A_1 V_1 = A2 V^2, hence we can write

$$Z_1 + \frac{P_1}{\gamma} + \left(\frac{A_2}{A_1}\right)^2 \frac{V_1^2}{2g} = Z_2 + \frac{P_2}{\gamma} + \frac{V_2^2}{2g}$$

which leads to

$$(V_2)_{ideal} = \frac{1}{\sqrt{1-(A_2/A_1)^2}} \sqrt{2g\left[\left(Z_1 + \frac{P_1}{\gamma}\right) - \left(Z_2 + \frac{P_2}{\gamma}\right)\right]}$$

The real energy equation accounts for head loss and is expressed as

$$Z_1 + \frac{P_1}{\gamma} + \frac{V_1^2}{2g} - h_{L1-2} = Z_2 + \frac{P_2}{\gamma} + \frac{V_2^2}{2g}$$

Which leads to

$$(V_2)_{actual} = \frac{1}{\sqrt{1-(A_2/A_1)^2}} \sqrt{2g\left[\left(Z_1 + \frac{P_1}{\gamma}\right) - \left(Z_2 + \frac{P_2}{\gamma}\right) - h_L\right]}$$

Remembering that V_{actual} = Cv V ideal, and combining this with the above expressions for V ideal and V_{actual} gives

$$h_{L1-2} = \left(\frac{1}{C_V} - 1\right)\left[1 - \left(\frac{A_2}{A_1}\right)^2\right]\frac{V_2^{\,2}}{2g}$$

This equation is perfectly general; it expresses the head loss between a section upstream of an orifice and the jet section A in Fig. 4.1 or between sections 1 and 2 in Fig. 4.2a, etc. If the orifice or nozzle takes off directly from a tank where V , then the velocity of approach is negligible and Eq. reduces

$$h_{L1-2} = \left(\frac{1}{C^2_V} - 1\right)\frac{V_2^{\,2}}{2g}$$

For the tubes of Fig. 4.10 with Cv = 0.98, 0.82, and 0.74,

h_L = 0.04 $V_2^{\,2}/2g$, 0.5 $V_2^{\,2}/2g$, and 0.8 γ , respectively.

4.3.1 VENTURI TUBE

The converging tube is an efficient device for converting pressure head to velocity head, while the diverging tube converts velocity head to pressure head. The two may be combined to form a venturi tube, named after Venturi, an Italian, who investigated its principle about 1791. It was applied to the measurement of water by Clemens Herschel in 1886. As shown in Fig. 4.7 it consists of a tube with a constricted throat, which produces an increased velocity accompanied by a reduction in pressure, followed by a gradually diverging portion in which the velocity is transformed back into pressure with slight friction loss. As there is a definite relation between the pressure differential and the rate of flow, the tube may be made to serve as a metering device. The venturi meter is used for measuring the rate of flow of both compressible and incompressible fluids. In this section we shall consider the application of the venturi meter to incompressible fluids. The application of the venturi meter to compressible fluids will be discussed.

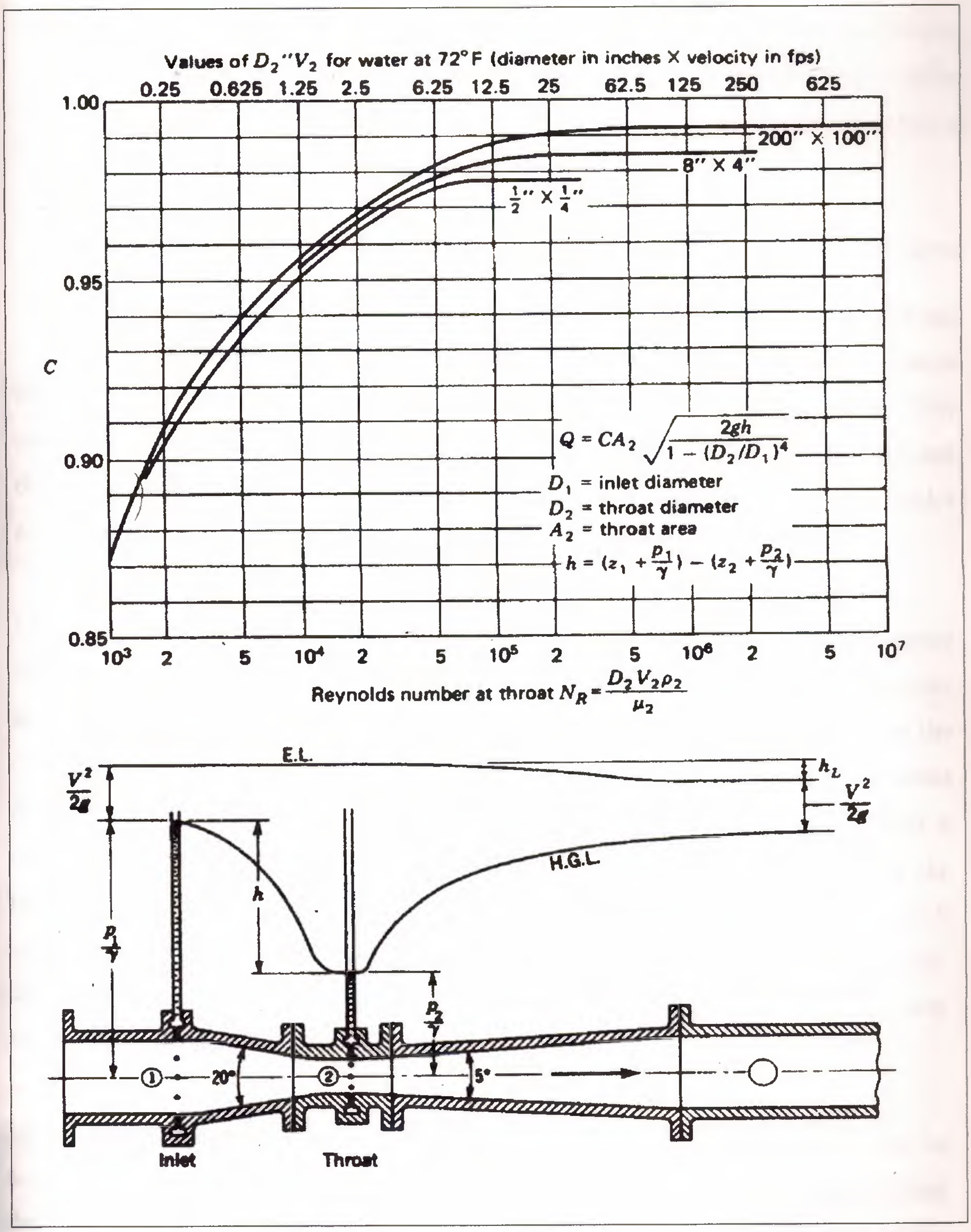

Figure 4.7 Venturi Tube With Conical Entrance And Flow Coefficient For D_2/D_1=0,5

The venturi tube provides an accurate means for measuring flow in pipelines. With a suitable recording device the flow rate can be integrated so as to give the total quantity of flow. Aside from the installation cost, the only disadvantage of the venturi meter is that it introduces a permanent frictional resistance in the pipeline.

Values of D_2 / D_1 may vary from $\frac{1}{4}$ to $\frac{3}{4}$ but a common ratio is $\frac{1}{2}$. A small ratio gives increased accuracy of the gage reading, but is accompanied by a higher friction loss and may produce an undesirably low pressure at the throat, sufficient in some cases to cause liberation of dissolved air or even vaporization of the liquid at this point. This phenomenon, called cavitation, has been described. The angles of convergence and divergence indicated in Fig.4.7 are considered optimum, though somewhat larger angles are sometimes used to reduce the length and cost of the tube.

For accuracy in use, the venturi meter should be preceded by a straight pipe whose length is at least 5 to 10 pipe diameters. The approach section becomes more important as the diameter ratio increases, and the required length of straight pipe depend on the conditions preceding it. Thus the vortex formed from two short-radius elbows in planes at right angles, for example, is not eliminated within 30 pipe diameters. Such a condition can be alleviated by the installation of straightening vanes preceding the meter.1 the pressure differential should be obtained from piezometer rings Fig. 3.9 surrounding the pipe, with a number of suitable openings in the two sections. In fact, these openings are sometimes replaced by very narrow slots extending most of the way around the circumference.

Unless specific information is available for a given venturi tube, the value of C may be assumed to be about 0.99 for large tubes and about 0.97 or 0.98 for small ones, provided the flow is such as to give reasonably high Reynolds numbers. A roughening of the surface of the converging section from age or scale deposit will reduce the coefficient slightly. Venturi tubes in service for many years have shown a decrease in C of the order of 1 to 2 percent. Dimensional analysis of a venturi tube indicates that the coefficient C should be a function of Reynolds number and of the geometric parameters D_1 and D_2 Values of venturi-tube coefficients are shown in Fig. 4.7 This diagram is for a diameter ratio of $D_1/D_1 = 0.5$, but it is reasonably valid for smaller ratios also. For best results a venturi meter should be calibrated by conducting a series of tests in which the flow rate is measure over a wide range of Reynolds numbers.

Occasionally, the precise calibration of a venturi tube has given a value of C greater than 1. Such an abnormal result is sometimes due to improper piezometer openings. But another explanation is that the (X's at sections 1 and 2 are such that this is so.

4.3.2 FLOW NOZZLE

If the diverging discharge cone of a venturi tube is omitted, the result is a flow nozzle of the type shown in Fig. 4.8 This is simpler than the venturi tube and can be installed between the flanges of a pipeline. It will answer the same purpose, though at the expense of an increased friction loss in the pipe. Although the venturi-meterequation Eq. can be employed for the flow nozzle, it is more convenient and customary to Include the correction for velocity of approach with the coefficient of discharge, so that

$$h_{L1-2} = \left(\frac{1}{C^2_V} - 1 \right) \frac{V_2^2}{2g}$$

where K is called the flow coefficient and A1 is the area of the nozzle throat. Comparison with Eq. Establishes the relation

$$K = \frac{C}{\sqrt{1 - \left(\frac{D_2}{D_1} \right)^4}}$$

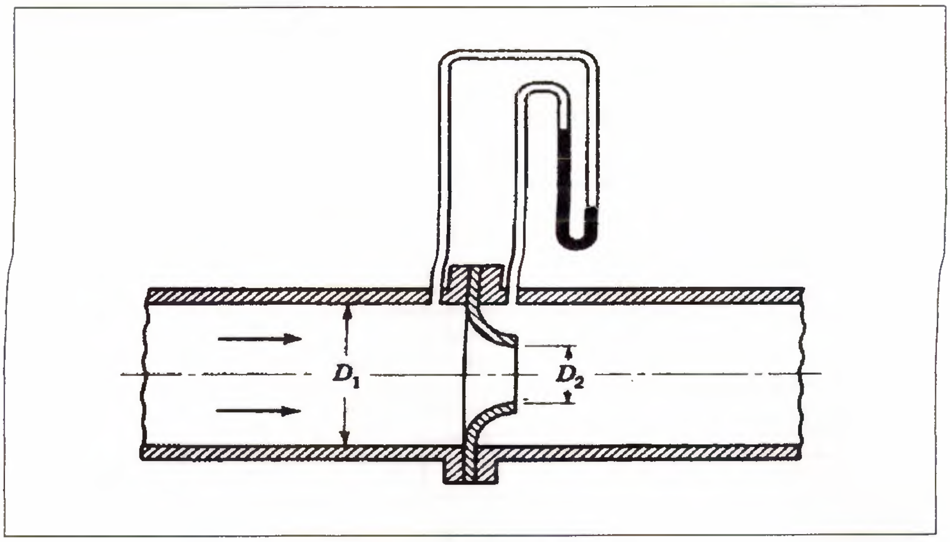

Figure 4.8 Flow Nozzle

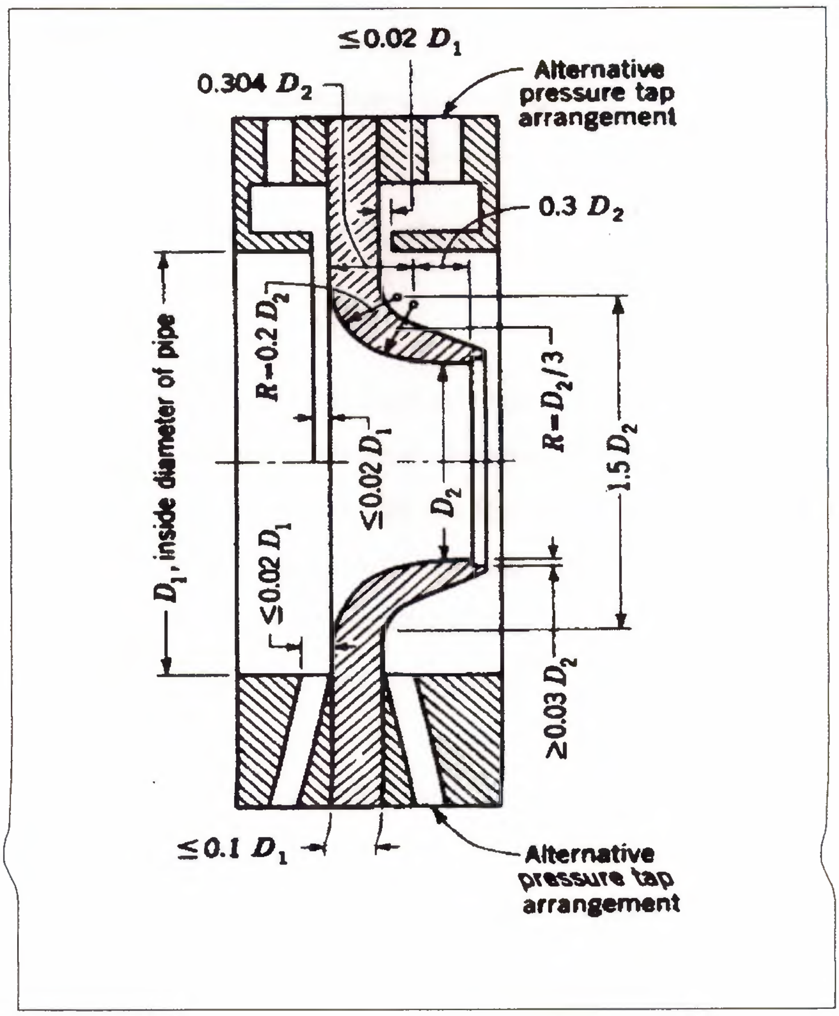

Figure 4.9 Isa Flow Nozzles

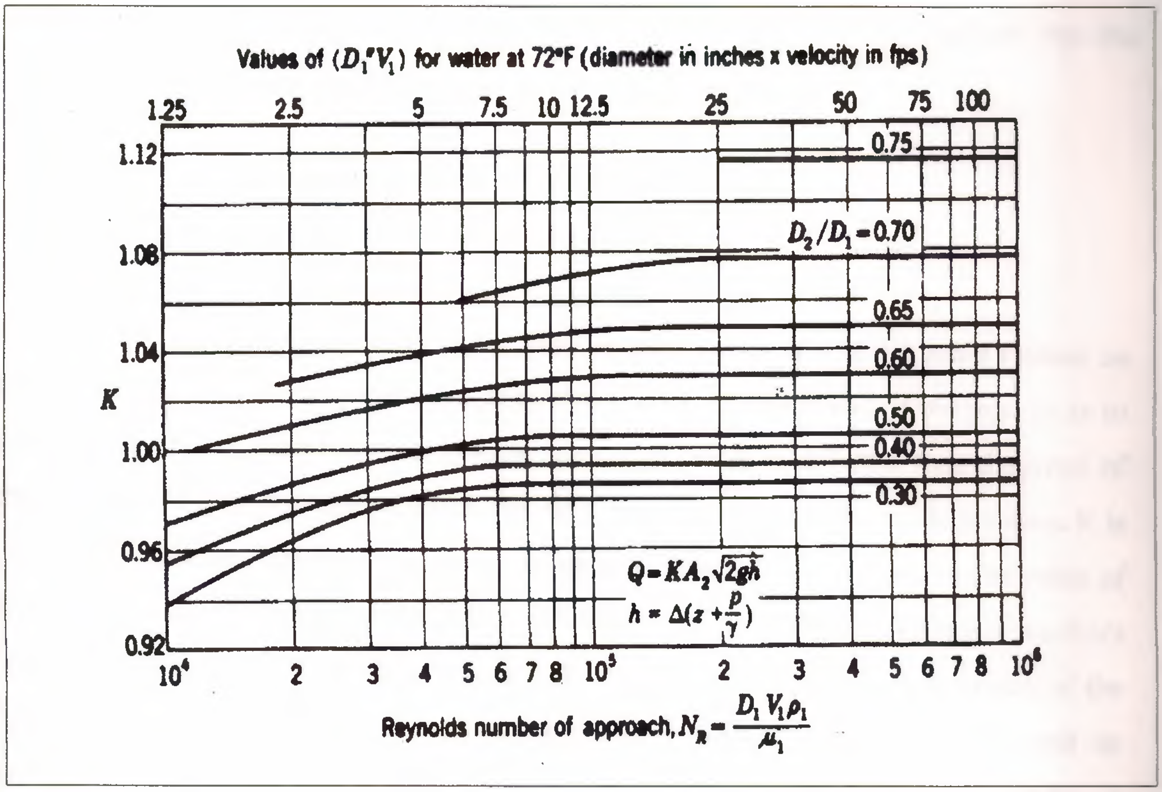

Figure 4.10 Flow Coefficients For ISA Nozzle

Although there are many designs of flow nozzles, the ISA (International Standards Association) nozzle Fig. 4.9 has become an accepted standard form in many countries. Values of K for various diameter ratios of the ISA nozzle are shown in Fig. 4.10 as a function of Reynolds number. Note that in this case the Reynolds number is computed for the approach pipe rather than for the nozzle throat, which is a convenience since N R in the pipe is frequently needed for other computations also.

As shown in Fig. 4.10, many of the values of K are greater than unity, which is a result of including the correction for approach velocity with the conventional coefficient of discharge. There have been many attempts to design a nozzle for which the velocity of approach correction would just cancel the discharge coefficient, leaving a value of the flow coefficient equal to unity. Detailed information on these so-called long-radius nozzles may be found in the ASME publications on fluid meters and flow measurement.

As in the case of the venturi meter, the flow nozzle should be preceded by at least 10 diameters of straight pipe for accurate measurement. Two alternative locations. For the pressure taps are shown in Fig. 4.9.

4.3.3 ORIFICE METER

An orifice in a pipeline, as in Fig. 4.11, may be used as a meter in the same manner as the venturi tube or the flow nozzle. It may also be placed on the end of the pipe so as to discharge a free jet. The flow rate through an orifice meter is different than the trend of the flow coefficients for venturi tubes and flow nozzles. At high Reynolds numbers K is essentially constant, but as the Reynolds number is lowered, an increase in the value of K for the orifice is noted with maximum values of K occurring at Reynolds numbers between 200 and 600, depending on the D/D1 ratio of the orifice. The lowering of the Reynolds number increases viscous action which causes a decrease in C v and an increase in Cc' the latter apparently predominates over the former until Cc reaches a maximum value of about 1.0. With a further decrease in Reynolds number K then becomes smaller because C v continues to decrease.

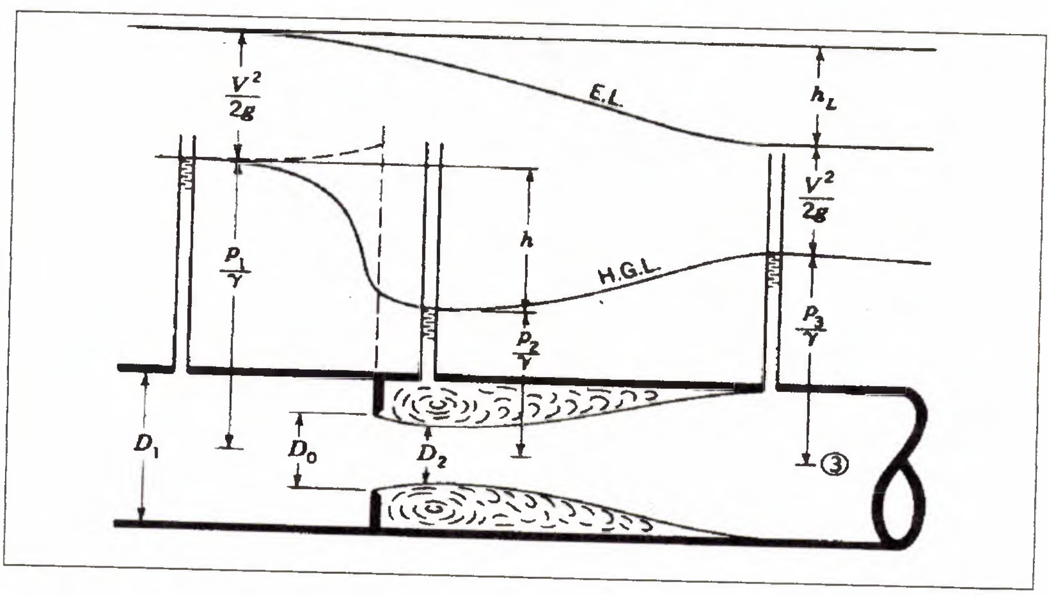

Figure 4.11 Thin-Plate Orifice In A Pipe.

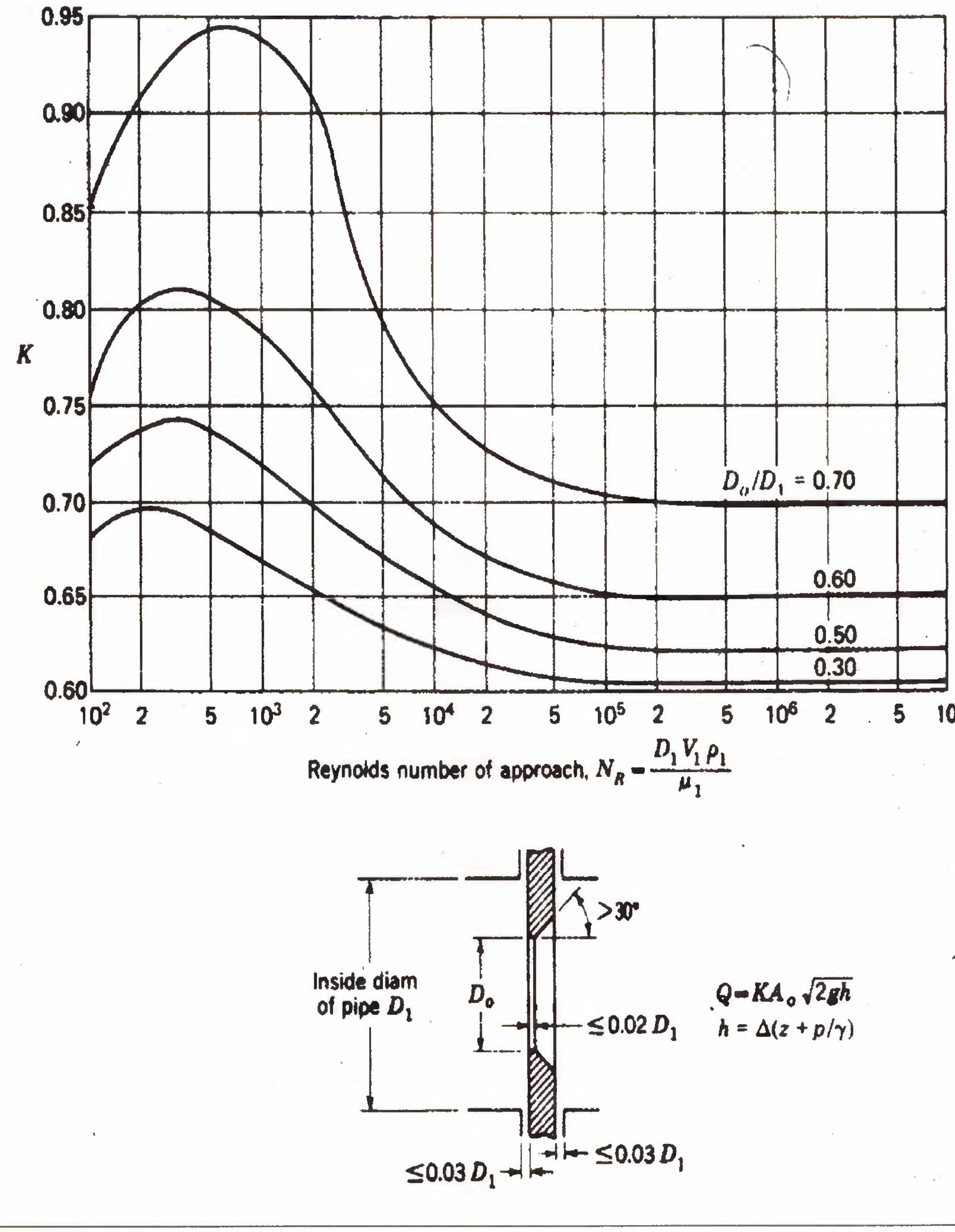

Figure 4.12 Vdi Orifice Meter And Flow Coefficients For Flange Taps

The difference between an orifice meter and a venturi tube or nozzle is that for both of the later there is no contraction so that A_2 is the area of the throat and is fixed, while for the orifice, A2 is the area of the jet and is a variable and is less than A_0 the area of the orifice. For the venturi tube or flow nozzle the discharge coefficient is practically a velocity coefficient, while for the orifice it is much more affected by variations in C_c is by Cv

The pressure differential may be measured between a point about one pipe diameter upstream of the orifice and the vena contract, approximately one half the pipe diameter downstream. The distance to the vena contract is not a constant, but decreases as Do/D1 increases. The differential can also be measured between the two corners on each side of the orifice plate. These flange taps have the advantage that the orifice meter is self-contained; the plate may be slipped into a pipeline without the necessity of making piezometer connections in the pipe.

The orifice has merit as a measuring device for it may be installed in a pipeline with a minimum of trouble and expense. Its principal disadvantage is the greater frictional resistance offered by it as compared with the venturi tube or flow nozzle.

4.2 MEASUREMENT OF MASS FLOW

The flow meters discussed thus far in this chapter are designed to produce an output signal that is proportional to the average velocity of flow or the volume flow rate. This is satisfactory when only the *volume delivered* through the meter is needed. However, some processes require a measurement of the *mass* of fluid delivered. For example, in food processing plants the production is of ten indicated as the amount delivered in kilograms, pounds-mass, or slugs. Some chemical processes are sensitive to the mass of the various constituents that are blended or that are introduced into a reaction. Two-phase fluids, such as steam, may be difficult to measure accurately if the temperature and pressure vary enough to cause significant changes in the amount of liquid and vapor in the steam.

One way to obtain mass flow rate measurements is to use a flow meter of the type just discussed that indicates volume flow rate and the n simultaneously measure the density of the fluid. Then the mass flow rate would be

$$M=pQ$$

That is, mass flow rate equals density times volume flow rate as discussed in Chapter 6 of this book. If the density of the fluid is known or can be conveniently measured, this is a simple calculation. For some fluids, the density can be calculated if the temperature of the fluid is known. Sometimes, particularly with gases, the pressure is also needed. Temperature probe s and pressure transducers are readily available to provide the necessary data. Specific gravity can be measured with a device called a *gravitometer*. Density can be measured directly for some fluids with a *densitometer*. The signals related to volume flow rate, temperature, pressure, specific gravity, or density can all be input to special electronic devices that effectively perform the calculation of $M = pQ$. This is shown schematically in Fig. 4.13 this process, while straightforward, requires several separate measurements to be made, each of which is subject to small errors then the errors are compounded in the final calculation.

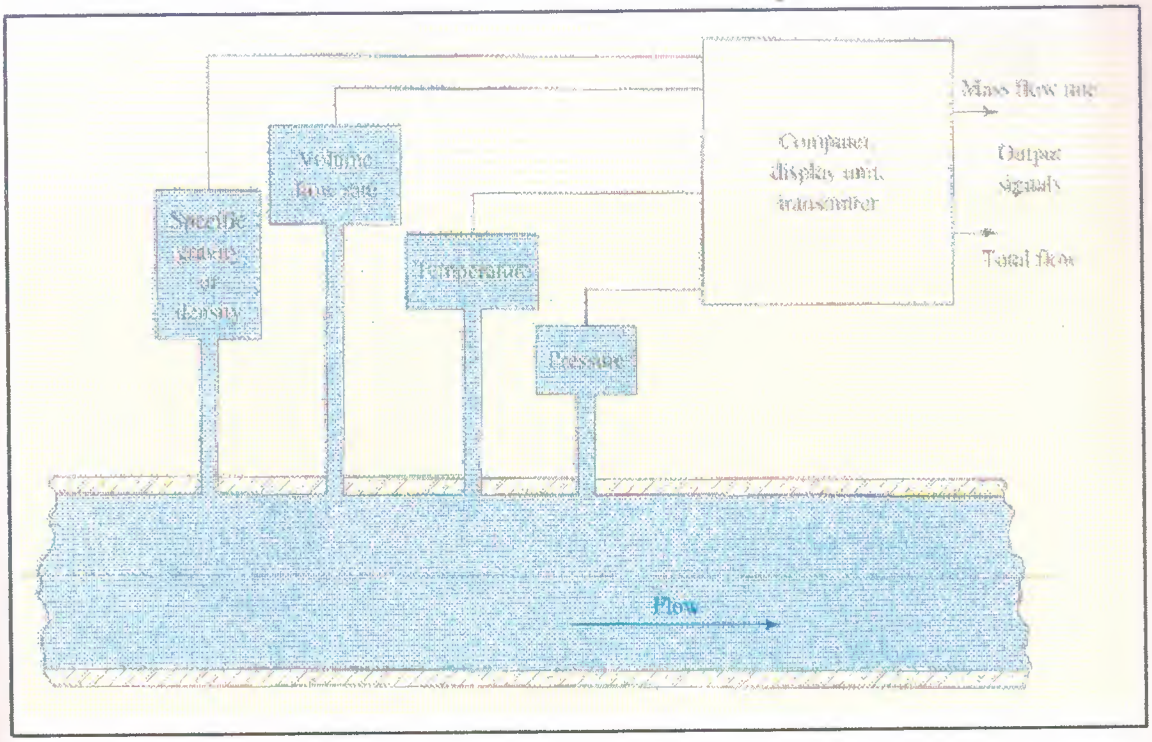

Figure 4.13 Shematic Represetation Of Mass Flow Measurement Using

Multiple Sensors.

True mass flow meters avoid the problems discussed above by generating a signal proportional to the mass flow rate directly. One such mass flow meter is called the *Cariolis mass flowtube,* shown in Fig. 4.14. The fluid enters the flow meter from the process piping and is directed through a continuous path of the same size that routes the fluid first through one loop, through a center body, then through the second loop, and the n out to the exit pipe. Two electromagnetic drivers bridge both loops at opposite extremities, equidistant from the center. The vibratory motion created moves the two parallel loops alternately toward each other and then apart. Fluid in the tubes is simultaneously following the path of the loops and moving perpendicular to that path because of the action of the drivers. A Coriolis acceleration (and a corresponding Coriolis force) is produced that is proportional to the mass of fluid flowing through the tubes. Sensors mounted near the drivers detect the Coriolis force and transmit a signal that can be related to the true mass flow rate through the meter. Accuracy is reported to be 0.2 percent of the indicated rate or 0.02 percent of full-scale capacity, whichever is greater.

Figure 4.14 Coriolis Mass Flow Tube

A) External View With Programmer And Indicator

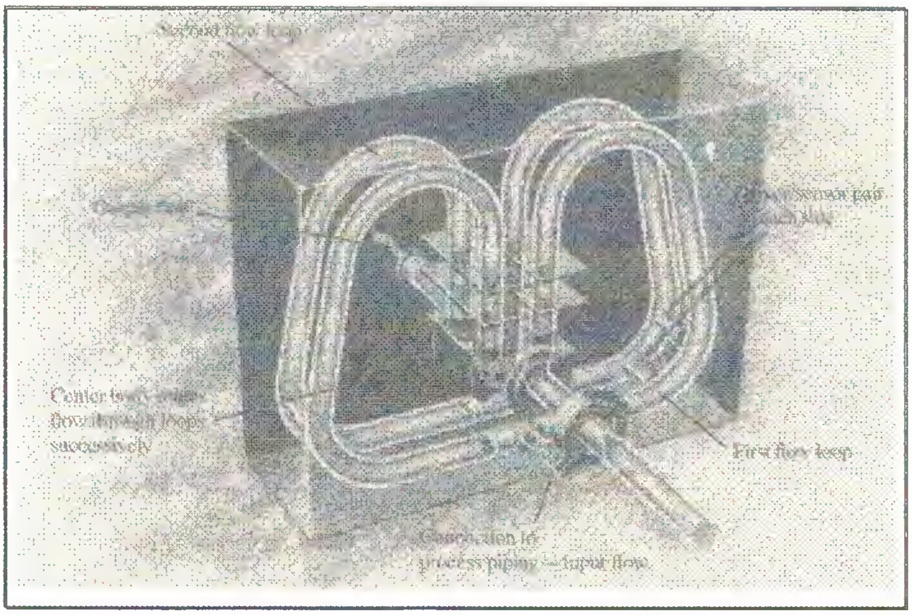

Figure 4.14 B) Internal View

Density of the fluid can also be measured with the Coriolis mass flow- tube because the driving frequency of the tubes is dependent on the density of the fluid flowing through the tubes. A temperature probe is also included in the system, completing a comprehensive set of fluid properties and mass flow rate data.

SUMMARY

In this chapter, we explain the subjects briefly.

This chapter is continue of third chapter and it is described the subjects below;

Orifices, Nozzlesand Tubes

Venturi Tube

Flow Nozzle

Orifice Meter

Finally, Measurement of Mass Flow is examined by using Formulas and figures.

CONCLUSION

In Chapter 1, flow phenomena and fluid properties are affected by the action of applied forces due to physical, gravitational, thermal and other environmental conditions. In practice, the treatment of fluid mechanics can be divided into two broad categories: internal flow systems and external flow systems. *Fluid mechanics is a more difficult* subject, however, because with solids one deals with separate and tangible elements, while with fluids there are no separate elements to be distinguished.

Development Of Fluid Mechanics; Fluid mechanics may be divided into three branches: fluid static's is the study of the mechanics of fluids at rest; kinematics deals with velocities and streamlines without considering forces or energy; and hydrodynamics is concerned with the relations between velocities and accelerations and the forces exerted by or upon fluids in motion

Fluid mechanics deals with both incompressible and compressible fluids that is, with fluids of either constant or variable density. Gases, too, may be considered incompressible when the pressure variation is small compared with the absolute pressure. The compressibility of a liquid is inversely proportional to its volume modulus of elasticity, also known as the bulk modulus.

An ideal fluid may be defined, as one in which there is no friction. That is, its viscosity is zero. The viscosity of a fluid is a measure of its resistance to shear or angular deformation. The friction forces in fluid flow result from the cohesion and momentum interchange between molecules in the fluid.The attraction between molecules forms an imaginary film capable of resisting tension at the interface between two immiscible liquids or at the interface between a liquid and a gas. The liquid property that creates *this capability is known as surface* tension. Surface-tension effects are generally negligible in most engineering situations.

The density ρ of a fluid is its mass per unit volume, white the specific weight γ is its weight per unit volume. *Specific weight γ represents the force exerted by gravity on a* unit volume of fluid and therefore must have the units *of force per unit volume, such as* N/m³ in SI units. Specific volume v is the volume occupied by a unit mass of fluid. It is commonly applied to gases. Specific gravity s of a liquid is the ratio of its density to that of pure water at a standard temperature.

In Chapter 2, the first type is known as laminar, streamline, or viscous flow. The significance of these terms is that the fluid appears to move by the sliding of laminations of infinitesimal thickness relative to adjacent layers; that the particles move in definite and observable paths or streamlines and also that the flow is characteristic of a viscous fluid or is one in which viscosity plays a significant part. The second type is known as turbulent flow and where represents the irregular motion of a large number of particles during a very brief time interval, while the erratic path followed by a single particle during a longer time interval. A distinguishing characteristic of turbulence is its irregularity, they're being no definite frequency, as in wave action, and no observable pattern, as in the case of eddies.

A steady flow is one in which all conditions at any point in a stream remain constant with respect to time, but the conditions may be different at different points. A truly uniform flow is one in which the velocity is the same in both magnitude and direction at a given instant at every point in the fluid. Both of these definitions must be modified somewhat, for true steady flow is found only in laminar flow. In turbulent flow there are continual fluctuations in velocity and pressure at every point, as has been explained.

A flow field is classified as one, two or three-dimensional depending on space coordinates required to specify the velocity field. Fluid flow is generally three-dimensional in character, which presents varying degrees of complexities and difficulties in nature during the analysis of different types of problems. A three-dimensional flow problem can be reduced to either a two- or a one-dimensional problem if the flow system allows the properties of interest to exist in two directions or one, respectively. Similarly, flow in pipes, rivers and artificial channels are assumed to be one- dimensional and the analysis of flow parameters is carried out accordingly.

In Chapter 3, fluid metrology is the science, associated with fluid-flow projects, which examines and measures flow properties such as density, viscosity, pressure, velocity, discharge. The measurement of liquid density is most commonly determined by weighing a known volume of the liquid. Other techniques Include hydrostatic weighing, The hydrometer is a variation of this technique. The densities are calculated from fluid statics. The measurement of viscosity is generally made with a device known as a viscometer. Various types of viscometers are available. They all depend on the creation of laminar-flow conditions. Several types of rotational viscometers are available. These generally consist of two concentric cylinders that are rotated with respect to one another. One difficulty with this type of viscometer is that mechanical friction, must be accounted for, and this is difficult to deal with accurately. The tube-type viscometer is perhaps the most reliable. In this device the flow is unsteady and the tube is of such small diameter that the flow may be assumed to be laminar. There are several other types of tube viscometers, but they are all based on the same principle.

The measurement of pressure in a fluid at rest is an easy task compared to pressure measurement of a flowing fluid. For a static fluid, the geometry of the piezometer opening dress not influences the accuracy of measurement. In a flowing fluid, however, orientation of the piezometer hale with respect to the direction of streamlines does affect the pressure readings. For a fluid in motion, the axis of the pressure hole should be perpendicular to the streamlines, because any deviation from the normal direction would result in erroneous pressure readings. In case the flow direction in a two-dimensional flow field is uncertain, a cylinder with two holes connected to a differential manometer, is rotated around its axis until the differential manometer shows a zero reading.

To get an accurate measurement of static pressure in a flowing fluid, it is important that the measuring device fit the streamlines perfectly so as to create no disturbance to the flow. In a straight reach of conduit the static pressure is ordinarily measured by attaching to a pyrometer a pressure gage or a U-tube manometer. The piezometer opening in the side of the conduit should be normal to and flush with the surface. To measure the static pressure in a flow field, the static tube is used. In this device the pressure is transmitted to a gage or manometer through piezometric holes that are evenly spaced around the circumference of the tube. This device will give good results if it is perfectly aligned with the flow. If the direction of the flow is unknown for two-dimensional flows, a direction finding tube may be used. This device is a cylindrical tube having two piezometer holes located. Each piezometer is connected to its own measuring device. The tube may be rotated until each tube shows the same reading.

One means of measuring the local velocity u in a flowing fluid is the pitot tube. The differential pressure may be measured with any suitable manometer arrangement. The formula for the pitot tube for incompressible flow may be derived by writing the energy equation. This equation gives the ideal velocity of flow at the point in the stream where the Pitot tube is located. In actuality the right-hand side of this equation must be multiplied by a factor varying from 0.98 to 0.995 to give the true velocity. This is so because the directional velocity fluctuations of turbulence cause a pitot tube to read a value somewhat higher than the temporal mean axial component of velocity. Another instrument, the pitometer, consists of two tubes, one pointing upstream and the other downstream. Most of these devices will give reasonably accurate results even if the tube is as much as $\pm 15°$ out of alignment with the direction of flow. The direction-finding tube may be used to determine velocity. This device has been used extensively in wind tunnels and in the investigation of hydraulic machinery.

The instrument used in water is called a current meter, and when designed for use in air, it is called an anemometer. These two instruments, which are the same in principle, determine the velocity as a function of the speed at which a series of cups or vanes rotate about an axis either parallel or normal to the flow. The hot-wire anemometer measures the instantaneous velocity at a point. It consists of a small sensing element that is placed in the flow field at the point where the velocity is to be measured. In one type of hot-wire anemometer the wire is maintained at a constant temperature by a variable voltage which changes the current through the wire. The voltage provides a measure of the velocity of the fluid. The camera is one of the most valuable tools in a fluid-mechanics research laboratory. If successive exposures are taken on the same film, the velocities and the accelerations of the particles can be determined.

There are various ways of measuring discharge in a pipe, for example, the velocity may be determined at various radii using a pitot-static tube or a pitot tube in combined with a wall piezometer. A pitot tube could be used for such measurements, but a current meter is more commonly used. Another widely used method is to take the average of the velocities at 0.2 x depth and 0.8-x depth. This procedure for determining stream discharge.

In Chapter 4, among the devices used for the measurement of discharge are orifices and nozzles. An orifice is an opening in the wall of a tank or in a plate normal to the axis of a pipe, the plate being either at the end of the pipe or in some intermediate location. An orifice is characterized by the fact that the thickness of the wall or plate is very small relative to the size of the opening. Hence such orifices should be calibrated if high accuracy is desired. In addition to possible use as a flow measuring device a nozzle has other important uses, such as providing a high-velocity stream for fire fighting or for power in a steam turbine or a Pelton water wheel.

A jet is a stream issuing from an orifice, nozzle, or tube. A free jet is a stream of liquid surrounded by a gas and is therefore directly under the influence of gravity. A submerged jet is a stream of any fluid surrounded by a fluid of the same type, that is, a gas jet discharging into a gas or a liquid jet discharging into a liquid. Where the streamlines converge in approaching an orifice, they continue to converge beyond the upstream section of the orifice until they reach the section by where they become parallel.

The converging tube is an efficient device for converting pressure head to velocity head, while the diverging tube converts velocity head to pressure head. The two may be combined to form a venturi tube. The venturi meter is used for measuring the rate of flow of both compressible and incompressible fluids. The venturi tube provides an accurate means for measuring flow in pipelines. With a suitable recording device the flow rate can be integrated so as to give the total quantity of flow. Aside from the installation cost, the only disadvantage of the venturi meter is that it introduces a permanent frictional resistance in the pipeline.

The venturi-meter equation can be employed for the flow nozzle, it is more convenient and customary to Include the correction for velocity of approach with the coefficient of discharge. In the case of the venturi meter, the flow nozzle should be preceded by at least 10 diameters of straight pipe for accurate measurement.

The orificemeter has merit as a measuring device for it may be installed in a pipeline with a minimum of trouble and expense. Its principal disadvantage is the greater frictional resistance offered by it as compared with the venturi tube or flow nozzle.

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