NEAR EAST UNIVERSITY

Faculty of Engineering

Department of Mechanical Engineering

FLUID PROPERTIES MEASUREMENTS

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ME-400

Student: Mohamed BADER (970859)

Supervisor: Assit. Prof. Guner OZMEN

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TABE OF CONTENT

CHAPTER IV

COMMERCIALLY FLOW MEASURMENTS

CONCLUSION

REFRENCES

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SUMMARY

The measurements of fluid flow are important as an application ranging from measurements of blood flow rate in human artery to the measurements of the flow of liquid oxygen in rockets. For this reason our main aim of this thesis is to define and analyze the fluid properties measurements, which are classified as follows;

- Pressure measurements
- Velocity measurements
- Orifices

In first chapter we are going to analyze the importance of the fluid measurements and it is classification. In second chapter we are going to explain the theoretical background of the flow Kinematics, Bernoulli's and quntinuaty equations on which fluid flow measurements based. The third chapter concern with flow measurements devices and their working principles. Commercially flow measuring devices, which are going to explain in the fourth chapter.

NOMENCLATURE

A	area (m^2/s)
C_c	contraction coefficient
C_d	drag coefficient
C_v	velocity coefficient
F	force (N)
F_f	frictional force (N)
g	gravitational acceleration (m/s^2)
h	head (m)
h_f	frictional head (m)
h_t	total head (m)
m	mass (kg)
P	pressure (Pa)
Q	volumetric flow rate (m^3/s)
Re	Reynolds number
T	time (s)
U	velocity on the x direction (m/s)
μ	absolute viscosity (m^2/s)
τ	shear stress (Pa)
ρ	mass density (kg/m^3)
γ	specific weight $kg/m.s^2$

CHAPTER 1

INTRODUCTION

The first section of this chapter explains the definition of measurement and its scientific meaning and its general functions in engineering. The second section is a statement about the importance of fluid measurements in engineering fields. Some important definitions are introduced in the third section. The third section also contains a classification of fluid that is important to determine the special cases of fluid properties. So that by assuming those cases, simplifications can be made to describe the fluid properties with reasonable approximations.

1.1 MEASUREMENTS

Measurement has been of great importance to human civilization and a factor that daily and necessarily contributes the life of mankind. Moreover, not only being a mean of quantifying but also the first step in any scientific experiment or observation that composes the basis of the theoretical work. This is because of the fact that laboratory work is mainly based on the good and successful performance of the measurement process. On other words, good design of measurement techniques and a good measuring procedure leads to accurate data and experimental observations, and thus correct decisions about the physical events.

In engineering areas measurement is one of the basic stages of any engineering work, design and inventions to be accomplished. In fact, measurement is a major principle for engineering to Perform successful primary experimental decisions and gaining practical properties of materials and substances

- Achieve good observations of the engineering processes and cycles
- Be able to control the performance of the working machines and engineering systems
- Make suitable predictions for the development of the concerned engineering work
- Help in the invention of a proper design to carry out specific tasks
- Compose reference researches and tabulated data, figures arid charts

It is necessary to say that, no absolute measurement is possible. That is, in any measurement process there will be always errors, deviations, estimations and measuring device calibrations. This is because of the environmental conditions associating the process and a lot of practically unavoidable factors restrict obtaining the absolute results. Consequently, only 'enough' measured data is always desired.

1.2 FLUID MEASUREMENTS

Fluids have great functions in many engineering fields, especially for mechanical engineers. In fact, a mechanical engineer must have a good knowledge of fluids properties and behavior because

- Fluids are involved as the working substances for many of mechanical machineries such as, power engines, turbines and combustion engines
- Also fluids in many engineering areas are considered to be the engineering systems themselves (as in hydraulic Systems and aircraft industries)
- They can be the substances that are to be handled by mechanical systems (e.g. pumps, piping constructions, pipelines, nozzles and diffusers, valves, etc.)

As a result, it is of great importance to observe their behavior and detect their properties by the mean of suitable measuring devices with the desired accuracy.

1.3 BASIC DEFINITIONS

A fluid can be defined as a substance that deforms continuously under the application shear stress no matter how small that shear stress may be. As this project is concerned of flow measurements and fluid flow properties, it is convenient to introduce a classification that can be made among fluid in order to simplify the analyses of the measuring devices.

The types of fluid properties can be classified as follows:

PRESSURE

Since pressure is a very important characteristic of a fluid field, it is not surprising that numerous devices and techniques are used in its measurement. As we know the pressure at a point within a fluid mass will he designated as either an *absolute* pressure or a *cage* pressure. Absolute pressure is measured relative to a perfect vacuum (absolute zero Pressure). Whereas gage pressure is measured relative to the local atmospheric pressure. Thus, a gage pressure of zero corresponds to a pressure that is equal to the local atmospheric pressure. Absolute pressures are always positive, but gage pressures can he either positive or negative depending on whether the pressure is above atmospheric pressure (a positive value) or below atmospheric pressure (a negative value). A negative gage pressure is also referred to as a suction or vacuum pressure.

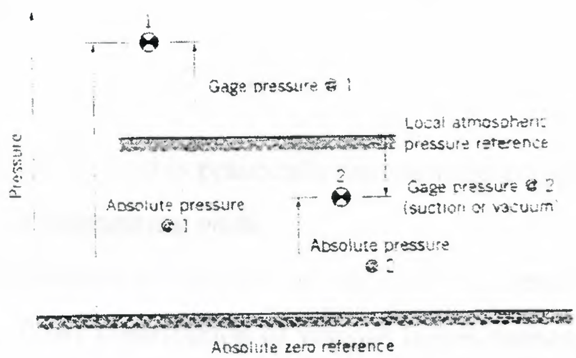

Fig 1.1 Various ways to represent pressure

In addition to the reference used for the pressure measurement. The units used to express the value are obviously of importance. Pressure is a force per unit area. . In the SI system the units are N/m^2; this combination is called the Pascal and written as Pa (1 N/m Pa).

$$P = \frac{F}{A} \quad \text{(N/m)}$$

VISCOS AND INVISCID FLOWS

Viscosity is that property of a fluid by virtue of which it resistance to shear or to angular deformations. Sir Isaac Newton (1642-1727) showed that the rate of angular deformation of certain fluids (like air, water, gasoline, etc.) is proportional to the shearing stress τ. The constant of proportionality is called a absolute or dynamic viscosity and is designated by μ. Viscosity is one of the most important fluid properties encountered in the study of fluid mechanics.

The defining equation for dynamic or absolute viscosity is

$$\tau = \mu \frac{du}{dy} \quad \text{where;}$$

τ : shear stress between fluid layers in laminar flow n/m^2

μ : dynamic viscosity, $N.s/m^2$

du/dy : normal velocity gradient

In many problem involving viscosity the viscosity is divided by density, this ratio defines the kinematics viscosity v, so called because forces is not involved ,the only dimension being length and time.

$$v = \frac{\mu}{\rho} \quad (m^2/s)$$

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

Thus, flow in which the effect of viscosity is negligible is termed to be inviscid flows. On other hand, in various flows contribution of viscous forces cannot be avoided so the flow is said to be viscous flow

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.

1.4 CONCLUSION

It is important that engineer to able to perform successful experimental, and it equally important that they know or able to estimate the accuracy of their measurements. this chapter explained the importance of fluid measurements in our life. Some of the classifications of the fluid were explained like laminar and turbulent flow, viscous and invisid flow, external and internal, pressure of the fluid and etc,

CHAPTER II

THEORETICAL BACKGROUND

This chapter defines and explains the theoretical concepts on which the measurements of fluid flow are based. In flow properties measurements there are two important equations that are used to analyze the working principles of the measuring devise. Those equations are named the Bernoulli equation and continuity equation. The two equations are discussed in the second and third sections whereas the first section is brief review of the important quantities in fluid kinematics

2.1 REVIEW OF FLOW KINEMATICS

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A fluid system refers to a specific mass of fluid within the boundaries that are defined by a closed surface. The closed surface, and hence the fluid system, is chosen according to the type of the flow and the fluids properties to make the analytical solution as simple as possible. According to the definition of tie fluid system the mass it contains cannot be changed But the shape of tile system as well as the boundaries can be changed with time if the fluid is a liquid that flows through a constriction or when the fluid is a compressible gas In contrast, a control volume refers to a fixed region in space that does not move or change its shape Because the mass of fluid that is contained in the control volume can change with time, thus using the control volume to analyze fluid flows is more suitable.

As the motion of a fluid is concerned, determination of flow velocity is important together with its variation in the flow field. Accordingly, the flow may be termed to be two-dimensional or three-dimensional regarding the velocity components that may result. Moreover, fluid is said to be steady when conditions do not vary with time or when variations are small with respect to mean flow values. In contrast, if the flow properties do change with time the flow it becomes unsteady flow.

A streamline is a continuous line drawn through the fluid so that it has the direction of the velocity vector at every point. There can be no flow across a streamline. In steady flow, since there is no change in direction of the velocity vector at any point, the streamline has fixed inclinations at every point and is. therefore, *fixed in space*. A particle always moves tangent to the streamline; hence, in steady flow the path of a particle is a streamline. In unsteady flow, since the direction of the velocity vector at any point may change with time, a streamline may shift in space from instant to instant. A particle then follows one streamline one instant, another one the next instant, and so on, so that the path of the particle may have no resemblance to any given instantaneous streamline.

To simplify the study of fluid flow it is convenient to assume a fluid system or a control volume, draw the necessary streamlines and to determine the type of the flow as being steady, unsteady, compressible or incompressible etc

The quantity of fluid flowing per unit time across any section of the stream is called the flow rate So in dealing with compressible fluids, the mass flow rate is commonly used, whereas the volumetric flow rate is used for incompressible fluids. It is also possible to define an average velocity, which is based on the mass flow rate in compressible flows, and on the volumetric flow rate in the case of incompressible flows.

2.2 MASS FLOW RATE

The mass flow rate represents the amount of mass of the flowing fluid that passes across a considered section on the stream per unit time or mathematically;

$$m = \int_A \rho.\vec{V}.\vec{n}\,3dA$$

Where m = mass flow rate in (Kg/s)

$\vec{V}$ = Velocity vector

ρ = the mass density of the fluid

$\vec{n}$ = normal unit vector to the assumed control

If the control surface is chosen to be perpendicular to the flow direction the dot product reduces to simply the magnitude of the velocity Furthermore if the flow is incompressible (i.e. fluid density is constant and uniform over the control volume's area)

And steady conditions are assumed the mass flow rate equation reduces to

$m = \rho A V$ where A is the cross sectional area of the flow

2.3 VOLUMETRIC FLOW RATE

For an incompressible fluid both sides of the derived mass flow equation may be divided by the constant density to result the volumetric flow rate.

$$Q = \frac{m}{\rho} = \int_A \vec{V} . \vec{n}\, dA$$

For a uniform and normal flow out through a control surface the equation reduces to

$$Q = V . A \quad (m^3/s)$$

Here area A being normal to the flow direction since the velocity does not change over this control surface.

2.4 THE AVARAGE VELOCITY

If the velocity is not uniform over a cross section of the stream then an average velocity is used to calculate the flow rate of that flow, it may expressed as:

$$\bar{V} = \frac{Q}{A} = \frac{1}{A} \int_A \vec{V} . \vec{n} . dA$$

2.5 THE CONTINUTY EQUATION

The application of principle of conservation of mass to a fluid flow yields an equation, which referred to as continuity equation. Which state that the time rate of change of the mass of the system is zero. If we consider steady flow through a portion of the stream tube of Fig 2.1.the control volume comprises the wall of the stream tube between sections 1 and 2,plus the end areas of sections 1 and 2.Because the flow is steady,

$$\int_{cs} \rho v . dA = 0$$

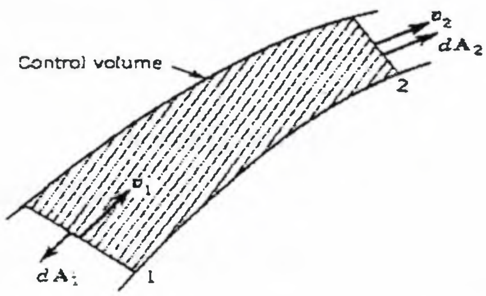

Fig 2.1 Steady flow through a stream tube.

Which states that the net mass flow rate outflow from the control volume must be zero.at section 1 the net mass outflow is $\rho_1 v_1 . dA_1 = -\rho_1 v_1 dA_1$, and at section 2 it is $\rho_2 v_2 . dA_2 = \rho_2 v_2 dA_2$ .since there is no flow through the wall of the stream tube,]

$$\rho_1 v_1 . dA_1 = \rho_2 v_2 dA_2$$

Is the continuity equation applied to two sections along a stream tube in steady flow.

For collection of stream tubes as in Fig2.2, if the ρ_1 are the average density at section 1 and ρ_2 the average density at section 2 then,

$$m = \rho_1 v_1 . A_1 = \rho_2 v_2 A_2$$

In which V_1, V_2 represent average velocities over the cross sections and m is the rate of mass flow. The average velocities over a cross section is given by

$$V = \frac{1}{A}\int v dA$$

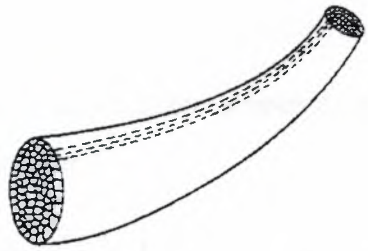

Fig 2.2 collection of stream tubes between fixed boundaries

If the discharge Q is defined as Q = V.A

The continuity takes the form

$$m = \rho_1 Q_1 = \rho_2 Q_2$$

For incompressible, steady flow

$$Q = A_1 V_1 = A_2 V_2$$

2.6 THE BERNNOULLI EQUATION

The Bernoulli equation gives a relation ship between pressure, velocity and position in a flow field. Normally these properties vary considerably in the flow. So by the formulation of the conservation of energy principle on an infinitesimal control volume for the fluid and by the help of Newton's second law of motion the Bernoulli's equation can be expressed for streamlines as following:

$$gz + \frac{v^2}{2} + \frac{p}{\rho} = const$$

This general formation varies from one-stream lines to another but remain constant along a streamline in steady, frictionless and incompressible flow. These four assumption are needed and must be kept in mind when applying this equation. Each term has the dimensions (L/T^2) or m^2/s^2.

For a streamline within flow , the Bernoulli equation is written as

$$\frac{V_1^2}{2}+\frac{p_1}{\rho g}+gz_1=\frac{V_2^2}{2}+\frac{p_2}{\rho}+z_2$$

Where the subscribes 1 and 2 indicates the properties at two points on the stream dividing by g the gravitational acceleration

$$\frac{V^2}{2g}+\frac{p_1}{\rho g}+z_1=\frac{V_2^2}{2g}+\frac{p_2}{\rho g}+z_2$$

Each of the above terms represents the work per unit weight 'i.e each term represents the head' and thus has the dimension of length. The fore the quantities in the equation are named as the velocity head, pressure head and gravitational head. Moreover if there exists non-conservative forces in the flow field and resulting in 'head losses', those losses represent the work done by the no conservative forces against the flow And by including them in the Bernoulli's equation yields an extended version of it. Similarly, if any external work is done on the flow its contribution should be considered in the equation accordingly, an external work may be the work done by a pump for example. The extended Bernoulli equation is;

$$\frac{V^2{}_1}{2g}+\frac{p_1}{\rho g}+z_1-h_f+h_s=\frac{V_2^2}{2g}+\frac{p_2}{\rho g}+z_2$$

Where

h_s : Head gained by the external work

h_f : Head loss due to non-conservative forces

Modification of assumption underlying Bernoulli's Equation

Under special condition each assumption of the four underlying **Bernoulli's** Equation may be waived

1. When all streamlines originate from a reservoir, where the energy content is everywhere the same, the constant of integration does not change from one streamline to another

and points 1 and 2 for application of Bernoulli's equation may be selected arbitrarily, i.e., not necessarily on the same streamline.

2. In the flow of a gas, as in a ventilation system, where the change in pressure is only a small fraction (a few percent) of the absolute pressure, the gas may be considered incompressible. Equation may be applied, with an average unit gravity force γ.
3. For unsteady flow with gradually changing conditions, e.g., emptying a reservoir, Bernoulli's equation may be applied without appreciable error.
4. Bernoulli's equation is of use in analyzing real-fluid cases by first neglecting viscous shear to obtain theoretical results. The resulting equation may then be modified by a coefficient, determined by experiment, which corrects the theoretical equation so that it conforms to the actual physical case. In general, losses are handled by use of the energy equation developed by steady-state energy equation.

The following examples are introduced to make the previous derived equation more clear and to show how can a flow property be calculated by their means.

EXAMPLE 1

An incompressible and inviscid fluid is flowing through a horizontal converging duct. The area at the inlet and the exit of the duct are known. If the pressure at the exit of the duct is 100 kPa, determine the pressure at the inlet of the duct in order to produce an exit velocity of 50 m/s.

SOLUTION

The cross sectional areas of the converging conduit, arid the fluid density are given as;

$$A_1 = 0.1m^2 \qquad \rho = 1000kg/m^3$$

$$A_2 = 0.02m^2$$

For the steady flow of an incompressible fluid with exit of the converging duct, the continuity equation is

$$V_1 A_1 = V_2 A_2$$

So that the velocity at the inlet of the duct is

$$V_1 = \frac{V_2 A_2}{V_2} = \frac{(50m/s)\times(0.02m^2)}{0.1m^2} = 10m/s$$

As long as the steady flow of an incompressible and inviscid fluid in a horizontal plane is considered, then the changes in elevation may be neglected. Therefore the Bernoulli's equation between two points on a streamline in the direction of the flow

$$\frac{p_2}{\rho} + \frac{V_2^2}{2} = \frac{p_1}{\rho} + \frac{V_1^2}{2}$$

$$p_1 = p_2 + \frac{\rho}{2}\left(V_2^2 - V_1^2\right)$$

$$P_1 = 100000N/m^2 + \frac{1000kg/m^3}{2}\left[(50m/s)^2 - (10m/s)^2\right]$$

$$= 1300 \text{ kPa}$$

2.7 CONCLUSION

In this chapter the definition of the mass flow rate and the volumetric flow rate were represented with their mathematical equation, in addition, two important equation were derived from the conservation of the mass and conservation of energy those two useful formulas are named as the continuity and Bernoulli's equation respectively. And by their mean we can calculate the flow velocity and flow rates of a fluid be considering a streamline in the direction of the flow.

CHAPTER III

FLOW MEASURMENTS

In this chapter the working principles of the simple and the most commonly used devices for the measurement of the flow properties are analyzed. Furthermore, according to the flow property they measure, the devices are classified to flow velocity measuring devices and flow rate measuring devices. So mathematical formulations are derived for each device separately to obtain the flow proprieties and by considering the sources of errors and the assumption made the measurements are obtained as accurate as possible.

3.1 PRESSURE MEASUREMENT

The measurement of pressure is required in many devices that determine the velocity of a fluid stream or its rate of flow, because of the relation between velocity and pressure given by the energy equation. The static pressure of a fluid in motion is its pressure when the velocity is undisturbed by the measurement.

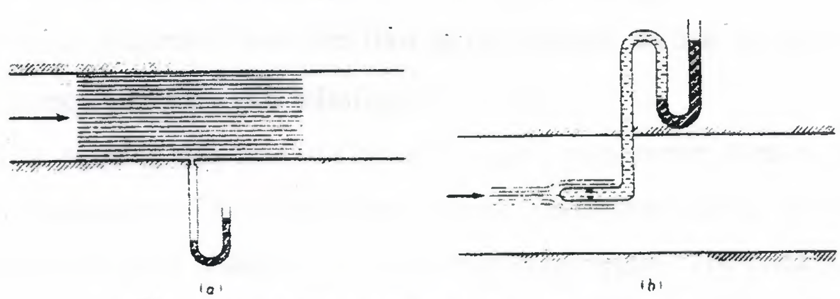

Figure 3.1 Static pressure-measuring devices
(a) Piezometer opening
(b) Static tube

Figure 3.1a indicates one method of measuring static pressure, the piezometer opening. When the flow is parallel, as indicated, the pressure variation is hydrostatic normal to the streamlines; hence, by measuring the pressure at the wall, the pressure at any other point in the cross section can be determined. The piezometer opening should be small, with length of opening at least twice the diameter, and should be normal to the surface, with no burrs at its edges, because small eddies would form and distort the measurement. A small amount of rounding of the opening is permissible. Any slight misalignment or roughness at the opening may cause errors in measurement; therefore, it is advisable to use several piezometer openings connected together into a piezometer ring. When the surface is rough in the vicinity of the opening, the reading is unreliable. For small irregularities it may be possible to smooth the surface around the opening. For rough surfaces, the *static* tube (Fig. 3.1b) may be used. It consists of a tube that is directed upstream with the end closed. It has radial holes in the cylindrical portion downstream from the nose. The flow is presumed to be moving by the openings as if it were undisturbed. There are disturbances, however, due to both the nose and the right-angled leg that is normal to the flow. The static tube should be calibrated, as it may read too high or too low. If it does not read true static pressure, the discrepancy Δh normally varies as the square of the velocity of flow by the tube;

$$\Delta h = C\frac{v^2}{2g}$$

In which C is determined by towing the tube in still fluid where pressure and velocity are known or by inserting it into a smooth pipe that contains a piezometer ring.

Such tubes are relatively insensitive to the Reynolds number and to Mach numbers below unity. Their alignment with the flow is not critical, so that an error of but a few percent is to be expected for a yaw misalignment of 15^{o}.

The piezometric opening may lead to a bourdon gage a manometer, a micro manometer, or an electronic transducer. The transducers depend upon very small deformations of a diaphragm due to pressure change to create an electronic signal. The principle may be that of a strain gage and a Wheatstone bridge circuit, or it may rely on motion in a differential transformer, a capacitance chamber, or the piezoelectric behavior of a crystal under stress.

3.2 VELOCITY MEASUREMENTS

Since determining velocity at a number of points in a cross section permits evaluating the discharge, velocity measurement is an important phase of measuring flow. Velocity can be found by measuring the time an identifiable particle takes to move a known distance. This is done whenever it is convenient or necessary. This technique has been developed to study flow in regions which are so small that the normal flow would be greatly disturbed and perhaps disappear if an instrument were introduced to measure the velocity. A transparent viewing region must be made available, and by means of a strong light and a powerful microscope the very minute impurities in the fluid can be photographed with a high-speed motion-picture camera. From such motion pictures the velocity of the particles, and therefore the velocity of the fluid in a small region, can be determined.

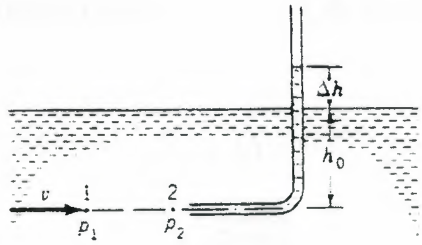

Fig 3.2 Simple Pitot Tube

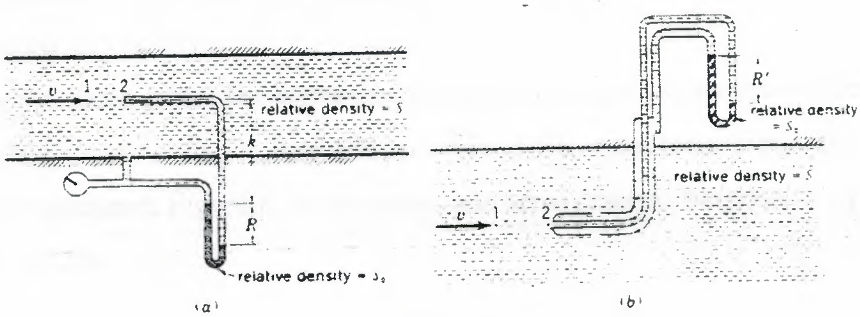

Fig 3.3 Velocity Measurements (a) Pitot tube and piezometer opening

(b) Pitot static tube

Normally, however, the device used does not measure velocity directly, but yields a measurable quantity that can be related to velocity. The pitot tube operates on such a principle and is one of the most accurate methods of measuring velocity. In Fig. 3.2 a glass tube or hypodermic needle with a right-angled bend is used to measure the velocity v in an open channel. The tube opening is directed upstream so that the fluid flows into the opening until the pressure builds up in the tube sufficiently to withstand the impact of velocity against it. Directly in front of the opening the fluid is at rest. The streamline through 1 leads to the point 2, called the *stagnation point,* where the fluid is at rest, and there divides and passes around the tube. The pressure at 2 is known from the liquid column within the tube. Bernoulli's equation, applied between points 1 and 2, produces

$$\frac{v^2}{2g} + \frac{p_1}{\gamma} = \frac{p_2}{\gamma} = h_0 + \Delta h$$

since both points are at the same elevation. As $p_1 / \gamma = h_0$ the equation reduces to

$$\frac{v^2}{2g} = \Delta h$$

or $$v = \sqrt{2g\Delta h}$$

Practically, it is very difficult to read the height Ah from a free surface.

The pitot tube measures the stagnation pressure, which is also referred to as the total pressure. The total pressure is composed of two parts, the static pressure h_0 and the dynamic pressure Δh, expressed in length of a column of the flowing fluid (Fig. 3.2). The dynamic pressure is related to velocity head.

By combining the static-pressure measurement and the total-pressure measurement, i.e., measuring each and connecting to opposite ends of a differential manometer, the dynamic pressure head is obtained. Figure 8.3a illustrates one arrangement. Bernoulli's equation applied from 1 to 2 is

$$\frac{v^2}{2g} + \frac{p_1}{\gamma} = \frac{p_2}{\gamma}$$

The equation for the manometer, in units of length of water, is

$$\frac{p_1}{\gamma} S + kS + R'S_0 - (k + R')S = \frac{p_2}{\gamma} S$$

for solving v

$$v = C\sqrt{2gR'\left(\frac{S_0}{S} - 1\right)}$$

The pitot tube is also insensitive to flow alignment, and an error of only a few percent occurs if the tube has a yaw misalignment of less than 15^0.
The static tube and pitot tube may be combined into one instrument, called a pitot-static tube (Fig. 3.3b). Analyzing this system in a manner similar to that in Fig. 8.3a shows that the same relations hold; last equation expresses the velocity, but the uncertainty in the measurement of static pressure requires a corrective coefficient C to be applied:

$$v = C\sqrt{2gR'\left(\frac{S_0}{S}-1\right)}$$

A particular form of pitot-static tube with a blunt nose, the Prandtl tube, has been so designed that the disturbances due to nose and leg cancel, leaving $C = 1$ in the equation. For other pitot-static tubes the constant C must be determined by calibration.

3.2.1 Velocity Measurement in Compressible Flow

The Pitot-static tube may be used for velocity determinations in compressible flow. In Fig. 3.3b the velocity reduction from free-stream velocity at 1 to zero at 2 takes place very rapidly without significant heat transfer. Friction plays a very small part, so that the compression may be assumed to be isentropic. With applying next equation between 1 and 2 with $V_2 = 0$ gives

$$\frac{V_1^2}{2} = c_p T_1\left[1-\left(\frac{p_1}{p_2}\right)^{(k-1)/k}\right]$$

The static pressure P_1 may be obtained from the side openings of the pitot tube, and the stagnation pressure may be obtained from the impact opening leading to a simple manometer, or $P_2 - P_1$ may be found from the differential manometer. If the tube is not so designed that true static pressure is measured, it must be calibrated and the true static pressure computed.
Gas velocities may be measured with A hot-*wire* anemometer, which works on the principle that the resistance to the flow of electricity through a fine platinum wire is a function of cooling due to gas flow around it. Cooled film sensors are also used for gas flow and have been adapted to liquid flow.

3.3 ORIFICES

A rate meter is a device that determines, generally by a single measurement, it quantity (weight or volume) per unit time that passes a given cross section. Included among rate meters are the orifice, nozzle, venturi meter, and weir. The orifice is discussed in this section; the venturi meter, nozzle, and some other closed-conduit devices are discussed in the next two section.

3.3.1 Orifice in a Reservoir

An orifice may be used for measuring the rate of flow out of a reservoir or through a pipe. An orifice in a reservoir or tank may be in the wall or in the bottom. It is opening, usually round, through which the fluid flows, as in Fig. 3.4. It may be square-edged, as shown, or rounded. The area of the orifice is it area of the opening. With the square-edged orifice, the fluid jet contracts during short distance of about one-half diameter downstream from the opening. The portion of the flow that approaches along the wall cannot make a right-angle turn at the opening and therefore maintains a radial velocity component the reduces the jet area. The cross section where the contraction is greatest is called the vena contracta. The streamlines are parallel throughout the jet at this section and the pressure is atmospheric.

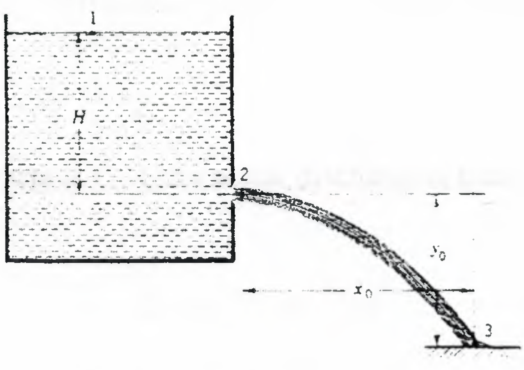

Fig 3.4 Orifier in a reservoir

The head H on the orifice is measured from the center of the orifice to the free surface. The head is assumed to be held constant. Bernoulli's equation applied from a point 1 on the free surface to the center of the vena contracta, point 2, with local atmospheric pressure as datum, neglecting losses, is written

$$\frac{V_1^2}{2g} + \frac{p_1}{\gamma} + z_1 = \frac{V_2^2}{2g} + \frac{p_2}{\gamma} + z_2$$

Inserting the values gives

$$0 + 0 + H = \frac{V_2^2}{2g} + 0 + 0$$

or

$$V_2 = \sqrt{2gH}$$

This is only the theoretical velocity, because the losses between the two points were neglected. The ratio of the actual velocity V_a to the theoretical velocity V_t is called the velocity coefficient *Cr;* that is,

$$C_v = \frac{V_a}{V_t}$$

Hence,

$$V_{2a} = C_v \sqrt{2gh}$$

The actual discharge Q_a from the orifice is the product of the actual velocity at the vena contracta and the area of the jet. The ratio of jet area A_2 at vena contracta to area of orifice A_0 is symbolized by another coefficient, called the coefficient of contraction C_c:

$$C_c = \frac{A_a}{A_0}$$

The area at the vena contracta is $C_c A_0$ the actual discharge is thus

$$Q_a = C_v C_c A_0 \sqrt{2gh}$$

It is customary to combine the two coefficients into a discharge coefficient C_d.

$$C_d = C_v C_c$$

then

$$Q_a = C_d A_0 \sqrt{2gH}$$

There is no way to compute the losses between points 1 and 2; hence, C_v be determined experimentally. It varies from 0.95 to 0.99 for the square-edge rounded orifice. For most orifices, such as the square-edged one, the amount contraction cannot be computed, and test results must be used. There are several methods for obtaining one or more of the coefficients. By measuring area A_0 head H, and the discharge Qa (by gravimetric or volumetric means), C_d is obtained from last equation. Determination of either C_c or C_v then permits determination the several methods follow.

3.3.2 LOSSES IN THE ORIFICE FLOW

The head loss in flow through an orifice is determined by applying the energy equation with a loss term for the distance between points 1 and 2 (Fig. 3.4.),

$$\frac{V_1^2}{2g} + \frac{p_1}{\gamma} z_1 = \frac{V_{2a}^2}{2g} + \frac{p_2}{\gamma} + z_2 + losses$$

Substituting the values for this case gives

$$Losses = H - \frac{V_{2a}^2}{2g} = H\left(1 - C_v^2\right) = \frac{V_{2a}^2}{2g}\left(\frac{1}{C_v^2} - 1\right)$$

3.3.3 ORIFICE IN A PIPE

The square-edged orifice in a pipe (Fig. 3.5) causes a contraction of the jet downstream from the orifice opening. For incompressible flow Bernoulli's equation applied from section 1 to the jet at its vena contracta, section 2, is

$$\frac{V_{1t}^2}{2g} + \frac{p_1}{\gamma} = \frac{V_{2t}^2}{2g} + \frac{p_2}{\gamma}$$

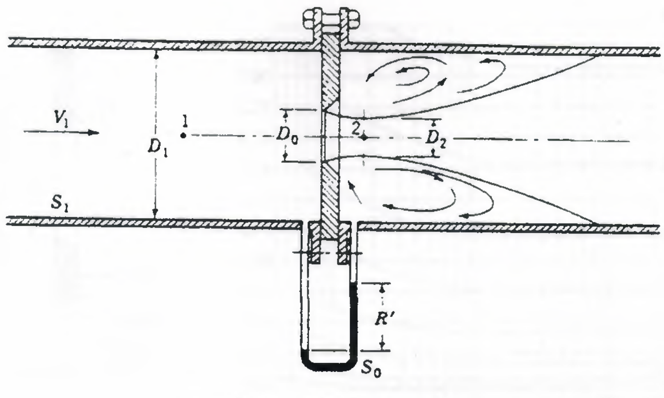

Fig 3.5 orifice in pipe

The continuity equation relates V_{1t} and V_{2t} with the contraction coefficient $C_c = A_2 / A_1$

And in which $C_d = C_v C_c$ .in term of the gage difference R' the equation become ;

$$Q = C_d A_0 \sqrt{\frac{2gR'(S_0 / S - 1)}{1 - C_c^{\,2}(D_0 / D_1)^4}}$$

Because of the difficulty in determining the two coefficients separately, a simplified formula is generally used,

$$Q = CA_0 \sqrt{2gR'\left(\frac{S_0}{S_1} - 1\right)}$$

where value of C is given in figures 3.6 for the VDI orificer.

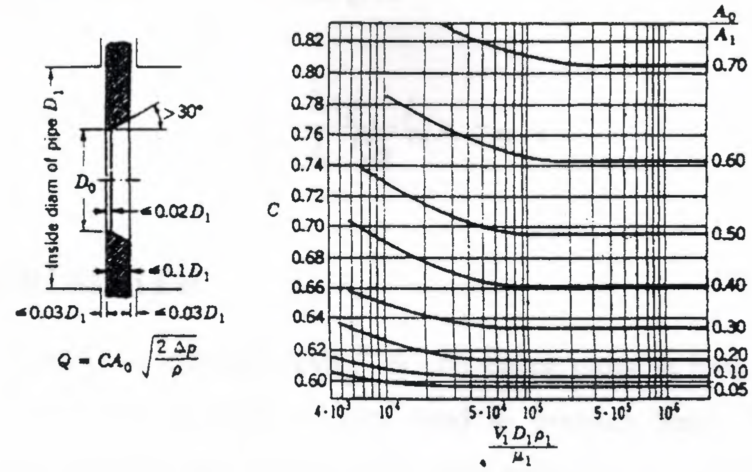

Fig 3.6 VDI Orifice And Discharge Coefficient

3.3.4 Unsteady Orifice Flow from Reservoirs

In the orifice situations considered, the liquid surface in the reservoir has been assumed to held constant. An unsteady-flow case of some practical interest is that of determining the time to lower the reservoir surface a given distance. Theoretically, Bernoulli's equation applies only to steady flow, but if the reservoir surface drops slowly enough, the error from using Bernoulli's equation is negligible.

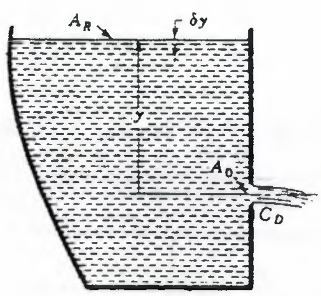

Fig 3.7 Notation for the falling head

The volume discharged from the orifice in time ∂t is $Q\partial t$. which must just equal the reduction in volume in the reservoir in the same time increment (Fig. 3.7), $A_r(-\partial y)$, in which A_R is the area of liquid surface at height y above

The orifice. Equating the two expressions give

$$t = \frac{2A_R}{C_d A_0 \sqrt{2g}}\left(\sqrt{y_1} - \sqrt{y_2}\right)$$

3.4 VENTURI METER

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 mav be combined to form a venturi tube.venturi meter was applied to measure the water by an amirican engineer in 1886.as shown in Fig 3.8 it consist of a tube with constricted throat, which produce 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 known as a venturi meter. The venturi meter is used measuring the rate of flow of both comprissible and incompressible

Writing the Bernoulli equation between section 1 and 2 of Fig 3.8 we have,

$$\frac{p_1}{\gamma} + z_1 + \frac{V_1^2}{2g} = \frac{p_2}{\gamma} + z_2 + \frac{V_2^2}{2g}$$

substituting the continuity equation $V_1 = (A_2 / A_1)V_2$ we get for the ideal throat velocity

$$V_{2i} = \sqrt{\frac{1}{1-(A_2/A_1)^2}}\sqrt{2g\left[\left(\frac{p_1}{\gamma} - z_1\right) - \left(\frac{p_2}{\gamma} + z_2\right)\right]}$$

As there is some friction loss between (1) and (2). The true velocity V_2 is slightly less than the ideal value given by this expression, Therefore we introduce a discharge coefficient ***C.*** so that the flow is given by CQ or

$$Q = A_2V_2 = CA_2V_{2_i} = \frac{CA_2}{\sqrt{1-(D_2-D_1)^4}} = \sqrt{2g\left[\left(\frac{p_1}{\gamma}+z_1\right)\right]-\left(\frac{p_2}{\gamma}+z_2\right)}$$

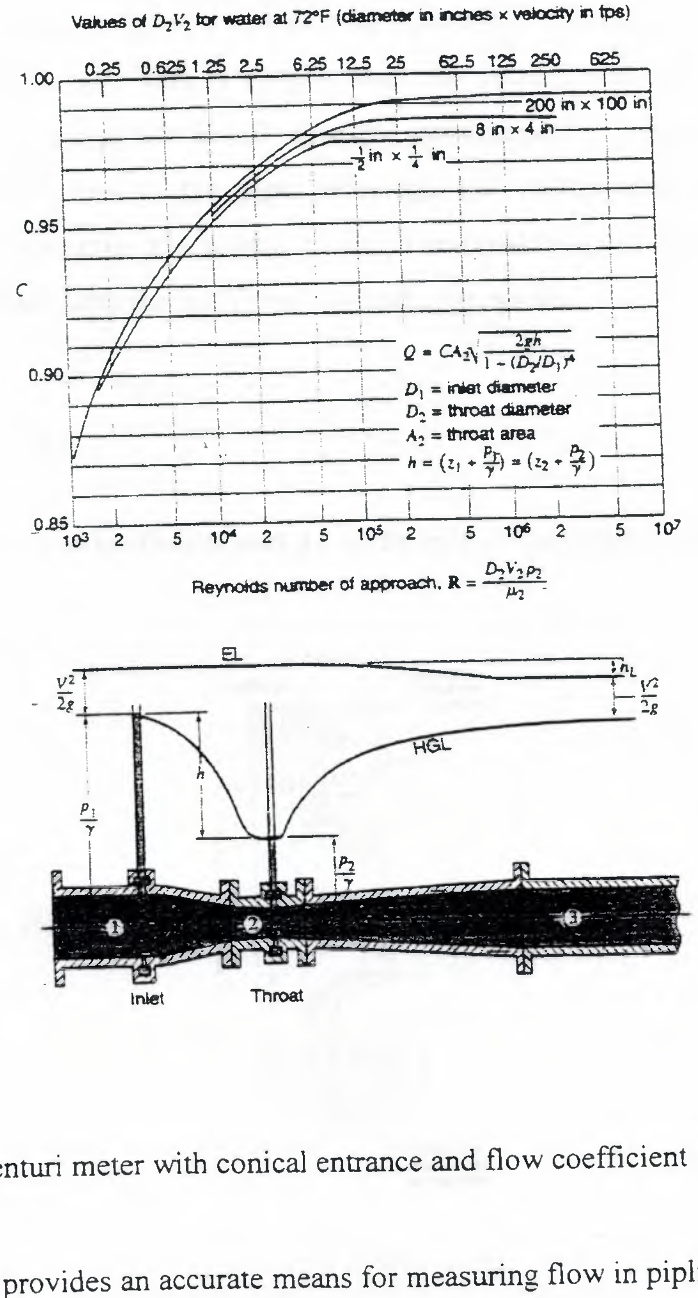

Fig 3.8 Venturi meter with conical entrance and flow coefficient $D_1 / D_2 = 0.5$

The venturi tube provides an accurate means for measuring flow in piplines. 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 venture meter is that it introduces a permanent frictional resistance in the pipeline. Practically all this loss occurs in the diverging part between sections (2) and (3).

3.5 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. 3.9. This is simpler than the venturi tube and can be installed between the flanges of a pipeline. It will serve the same purpose. Though at the expense of an increased frictional loss in the pipe. Although 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, so that

$$Q = KA_2\sqrt{2g\left[\left(\frac{p_1}{\gamma}+z_1\right)-\left(\frac{p_2}{\gamma}+z_2\right)\right]}$$

where $\boldsymbol{K}$ is called the flow coefficient and A_2 is the area of the nozzle throat.

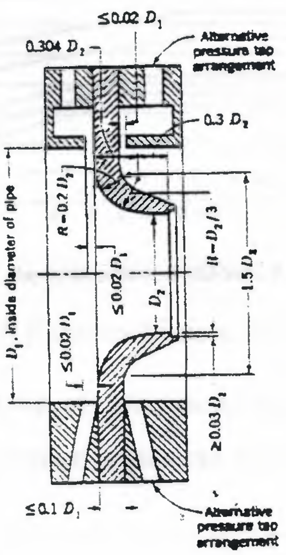

Fig 3.9 ISA Flow Nozzle

Although there are many designs of flow nozzles, the ISA (International Standards Association) nozzle (Fig. 3.9) has become an accepted standard form in many countries. The quoted 'nozzle diameter' is the throat diameter $\boldsymbol{D_2}$. Values of $\boldsymbol{K}$ for various diameter ratios of the ISA nozzle are given in Fig. 11.10 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 R in the pipe is frequently needed for other computations also.

As shown in Fig. 3.10, many of the values of K are greater than unitv, which results from 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 compensate for the discharge coefficient, leaving a value of the flow coefficient equal to unity. Principally using so-called long-radius nozzles. Usually such a coefficient of unity is approached over only a limited range.

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 arrangements for the pressure taps are shown in Fig. 3.9

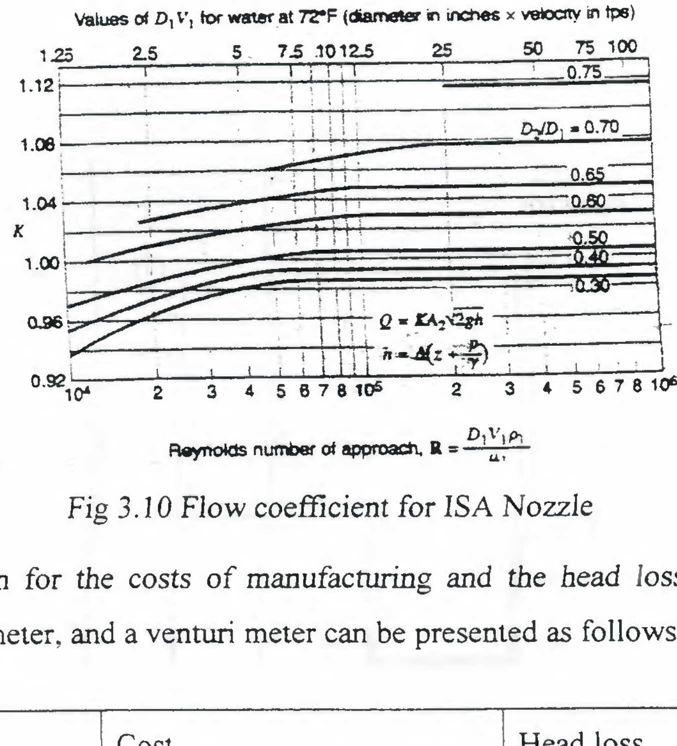

Fig 3.10 Flow coefficient for ISA Nozzle

A relative comparison for the costs of manufacturing and the head losses in an orifice meter, a nozzle flow meter, and a venturi meter can be presented as follows;

Flow meter	Cost	Head loss
Orifice meter	Low	High
Nozzle meter	Medium	Medium
Venturi meter	High	Low

NEAR EAST UNIVERSITY

Faculty of Engineering

Department of Mechanical Engineering

FLUID PROPERTIES MEASUREMENTS

Graduation Project
ME-400

Student: Mohamed BADER (970859)

Supervisor: Assit. Prof. Guner OZMEN

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TABE OF CONTENT

CHAPTER IV

COMMERCIALLY FLOW MEASURMENTS

CONCLUSION

REFRENCES

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SUMMARY

The measurements of fluid flow are important as an application ranging from measurements of blood flow rate in human artery to the measurements of the flow of liquid oxygen in rockets. For this reason our main aim of this thesis is to define and analyze the fluid properties measurements, which are classified as follows;

- Pressure measurements
- Velocity measurements
- Orifices

In first chapter we are going to analyze the importance of the fluid measurements and it is classification. In second chapter we are going to explain the theoretical background of the flow Kinematics, Bernoulli's and quntinuaty equations on which fluid flow measurements based. The third chapter concern with flow measurements devices and their working principles. Commercially flow measuring devices, which are going to explain in the fourth chapter.

NOMENCLATURE

A	area (m^2/s)
C_c	contraction coefficient
C_d	drag coefficient
C_v	velocity coefficient
F	force (N)
F_f	frictional force (N)
g	gravitational acceleration (m/s^2)
h	head (m)
h_f	frictional head (m)
h_t	total head (m)
m	mass (kg)
P	pressure (Pa)
Q	volumetric flow rate (m^3/s)
Re	Reynolds number
T	time (s)
U	velocity on the x direction (m/s)
μ	absolute viscosity (m^2/s)
τ	shear stress (Pa)
ρ	mass density (kg/m^3)
γ	specific weight $kg/m.s^2$

CHAPTER 1

INTRODUCTION

The first section of this chapter explains the definition of measurement and its scientific meaning and its general functions in engineering. The second section is a statement about the importance of fluid measurements in engineering fields. Some important definitions are introduced in the third section. The third section also contains a classification of fluid that is important to determine the special cases of fluid properties. So that by assuming those cases, simplifications can be made to describe the fluid properties with reasonable approximations.

1.1 MEASUREMENTS

Measurement has been of great importance to human civilization and a factor that daily and necessarily contributes the life of mankind. Moreover, not only being a mean of quantifying but also the first step in any scientific experiment or observation that composes the basis of the theoretical work. This is because of the fact that laboratory work is mainly based on the good and successful performance of the measurement process. On other words, good design of measurement techniques and a good measuring procedure leads to accurate data and experimental observations, and thus correct decisions about the physical events.

In engineering areas measurement is one of the basic stages of any engineering work, design and inventions to be accomplished. In fact, measurement is a major principle for engineering to Perform successful primary experimental decisions and gaining practical properties of materials and substances

- Achieve good observations of the engineering processes and cycles
- Be able to control the performance of the working machines and engineering systems
- Make suitable predictions for the development of the concerned engineering work
- Help in the invention of a proper design to carry out specific tasks
- Compose reference researches and tabulated data, figures arid charts

It is necessary to say that. no absolute measurement is possible. That is, in any measurement process there will be always errors, deviations, estimations and measuring device calibrations. This is because of the environmental conditions associating the process and a lot of practically unavoidable factors restrict obtaining the absolute results. Consequently, only 'enough' measured data is always desired.

1.2 FLUID MEASUREMENTS

Fluids have great functions in many engineering fields, especially for mechanical engineers. In fact, a mechanical engineer must have a good knowledge of fluids properties and behavior because

- Fluids are involved as the working substances for many of mechanical machineries such as, power engines, turbines and combustion engines
- Also fluids in many engineering areas are considered to be the engineering systems themselves (as in hydraulic Systems and aircraft industries)
- They can be the substances that are to be handled by mechanical systems (e.g. pumps, piping constructions, pipelines, nozzles and diffusers, valves, etc.)

As a result, it is of great importance to observe their behavior and detect their properties by the mean of suitable measuring devices with the desired accuracy.

1.3 BASIC DEFINITIONS

A fluid can be defined as a substance that deforms continuously under the application shear stress no matter how small that shear stress may be. As this project is concerned of flow measurements and fluid flow properties, it is convenient to introduce a classification that can be made among fluid in order to simplify the analyses of the measuring devices.

The types of fluid properties can be classified as follows:

PRESSURE

Since pressure is a very important characteristic of a fluid field, it is not surprising that numerous devices and techniques are used in its measurement. As we know the pressure at a point within a fluid mass will he designated as either an *absolute* pressure or a *cage* pressure. Absolute pressure is measured relative to a perfect vacuum (absolute zero Pressure). Whereas gage pressure is measured relative to the local atmospheric pressure. Thus, a gage pressure of zero corresponds to a pressure that is equal to the local atmospheric pressure. Absolute pressures are always positive, but gage pressures can he either positive or negative depending on whether the pressure is above atmospheric pressure (a positive value) or below atmospheric pressure (a negative value). A negative gage pressure is also referred to as a suction or vacuum pressure.

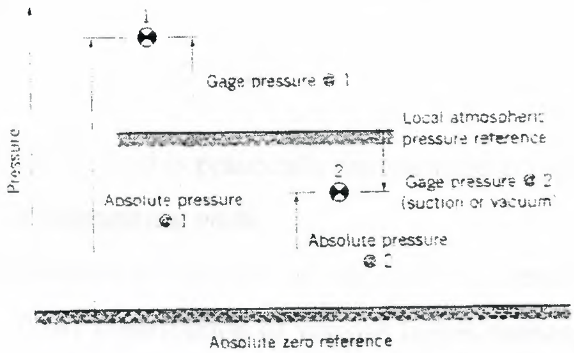

Fig 1.1 Various ways to represent pressure

In addition to the reference used for the pressure measurement. The units used to express the value are obviously of importance. Pressure is a force per unit area. . In the SI system the units are N/m^2; this combination is called the Pascal and written as Pa (1 N/m Pa).

$$P = \frac{F}{A} \quad \text{(N/m)}$$

VISCOS AND INVISCID FLOWS

Viscosity is that property of a fluid by virtue of which it resistance to shear or to angular deformations. Sir Isaac Newton (1642-1727) showed that the rate of angular deformation of certain fluids (like air, water, gasoline, etc.) is proportional to the shearing stress τ. The constant of proportionality is called a absolute or dynamic viscosity and is designated by μ. Viscosity is one of the most important fluid properties encountered in the study of fluid mechanics.

The defining equation for dynamic or absolute viscosity is

$$\tau = \mu \frac{du}{dy} \quad \text{where;}$$

τ : shear stress between fluid layers in laminar flow n/m^2

μ : dynamic viscosity, $N.s/m^2$

du/dy : normal velocity gradient

In many problem involving viscosity the viscosity is divided by density, this ratio defines the kinematics viscosity v, so called because forces is not involved ,the only dimension being length and time.

$$v = \frac{\mu}{\rho} \quad (m^2/s)$$

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

Thus, flow in which the effect of viscosity is negligible is termed to be inviscid flows. On other hand, in various flows contribution of viscous forces cannot be avoided so the flow is said to be viscous flow

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.

1.4 CONCLUSION

It is important that engineer to able to perform successful experimental, and it equally important that they know or able to estimate the accuracy of their measurements. this chapter explained the importance of fluid measurements in our life. Some of the classifications of the fluid were explained like laminar and turbulent flow, viscous and invisid flow, external and internal, pressure of the fluid and etc,

CHAPTER II

THEORETICAL BACKGROUND

This chapter defines and explains the theoretical concepts on which the measurements of fluid flow are based. In flow properties measurements there are two important equations that are used to analyze the working principles of the measuring devise. Those equations are named the Bernoulli equation and continuity equation. The two equations are discussed in the second and third sections whereas the first section is brief review of the important quantities in fluid kinematics

2.1 REVIEW OF FLOW KINEMATICS

.

A fluid system refers to a specific mass of fluid within the boundaries that are defined by a closed surface. The closed surface, and hence the fluid system, is chosen according to the type of the flow and the fluids properties to make the analytical solution as simple as possible. According to the definition of tie fluid system the mass it contains cannot be changed But the shape of tile system as well as the boundaries can be changed with time if the fluid is a liquid that flows through a constriction or when the fluid is a compressible gas In contrast, a control volume refers to a fixed region in space that does not move or change its shape Because the mass of fluid that is contained in the control volume can change with time, thus using the control volume to analyze fluid flows is more suitable.

As the motion of a fluid is concerned, determination of flow velocity is important together with its variation in the flow field. Accordingly, the flow may be termed to be two-dimensional or three-dimensional regarding the velocity components that may result. Moreover, fluid is said to be steady when conditions do not vary with time or when variations are small with respect to mean flow values. In contrast, if the flow properties do change with time the flow it becomes unsteady flow.

A streamline is a continuous line drawn through the fluid so that it has the direction of the velocity vector at every point. There can be no flow across a streamline. In steady flow, since there is no change in direction of the velocity vector at any point, the streamline has fixed inclinations at every point and is, therefore, *fixed in space*. A particle always moves tangent to the streamline; hence, in steady flow the path of a particle is a streamline. In unsteady flow, since the direction of the velocity vector at any point may change with time, a streamline may shift in space from instant to instant. A particle then follows one streamline one instant, another one the next instant, and so on, so that the path of the particle may have no resemblance to any given instantaneous streamline.

To simplify the study of fluid flow it is convenient to assume a fluid system or a control volume, draw the necessary streamlines and to determine the type of the flow as being steady, unsteady, compressible or incompressible etc

The quantity of fluid flowing per unit time across any section of the stream is called the flow rate So in dealing with compressible fluids, the mass flow rate is commonly used, whereas the volumetric flow rate is used for incompressible fluids. It is also possible to define an average velocity, which is based on the mass flow rate in compressible flows, and on the volumetric flow rate in the case of incompressible flows.

2.2 MASS FLOW RATE

The mass flow rate represents the amount of mass of the flowing fluid that passes across a considered section on the stream per unit time or mathematically;

$$m = \int_A \rho.\vec{V}.\vec{n}\,3dA$$

Where m = mass flow rate in (Kg/s)

$\vec{V}$ = Velocity vector

ρ = the mass density of the fluid

$\vec{n}$ = normal unit vector to the assumed control

If the control surface is chosen to be perpendicular to the flow direction the dot product reduces to simply the magnitude of the velocity Furthermore if the flow is incompressible (i.e. fluid density is constant and uniform over the control volume's area)

And steady conditions are assumed the mass flow rate equation reduces to

$m = \rho A V$ where A is the cross sectional area of the flow

2.3 VOLUMETRIC FLOW RATE

For an incompressible fluid both sides of the derived mass flow equation may be divided by the constant density to result the volumetric flow rate.

$$Q = \frac{m}{\rho} = \int_A \vec{V} . \vec{n} \, dA$$

For a uniform and normal flow out through a control surface the equation reduces to

$$Q = V . A \quad (m^3/s)$$

Here area A being normal to the flow direction since the velocity does not change over this control surface.

2.4 THE AVARAGE VELOCITY

If the velocity is not uniform over a cross section of the stream then an average velocity is used to calculate the flow rate of that flow, it may expressed as:

$$\bar{V} = \frac{Q}{A} = \frac{1}{A} \int_A \vec{V} . \vec{n} . dA$$

2.5 THE CONTINUTY EQUATION

The application of principle of conservation of mass to a fluid flow yields an equation, which referred to as continuity equation. Which state that the time rate of change of the mass of the system is zero. If we consider steady flow through a portion of the stream tube of Fig 2.1.the control volume comprises the wall of the stream tube between sections 1 and 2,plus the end areas of sections 1 and 2.Because the flow is steady,

$$\int_{cs} \rho v . dA = 0$$

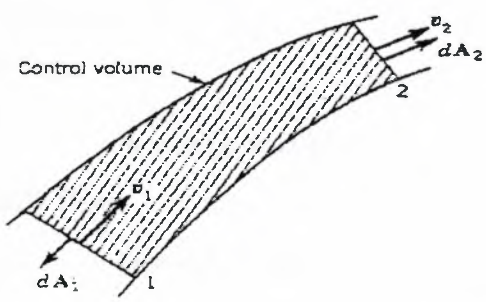

Fig 2.1 Steady flow through a stream tube.

Which states that the net mass flow rate outflow from the control volume must be zero.at section 1 the net mass outflow is $\rho_1 v_1 .dA_1 = -\rho_1 v_1 dA_1$, and at section 2 it is $\rho_2 v_2 .dA_2 = \rho_2 v_2 dA_2$ .since there is no flow through the wall of the stream tube,]

$$\rho_1 v_1 .dA_1 = \rho_2 v_2 dA_2$$

Is the continuity equation applied to two sections along a stream tube in steady flow.

For collection of stream tubes as in Fig2.2, if the ρ_1 are the average density at section 1 and ρ_2 the average density at section 2 then,

$$m = \rho_1 v_1 .A_1 = \rho_2 v_2 A_2$$

In which V_1, V_2 represent average velocities over the cross sections and m is the rate of mass flow. The average velocities over a cross section is given by

$$V = \frac{1}{A}\int v dA$$

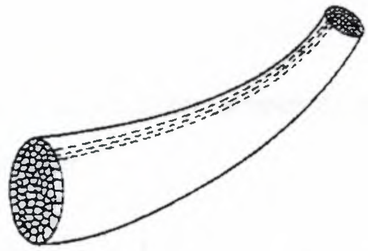

Fig 2.2 collection of stream tubes between fixed boundaries

If the discharge Q is defined as Q = V.A

The continuity takes the form

$$m = \rho_1 Q_1 = \rho_2 Q_2$$

For incompressible, steady flow

$$Q = A_1 V_1 = A_2 V_2$$

2.6 THE BERNNOULLI EQUATION

The Bernoulli equation gives a relation ship between pressure, velocity and position in a flow field. Normally these properties vary considerably in the flow. So by the formulation of the conservation of energy principle on an infinitesimal control volume for the fluid and by the help of Newton's second law of motion the Bernoulli's equation can be expressed for streamlines as following:

$$gz + \frac{v^2}{2} + \frac{p}{\rho} = const$$

This general formation varies from one-stream lines to another but remain constant along a streamline in steady, frictionless and incompressible flow. These four assumption are needed and must be kept in mind when applying this equation. Each term has the dimensions (L/T^2) or m^2/s^2.

For a streamline within flow , the Bernoulli equation is written as

$$\frac{V_1^2}{2}+\frac{p_1}{\rho g}+gz_1=\frac{V_2^2}{2}+\frac{p_2}{\rho}+z_2$$

Where the subscribes 1 and 2 indicates the properties at two points on the stream dividing by g the gravitational acceleration

$$\frac{V^2}{2g}+\frac{p_1}{\rho g}+z_1=\frac{V_2^2}{2g}+\frac{p_2}{\rho g}+z_2$$

Each of the above terms represents the work per unit weight 'i.e each term represents the head' and thus has the dimension of length. The fore the quantities in the equation are named as the velocity head, pressure head and gravitational head. Moreover if there exists non-conservative forces in the flow field and resulting in 'head losses', those losses represent the work done by the no conservative forces against the flow And by including them in the Bernoulli's equation yields an extended version of it. Similarly, if any external work is done on the flow its contribution should be considered in the equation accordingly, an external work may be the work done by a pump for example. The extended Bernoulli equation is;

$$\frac{V^2{}_1}{2g}+\frac{p_1}{\rho g}+z_1-h_f+h_s=\frac{V_2^2}{2g}+\frac{p_2}{\rho g}+z_2$$

Where

h_s : Head gained by the external work

h_f : Head loss due to non-conservative forces

Modification of assumption underlying Bernoulli's Equation

Under special condition each assumption of the four underlying **Bernoulli's** Equation may be waived

1. When all streamlines originate from a reservoir, where the energy content is everywhere the same, the constant of integration does not change from one streamline to another

and points 1 and 2 for application of Bernoulli's equation may be selected arbitrarily, i.e., not necessarily on the same streamline.

2. In the flow of a gas, as in a ventilation system, where the change in pressure is only a small fraction (a few percent) of the absolute pressure, the gas may be considered incompressible. Equation may be applied, with an average unit gravity force γ.
3. For unsteady flow with gradually changing conditions, e.g., emptying a reservoir, Bernoulli's equation may be applied without appreciable error.
4. Bernoulli's equation is of use in analyzing real-fluid cases by first neglecting viscous shear to obtain theoretical results. The resulting equation may then be modified by a coefficient, determined by experiment, which corrects the theoretical equation so that it conforms to the actual physical case. In general, losses are handled by use of the energy equation developed by steady-state energy equation.

The following examples are introduced to make the previous derived equation more clear and to show how can a flow property be calculated by their means.

EXAMPLE 1

An incompressible and inviscid fluid is flowing through a horizontal converging duct. The area at the inlet and the exit of the duct are known. If the pressure at the exit of the duct is 100 kPa, determine the pressure at the inlet of the duct in order to produce an exit velocity of 50 m/s.

SOLUTION

The cross sectional areas of the converging conduit, arid the fluid density are given as;

$$A_1 = 0.1 m^2 \qquad \rho = 1000 kg/m^3$$

$$A_2 = 0.02 m^2$$

For the steady flow of an incompressible fluid with exit of the converging duct, the continuity equation is

$$V_1 A_1 = V_2 A_2$$

So that the velocity at the inlet of the duct is

$$V_1 = \frac{V_2 A_2}{V_2} = \frac{(50m/s)\times(0.02m^2)}{0.1m^2} = 10m/s$$

As long as the steady flow of an incompressible and inviscid fluid in a horizontal plane is considered, then the changes in elevation may be neglected. Therefore the Bernoulli's equation between two points on a streamline in the direction of the flow

$$\frac{p_2}{\rho} + \frac{V_2^{\ 2}}{2} = \frac{p_1}{\rho} + \frac{V_1^{\ 2}}{2}$$

$$p_1 = p_2 + \frac{\rho}{2}\left(V_2^{\ 2} - V_1^{\ 2}\right)$$

$$P_1 = 100000N/m^2 + \frac{1000kg/m^3}{2}\left[(50m/s)^2 - (10m/s)^2\right]$$

$$= 1300 \text{ kPa}$$

2.7 CONCLUSION

In this chapter the definition of the mass flow rate and the volumetric flow rate were represented with their mathematical equation, in addition, two important equation were derived from the conservation of the mass and conservation of energy those two useful formulas are named as the continuity and Bernoulli's equation respectively. And by their mean we can calculate the flow velocity and flow rates of a fluid be considering a streamline in the direction of the flow.

CHAPTER III

FLOW MEASURMENTS

In this chapter the working principles of the simple and the most commonly used devices for the measurement of the flow properties are analyzed. Furthermore, according to the flow property they measure, the devices are classified to flow velocity measuring devices and flow rate measuring devices. So mathematical formulations are derived for each device separately to obtain the flow proprieties and by considering the sources of errors and the assumption made the measurements are obtained as accurate as possible.

3.1 PRESSURE MEASUREMENT

The measurement of pressure is required in many devices that determine the velocity of a fluid stream or its rate of flow, because of the relation between velocity and pressure given by the energy equation. The static pressure of a fluid in motion is its pressure when the velocity is undisturbed by the measurement.

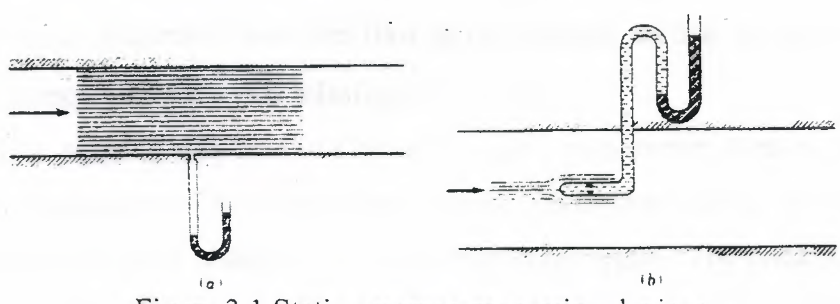

Figure 3.1 Static pressure-measuring devices
(a) Piezometer opening
(b) Static tube

Figure 3.1a indicates one method of measuring static pressure, the piezometer opening. When the flow is parallel, as indicated, the pressure variation is hydrostatic normal to the streamlines; hence, by measuring the pressure at the wall, the pressure at any other point in the cross section can be determined. The piezometer opening should be small, with length of opening at least twice the diameter, and should be normal to the surface, with no burrs at its edges, because small eddies would form and distort the measurement. A small amount of rounding of the opening is permissible. Any slight misalignment or roughness at the opening may cause errors in measurement; therefore, it is advisable to use several piezometer openings connected together into a piezometer ring. When the surface is rough in the vicinity of the opening, the reading is unreliable. For small irregularities it may be possible to smooth the surface around the opening. For rough surfaces, the *static* tube (Fig. 3.1b) may be used. It consists of a tube that is directed upstream with the end closed. It has radial holes in the cylindrical portion downstream from the nose. The flow is presumed to be moving by the openings as if it were undisturbed. There are disturbances, however, due to both the nose and the right-angled leg that is normal to the flow. The static tube should be calibrated, as it may read too high or too low. If it does not read true static pressure, the discrepancy Δh normally varies as the square of the velocity of flow by the tube;

$$\Delta h = C\frac{v^2}{2g}$$

In which C is determined by towing the tube in still fluid where pressure and velocity are known or by inserting it into a smooth pipe that contains a piezometer ring.

Such tubes are relatively insensitive to the Reynolds number and to Mach numbers below unity. Their alignment with the flow is not critical, so that an error of but a few percent is to be expected for a yaw misalignment of $15''$.

The piezometric opening may lead to a bourdon gage a manometer, a micro manometer, or an electronic transducer. The transducers depend upon very small deformations of a diaphragm due to pressure change to create an electronic signal. The principle may be that of a strain gage and a Wheatstone bridge circuit, or it may rely on motion in a differential transformer, a capacitance chamber, or the piezoelectric behavior of a crystal under stress.

3.2 VELOCITY MEASUREMENTS

Since determining velocity at a number of points in a cross section permits evaluating the discharge, velocity measurement is an important phase of measuring flow. Velocity can be found by measuring the time an identifiable particle takes to move a known distance. This is done whenever it is convenient or necessary. This technique has been developed to study flow in regions which are so small that the normal flow would be greatly disturbed and perhaps disappear if an instrument were introduced to measure the velocity. A transparent viewing region must be made available, and by means of a strong light and a powerful microscope the very minute impurities in the fluid can be photographed with a high-speed motion-picture camera. From such motion pictures the velocity of the particles, and therefore the velocity of the fluid in a small region, can be determined.

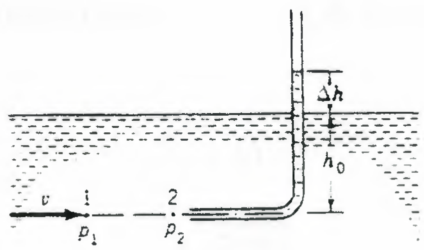

Fig 3.2 Simple Pitot Tube

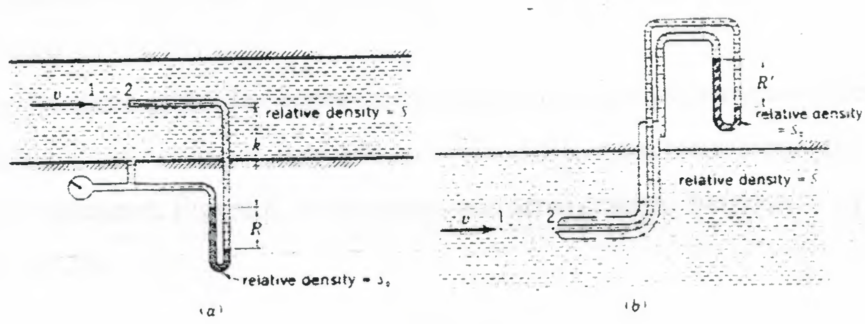

Fig 3.3 Velocity Measurements (a) Pitot tube and piezometer opening

(b) Pitot static tube

Normally, however, the device used does not measure velocity directly, but yields a measurable quantity that can be related to velocity. The pitot tube operates on such a principle and is one of the most accurate methods of measuring velocity. In Fig. 3.2 a glass tube or hypodermic needle with a right-angled bend is used to measure the velocity v in an open channel. The tube opening is directed upstream so that the fluid flows into the opening until the pressure builds up in the tube sufficiently to withstand the impact of velocity against it. Directly in front of the opening the fluid is at rest. The streamline through 1 leads to the point 2, called the *stagnation point,* where the fluid is at rest, and there divides and passes around the tube. The pressure at 2 is known from the liquid column within the tube. Bernoulli's equation, applied between points 1 and 2, produces

$$\frac{v^2}{2g}+\frac{p_1}{\gamma}=\frac{p_2}{\gamma}=h_0+\Delta h$$

since both points are at the same elevation. As $p_1/\gamma = h_0$ the equation reduces to

$$\frac{v^2}{2g}=\Delta h$$

or $$v=\sqrt{2g\Delta h}$$

Practically, it is very difficult to read the height Ah from a free surface.

The pitot tube measures the stagnation pressure, which is also referred to as the total pressure. The total pressure is composed of two parts, the static pressure h_0 and the dynamic pressure Δh, expressed in length of a column of the flowing fluid (Fig. 3.2). The dynamic pressure is related to velocity head.

By combining the static-pressure measurement and the total-pressure measurement, i.e., measuring each and connecting to opposite ends of a differential manometer, the dynamic pressure head is obtained. Figure 8.3a illustrates one arrangement. Bernoulli's equation applied from 1 to 2 is

$$\frac{v^2}{2g}+\frac{p_1}{\gamma}=\frac{p_2}{\gamma}$$

The equation for the manometer, in units of length of water, is

$$\frac{p_1}{\gamma}S+kS+R'S_0-(k+R')S=\frac{p_2}{\gamma}S$$

for solving v

$$v=C\sqrt{2gR'\left(\frac{S_0}{S}-1\right)}$$

The pitot tube is also insensitive to flow alignment, and an error of only a few percent occurs if the tube has a yaw misalignment of less than 15^0.

The static tube and pitot tube may be combined into one instrument, called a pitot-static tube (Fig. 3.3b). Analyzing this system in a manner similar to that in Fig. 8.3a shows that the same relations hold; last equation expresses the velocity, but the uncertainty in the measurement of static pressure requires a corrective coefficient C to be applied:

$$v = C\sqrt{2gR'\left(\frac{S_0}{S} - 1\right)}$$

A particular form of pitot-static tube with a blunt nose, the Prandtl tube, has been so designed that the disturbances due to nose and leg cancel, leaving $C = 1$ in the equation. For other pitot-static tubes the constant C must be determined by calibration.

3.2.1 Velocity Measurement in Compressible Flow

The Pitot-static tube may be used for velocity determinations in compressible flow. In Fig. 3.3b the velocity reduction from free-stream velocity at 1 to zero at 2 takes place very rapidly without significant heat transfer. Friction plays a very small part, so that the compression may be assumed to be isentropic. With applying next equation between 1 and 2 with $V_2 = 0$ gives

$$\frac{V_1^2}{2} = c_p T_1 \left[1 - \left(\frac{p_1}{p_2}\right)^{(k-1)/k}\right]$$

The static pressure P_1 may be obtained from the side openings of the pitot tube, and the stagnation pressure may be obtained from the impact opening leading to a simple manometer, or $P_2 - P_1$ may be found from the differential manometer. If the tube is not so designed that true static pressure is measured, it must be calibrated and the true static pressure computed.

Gas velocities may be measured with A hot-*wire* anemometer, which works on the principle that the resistance to the flow of electricity through a fine platinum wire is a function of cooling due to gas flow around it. Cooled film sensors are also used for gas flow and have been adapted to liquid flow.

3.3 ORIFICES

A rate meter is a device that determines, generally by a single measurement, it quantity (weight or volume) per unit time that passes a given cross section. Included among rate meters are the orifice, nozzle, venturi meter, and weir. The orifice is discussed in this section; the venturi meter, nozzle, and some other closed-conduit devices are discussed in the next two section.

3.3.1 Orifice in a Reservoir

An orifice may be used for measuring the rate of flow out of a reservoir or through a pipe. An orifice in a reservoir or tank may be in the wall or in the bottom. It is opening, usually round, through which the fluid flows, as in Fig. 3.4. It may be square-edged, as shown, or rounded. The area of the orifice is it area of the opening. With the square-edged orifice, the fluid jet contracts during short distance of about one-half diameter downstream from the opening. The portion of the flow that approaches along the wall cannot make a right-angle turn at the opening and therefore maintains a radial velocity component the reduces the jet area. The cross section where the contraction is greatest is called the vena contracta. The streamlines are parallel throughout the jet at this section and the pressure is atmospheric.

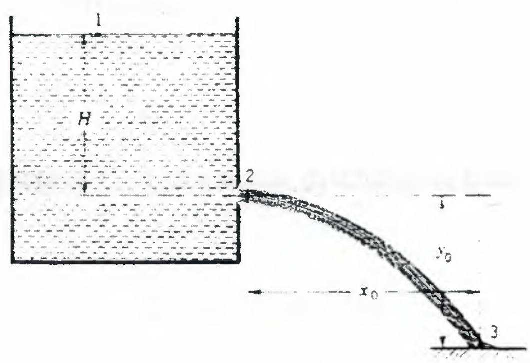

Fig 3.4 Orifier in a reservoir

The head H on the orifice is measured from the center of the orifice to the free surface. The head is assumed to be held constant. Bernoulli's equation applied from a point 1 on the free surface to the center of the vena contracta, point 2, with local atmospheric pressure as datum, neglecting losses, is written

$$\frac{V_1^2}{2g} + \frac{p_1}{\gamma} + z_1 = \frac{V_2^2}{2g} + \frac{p_2}{\gamma} + z_2$$

Inserting the values gives

$$0 + 0 + H = \frac{V_2^2}{2g} + 0 + 0$$

or $$V_2 = \sqrt{2gH}$$

This is only the theoretical velocity, because the losses between the two points were neglected. The ratio of the actual velocity V_a to the theoretical velocity V_t is called the velocity coefficient *Cr;* that is,

$$C_v = \frac{V_a}{V_t}$$

Hence, $$V_{2a} = C_v \sqrt{2gh}$$

The actual discharge Q_a from the orifice is the product of the actual velocity at the vena contracta and the area of the jet. The ratio of jet area A_2 at vena contracta to area of orifice A_0 is symbolized by another coefficient, called the coefficient of contraction C_c:

$$C_c = \frac{A_a}{A_0}$$

The area at the vena contracta is $C_c A_0$ the actual discharge is thus

$$Q_a = C_v C_c A_0 \sqrt{2gh}$$

It is customary to combine the two coefficients into a discharge coefficient C_d.

$$C_d = C_v C_c$$

then $$Q_a = C_d A_0 \sqrt{2gH}$$

There is no way to compute the losses between points 1 and 2; hence, C_v be determined experimentally. It varies from 0.95 to 0.99 for the square-edge rounded orifice. For most orifices, such as the square-edged one, the amount contraction cannot be computed, and test results must be used. There are several methods for obtaining one or more of the coefficients. By measuring area A_0 head H, and the discharge Qa (by gravimetric or volumetric means), C_d is obtained from last equation. Determination of either C_c or C_v then permits determination the several methods follow.

3.3.2 LOSSES IN THE ORIFICE FLOW

The head loss in flow through an orifice is determined by applying the energy equation with a loss term for the distance between points 1 and 2 (Fig. 3.4.),

$$\frac{V_1^2}{2g} + \frac{p_1}{\gamma} z_1 = \frac{V_{2a}^2}{2g} + \frac{p_2}{\gamma} + z_2 + losses$$

Substituting the values for this case gives

$$Losses = H - \frac{V_{2a}^2}{2g} = H(1 - C_v^2) = \frac{V_{2a}^2}{2g}\left(\frac{1}{C_v^2} - 1\right)$$

3.3.3 ORIFICE IN A PIPE

The square-edged orifice in a pipe (Fig. 3.5) causes a contraction of the jet downstream from the orifice opening. For incompressible flow Bernoulli's equation applied from section 1 to the jet at its vena contracta, section 2, is

$$\frac{V_{1t}^2}{2g} + \frac{p_1}{\gamma} = \frac{V_{2t}^2}{2g} + \frac{p_2}{\gamma}$$

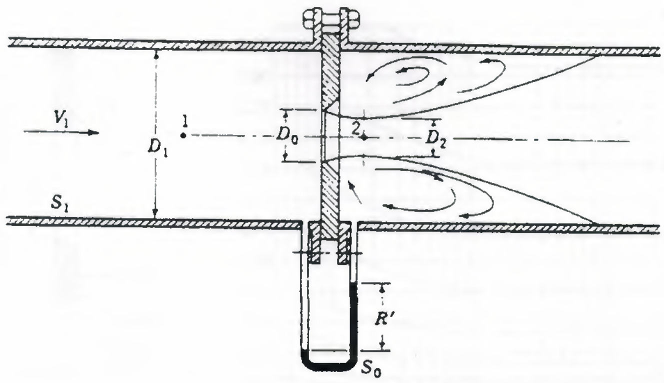

Fig 3.5 orifice in pipe

The continuity equation relates V_{1t} and V_{2t} with the contraction coefficient $C_c = A_2 / A_1$

And in which $C_d = C_v C_c$ .in term of the gage difference R' the equation become ;

$$Q = C_d A_0 \sqrt{\frac{2gR'(S_0 / S - 1)}{1 - C_c^{\,2}(D_0 / D_1)^4}}$$

Because of the difficulty in determining the two coefficients separately, a simplified formula is generally used,

$$Q = CA_0 \sqrt{2gR'\left(\frac{S_0}{S_1} - 1\right)}$$

where value of C is given in figures 3.6 for the VDI orificer.

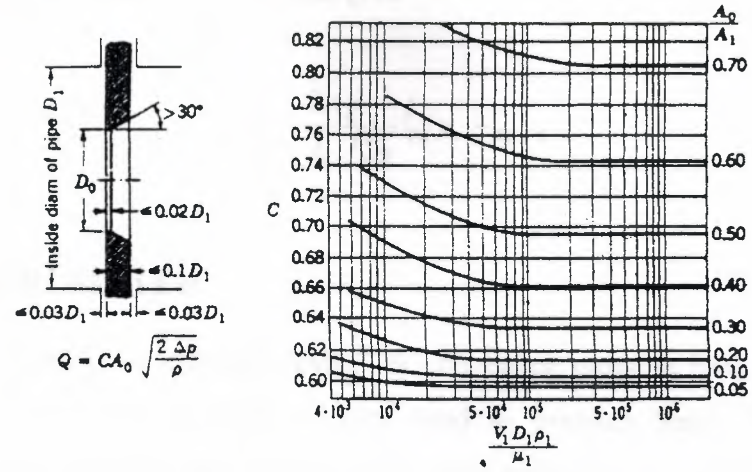

Fig 3.6 VDI Orifice And Discharge Coefficient

3.3.4 Unsteady Orifice Flow from Reservoirs

In the orifice situations considered, the liquid surface in the reservoir has been assumed to held constant. An unsteady-flow case of some practical interest is that of determining the time to lower the reservoir surface a given distance. Theoretically, Bernoulli's equation applies only to steady flow, but if the reservoir surface drops slowly enough, the error from using Bernoulli's equation is negligible.

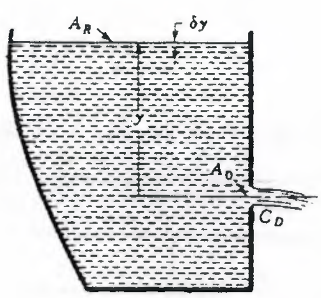

Fig 3.7 Notation for the falling head

The volume discharged from the orifice in time ∂t is $Q\partial t$. which must just equal the reduction in volume in the reservoir in the same time increment (Fig. 3.7), $A_r(-\partial y)$, in which A_R is the area of liquid surface at height y above

The orifice. Equating the two expressions give

$$t = \frac{2A_R}{C_d A_0 \sqrt{2g}}\left(\sqrt{y_1} - \sqrt{y_2}\right)$$

3.4 VENTURI METER

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 mav be combined to form a venturi tube.venturi meter was applied to measure the water by an amirican engineer in 1886.as shown in Fig 3.8 it consist of a tube with constricted throat, which produce 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 known as a venturi meter. The venturi meter is used measuring the rate of flow of both comprissible and incompressible

Writing the Bernoulli equation between section 1 and 2 of Fig 3.8 we have,

$$\frac{p_1}{\gamma} + z_1 + \frac{V_1^2}{2g} = \frac{p_2}{\gamma} + z_2 + \frac{V_2^2}{2g}$$

substituting the continuity equation $V_1 = (A_2 / A_1)V_2$ we get for the ideal throat velocity

$$V_{2i} = \sqrt{\frac{1}{1-(A_2/A_1)^2}}\sqrt{2g\left[\left(\frac{p_1}{\gamma} - z_1\right) - \left(\frac{p_2}{\gamma} + z_2\right)\right]}$$

As there is some friction loss between (1) and (2). The true velocity V_2 is slightly less than the ideal value given by this expression, Therefore we introduce a discharge coefficient ***C.*** so that the flow is given by ***CQ*** or

$$Q = A_2V_2 = CA_2V_{2,} = \frac{CA_2}{\sqrt{1-(D_2-D_1)^4}} = \sqrt{2g\left[\left(\frac{p_1}{\gamma}+z_1\right)\right]-\left(\frac{p_2}{\gamma}+z_2\right)}$$

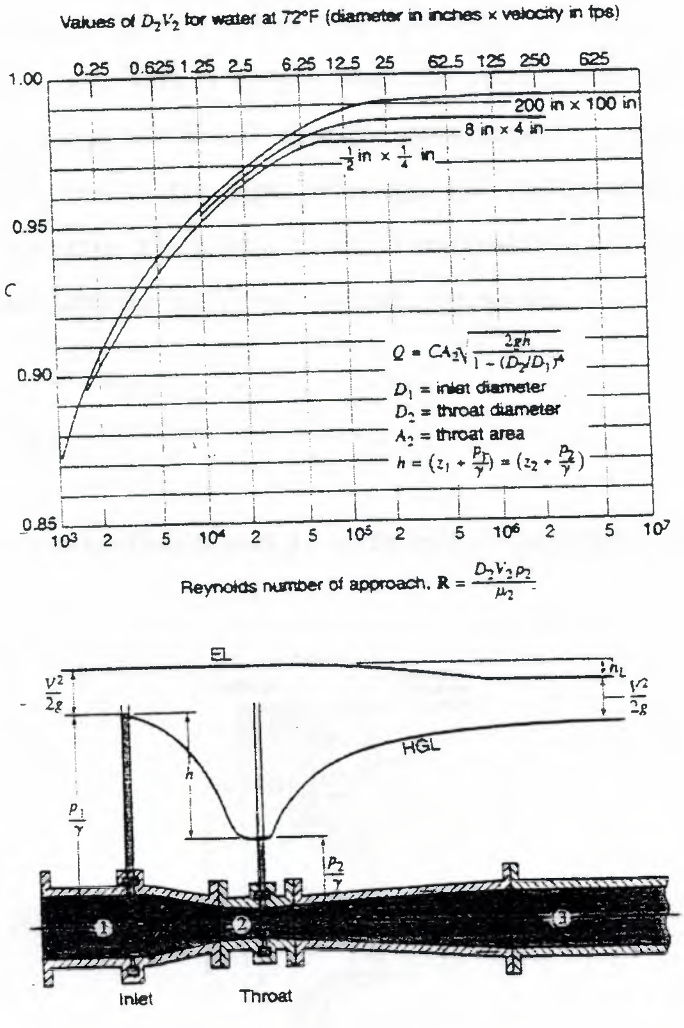

Fig 3.8 Venturi meter with conical entrance and flow coefficient $D_1 / D_2 = 0.5$

The venturi tube provides an accurate means for measuring flow in piplines. 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 venture meter is that it introduces a permanent frictional resistance in the pipeline. Practically all this loss occurs in the diverging part between sections (2) and (3).

3.5 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. 3.9. This is simpler than the venturi tube and can be installed between the flanges of a pipeline. It will serve the same purpose. Though at the expense of an increased frictional loss in the pipe. Although 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, so that

$$Q = KA_2\sqrt{2g\left[\left(\frac{p_1}{\gamma}+z_1\right)-\left(\frac{p_2}{\gamma}+z_2\right)\right]}$$

where K is called the flow coefficient and A_2 is the area of the nozzle throat.

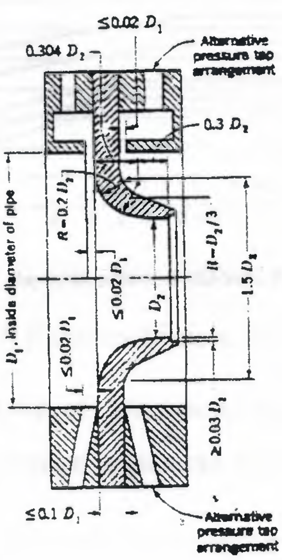

Fig 3.9 ISA Flow Nozzle

Although there are many designs of flow nozzles, the ISA (International Standards Association) nozzle (Fig. 3.9) has become an accepted standard form in many countries. The quoted 'nozzle diameter' is the throat diameter D_2. Values of K for various diameter ratios of the ISA nozzle are given in Fig. 11.10 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 R in the pipe is frequently needed for other computations also.

As shown in Fig. 3.10, many of the values of K are greater than unitv, which results from 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 compensate for the discharge coefficient, leaving a value of the flow coefficient equal to unity. Principally using so-called long-radius nozzles. Usually such a coefficient of unity is approached over only a limited range.

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 arrangements for the pressure taps are shown in Fig. 3.9

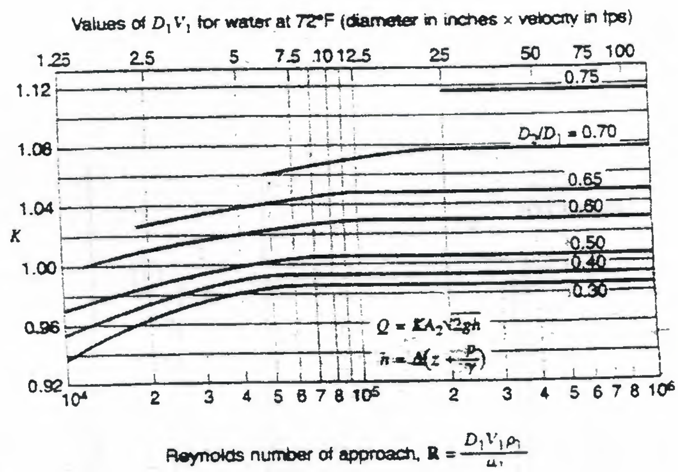

Fig 3.10 Flow coefficient for ISA Nozzle

A relative comparison for the costs of manufacturing and the head losses in an orifice meter, a nozzle flow meter, and a venturi meter can be presented as follows;

Flow meter	Cost	Head loss
Orifice meter	Low	High
Nozzle meter	Medium	Medium
Venturi meter	High	Low

3.6 NUMERICAL EXAMPLES

The aim of this section of the chapter is to introduce some examples for the flow measurements with their numerical calculations. By the mean of those examples a clear view of the usage of the flow measuring devices in the practical applications is achieved. The given numerical values are given to be as close as possible to the real measuring process.

Example 3.1

A simple pitot tube and apiezometer are installed in a vertical pipe, as shown in figure 3.9. if the deflection of mercury in the manometer is 0.1 m, then determine the velocity of water at the center of the pipe. The densities of water and mercury are 1000 kg/m^3 and 13600 kg/m^3 respectively.

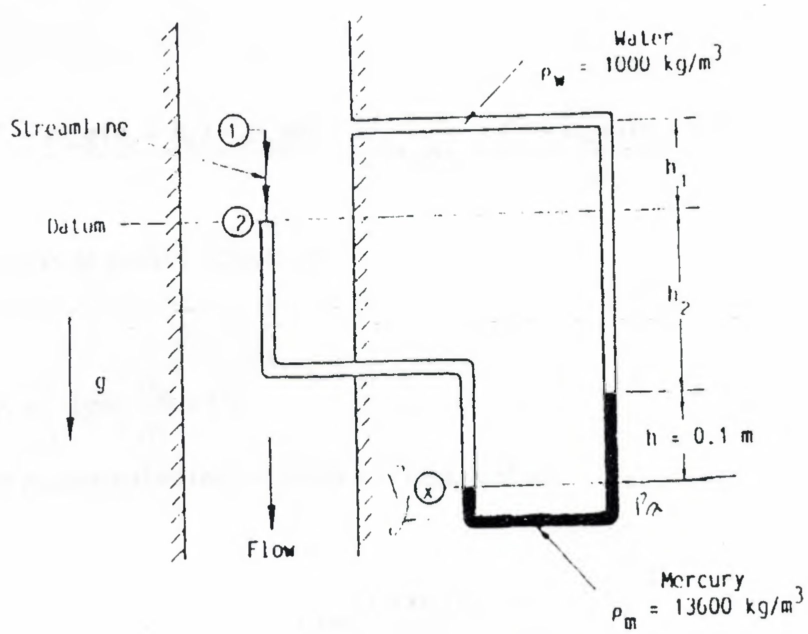

Figure 3.11 Sketch of Example 3.1

Solution

The Bernoulli equation for steady flow of an incompressible fluid may be applied between points 1 and 2 along the streamline, shown if Figure 3,9 such that;

$$\frac{P_1}{\rho_w} + \frac{v_1^2}{2} + gz_1 = \frac{P_2}{\rho_w} + \frac{v_2^2}{2} + gz_2$$

However; from the principle of manometer

$$P_1 = P_x - \rho_w g(h_1 - h_2) - \rho_m gh$$

And

$$P_2 = P_x - \rho_w g(h_2 + h)$$

Also, according to the chosen datum in the Figure 3.9 Z_1=h_1 and Z_2 is zero Finally as long as point 2 is a stagnation point; then the velocity at this point is also zero, then the Bernoulli equation takes the form;

$$\frac{P_x - \rho_w g(h_1 + h_2) - \rho_m gh}{\rho_w} + \frac{v_1^2}{2} + gh_1 = \frac{P_x - \rho_w g(h_2 + h)}{\rho_w}$$

Solving the velocity at point 1 results in ;

$$v_1 = \left(2gh\left(\frac{\rho_m}{\rho_w} - 1\right)\right)^{1/2}$$

Substituting the numerical values at point 1 is obtained as;

$$v_1 = \left(2 \times 9.81(m/s^2) \times 0.1m\left(\frac{13600(kg/m^3)}{1000(kg/m^3)} - 1\right)\right)^{1/2}$$

$$v_1 = 4.97m/s$$

Example 3.2

Find the discharge rate of 20^0C water through the venturi tube shown if D_1=80 cm, D_2=40 cm, Δz =200 cm and y=15 cmHg.

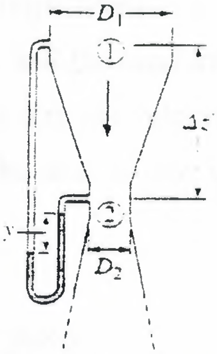

Fig3.12 Sketch for Example 3.2

Solution

For water at 20^0C : $v = 1.003 \times 10^{-6} m^2 / s$

Venturi size is 80cm $\times$ 40 cm = 31.5 in $\times$ 15.75 in

This is a bout midway between the 8in $\times$ 4inand 200in $\times$ 100in in curves in Fig 3.8 so, the maximum $C \approx 0.988$ assume this value

$$Q = CA_2 \sqrt{\frac{2gh}{1-(D_2/D_1)^4}}$$

$$Q = \frac{0.988\pi(.40/2)^2}{\sqrt{1-(40/80)^4}} \sqrt{2(9.81)0.15\left(\frac{13.55}{1} - 1\right)}$$

$$= 0.779 m^{3/s}$$

Example 3.3

A fire nozzle, which is used at an elevation of 10 m above the level of a reservoir as shown in Figure 3.11. The velocity of the jet is to 15 m/s. the cross section areas of the hose and the nozzle are $0.004m^2$ and $0.001m^2$ respectively. The head loss coefficient between point 1 and 2 the inlet of the pump is 5 m. and the head loss between the discharge side of the pump and the entrance of the nozzle is 6 m. the velocity coefficient of the nozzle is 0.9 and the contraction coefficient is 1.0. The area of the inlet pipe is the same as the hose. Determine,

a) The inlet to be supplied by the pump.
b) The power required to derive the pump, if the pump efficiency is 70 percent.

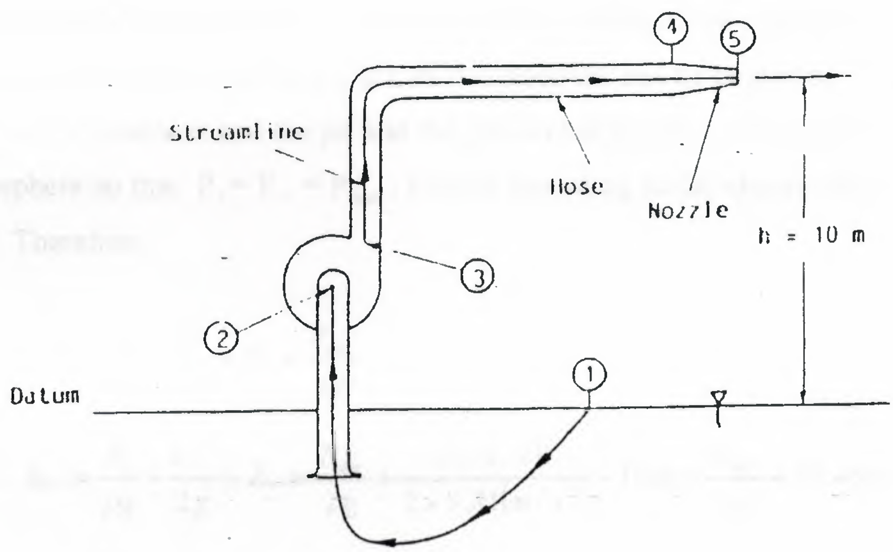

Fig 3.13 Sketch for example 3.3

Solution

The velocity of the fluid in the pipe and the hose may be determined by applying the continuity equation to the nozzle for the steady flow of an incompressible fluid such that;

$$V_4 A_4 = V_5 A_5$$

Also $A_1 = A_2 = A_4$ so that;

$$V_2 = V_3 = V_4 = \frac{V_5 A_5}{A_4} = \frac{15(m/s) \times 0.001(m^2)}{0.004(m^2)} = 3.75\ (m/s)$$

The required pump head may be obtained by applying the extended Bernoulli equation between point 5 and 1 along the streaming that is shown in Figure 3.10 as;

$$h_{t5} = h_{t1} + h_s - h_{f1-2} - h_{f3-4} - h_{f4-5}$$

where h_t represents the head at the exit and the outlet areas and h_f represents the head loss

$$h_s = h_{t5} + h_{f1-2} + h_{f3-4} + h_{4-5} - h_{t1}$$

as long as the area of the reservoir is very large when compared the cross sectional area of the nozzle; then the velocity at the surface of the reservoir can be neglected. Also both the free surface of the reservoir and the jet and the jet discharging from the nozzle are exposed to the atmosphere so that $P_1 = P_5 = P_{atm}$. Finally according to the chosen datum in Figure 3.10 Z_{10}=0. Therefore;

$$h_{t1} = \frac{P_1}{\rho g} + \frac{V_1^2}{2g} + Z_1 = \frac{P_{atm}}{\rho g}$$

$$h_{t5} = \frac{P_5}{\rho g} + \frac{V_5^2}{2g} + Z_5 = \frac{P_{atm}}{\rho g} + \frac{(15m/s)^2}{2 \times 9.81(m/s^2)} + 10m = \frac{P_{atm}}{\rho g} + 21.46m$$

$$h_{f1-2} = k_{1-2}\frac{V_2^2}{2g} = \frac{5 \times (3.75m/s)^2}{2 \times 9.81(m/s^2)} = 3.58m$$

$$h_{f3-4} = k_{3-4}\frac{V_4^2}{2g} = \frac{6 \times (3.75m/s^2)}{2 \times 9.81(m/s^2)} = 4.3m$$

And for the nozzle

$$h_{f4-5} = k_{4-5}\frac{V_5^2}{2g} = \left[\frac{1}{C_v^2} - 1\right]\frac{V_5^2}{2g} = \left[\frac{1}{0.9^2} - 1\right]\frac{(15m/s)^2}{2\times 9.81(m/s^2)} = 2.69m$$

The required pump head is obtained as;

$$h_s \frac{P_{atm}}{\rho g} + 21.46m - \frac{P_{atm}}{\rho g} + 3.58m + 4.3m + 2.69m = 32.03m$$

The volumetric flow rate may now be determined as;

$$Q = V_5 A_5 = 15(m/s)\times 0.001(m^2) = 0.015(m^3/s)$$

The net power delivered to the water by the pump may be evaluated as;

$$P_f = \rho g Q h_s = 1000(kg/m^3)\times 9.81(m/s^2)\times 0.015(m^3/s)\times 32.03m$$

$$P_f = 4.71kW$$

The power required to derive the pump is

$$P_p = \frac{P_f}{\eta_p} = \frac{4.71kW}{0.7} = 6.73kW$$

3.7 CONCLUSION

In this chapter the flow measurements were explained with basic equation and formulas. There was a relation between the pressure and velocity given by the energy equation. Then the techniques were developed to study velocity measurements like pitot tube and peizemeter. Moreover, some techniques were shown to determine the flow measurements devices like orifics in reservoir, nozzle tube and venturi tube. Some exampled was solved to let this devices is easy to understand.

CHAPTER IV

COMMERICALLY FLOW MEASURMENT DEVICES

In commercial applications, there are a number of other designs of flow meters such as those that ate based on balancing a float inside a closed pipe by using the drag of the flout as the fluid flows past it. Other meters are based on the frequency of shedding from an obstacle placed in the pipe. More sophisticated meters are based on induced electromagnetic forces or the dynamics of an acoustic field using ultrasound methods. these and more will be discus in the following sections.

4.1 POSITIVE-DISPLACEMENT METHOD

The flow rate of a liquid like water may be measured through a direct-weighing technique. That is to say, the time necessary to collect a quantity of liquid in a tank is measured and an accurate measurement is then made of the weight of the collected liquid. The average flow rate is thus calculated very easily. Improved accuracy may be obtained by using longer or more exact timing or more precise weight measurement The direct-weighing technique is frequently used for calibration of flow meters, and thus may be taken as a standard calibration technique.

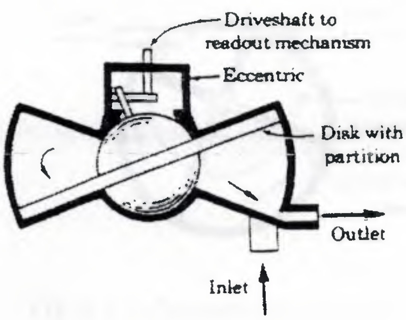

Fig 4.1 Schematic of a nutating-disc meter.

Positive-displacement flow meters are generally used for the applications where high accuracy is desired under steady flow conditions. A typical positive-displacement device is the home water meter, which is shown schematically in Figure 4.1. This meter operates on the notating-disk principle. Water enters the left side of the meter and strikes the disk, which is eccentrically mounted. In order for the liquid to move through the meter the disk must rotate or 'nutate' about a vertical axis since both the top and the bottom of the disk remain in contact with the mounting chamber. A partition separates the inlet and the out let chamber of the disk. As the disk nutates, it gives direct indication of the volume of the liquid, which has passed through the meter. The measurement of the volumetric flow rate is given through a gearing and counter arrangement which is connected to the nutating disk. The nutating disk metre may give reliable flow measurements within 1 percent deviation.

An other type of positive-displacement device is the rotary-vane meter, which is shown in Figure 4.2. The vanes are attached to springs so that they are continuously in contact with the meter. A fixed quantity of fluid enters each section when the eccentric drum rotates, and this fluid eventually flow out through the exit. An appropriate register is connected to the shaft of the eccentric drum to record the volume of the displaced fluid. The uncertainties of the rotary-vane meters are about 0.5 percent, and the meters are relatively insensitive to viscosity since the vanes always maintain good contact with the inside of the body of the meter.

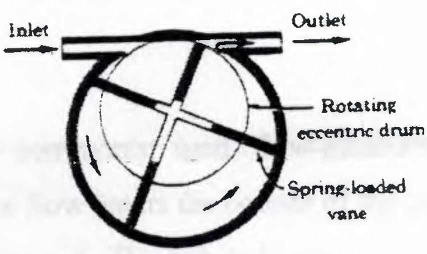

Fig 4.2 Schematic of rotary-vane flowmeter.

The lobed-impeller meter that is shown in Figure 4.3 may be used for either gas or liquid flow measurements. The impellers and the covering case are carefully machined so that accurate fit is maintained. In this way the incoming fluid is always trapped between the two rotors and is allowed to flow through the outlet as a result of their rotation. The number of revolutions of the rotors is an indication of the volumetric flow rate measurement.

Remoting sensing of all the positive-displacement meters may be accomplished with rotational transducers or sensors and with appropriate electronic counters.

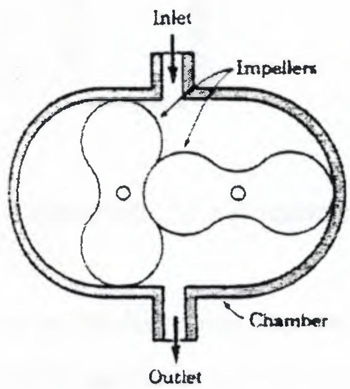

Fig 4.3 Schematic of lobed flowmeter.

4.2FLOW MEASUREMENTS BY DRAG EFFECT

4.2.1 ROTAMETER

The Rotamerer is a very commonly used flow-measurement device and is shown schematically in Fig. 4.4. The flow enters the bottom of the tapered vertical tube and causes the bob or "float' to move upward. The bob will use- to a point in the tube such that the drag forces are just balanced by the weight and buoyancy forces. The position of the bob in the tube is then taken as an indication of the flow rate. The device is sometimes called an area meter because the elevation of the bob is dependent on the annular area between it and the tapered glass tube; however, the meter operates on the physical physical of drag so that we choose to classify it in this category.

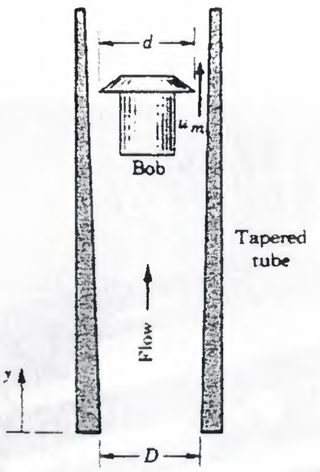

Fig 4.4 Schematic of a Rotameter.

The drag coefficient is dependent on the Reynolds number and hence on the fluid viscosity; however, special bobs may be used that have an essentially constant drag coefficient, and thus offer the advantage that the meter reading will be essentially independent of viscosity.

4.2.2 TURBINE METERS

A popular type of flow-measurement device is the turbine meter shown in Fig. 4.5. As the fluid moves through the meter, it cause a rotation of the small turbine wheel. In the turbine-wheel body a permanent magnet is enclosed so that it rotates with the wheel. A reluctance pickup attached to the top of the meter detects a pulse for each revolution of the turbine wheel. Since the volumetric flow is proportional to the number of wheel revolutions, the total pulse output may be taken as an indication of total flow. The pulse rate is proportional to flow rate, and the transient response of the meter is very good. A flow coefficient K for the turbine meter is defined so that

$$Q = \frac{f}{K}$$

Where f is the pulse frequency. The flow coefficient is dependent on the flow rate and the kinematics viscosity of the fluid.

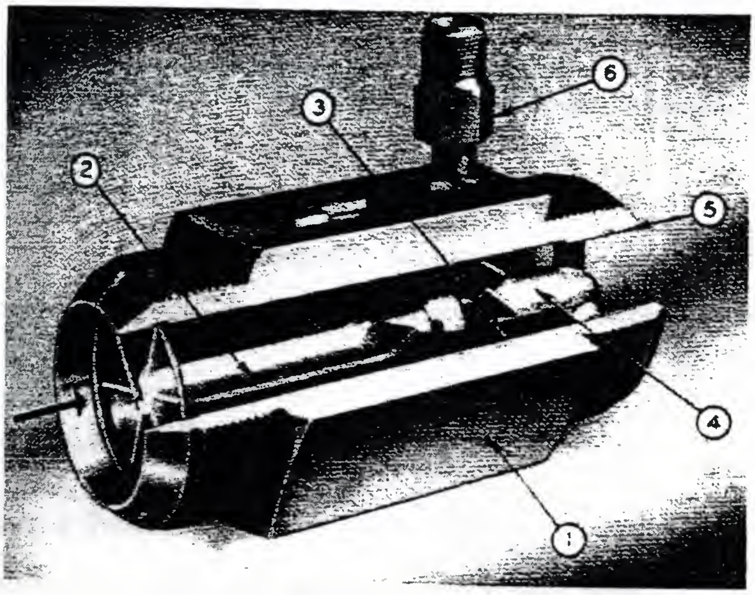

Fig 4.5
Turbine flow meter. (1) Meter body; (2) Inlet-straightening vanes; (3) Turbines blades; (4) Down steam after body to maintain smooth flow; |(5) Pipe or tube connector (6) R-eluctance pickup.

4.2.3 VORTEX-SHEDDING FLOWMETERS

Vortex flow meters operate on the principle illustrated in Fig 4.6. when a bluff body is placed in a flow stream, vortices are shed alternately from the back side

The frequency of vortex shedding is directly proportional to the liquid velocity. A piezoelectric sensor mounted inside the vortex shedder detects the vortices and subsequent amplification circuits can be used to indicate either the instantaneous flow rate or a totalized flow over a selected time interval. The meter is precalibrated by the manufacturer for a specific pipe size. It is generally unsuitable for use with highly viscous liquids. A number of special installation requirements must be met and are described in manufacture's literature.

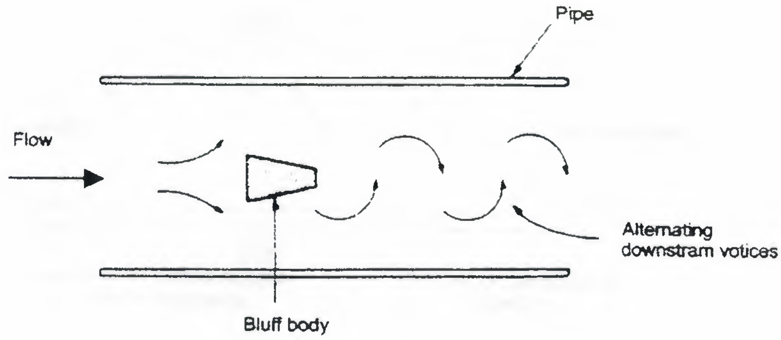

Fig 4.6 Vortex Flowmeter.

The fluid parameter which governs the operation of the vortex-shedding meter is the Strouhal number S

$$S = \frac{f_s d}{u}$$

Where f_s : shedding frequency

d : diameter of characteristic dimension of the bluff body

u : velocity

4.2.4 ULTRASONIC FLOW METER

The Doppler effect is the basis for operation of the ultrasonic flowmeter illustrated in Fig.4.6. A signal of known ultrasonic frequency is transmitted through the liquid. Solids, bubbles, or any discontinuity in the liquid will reflect the signal back to the receiving element. Because of the velocity of the liquid, there will be a frequency shift at the receiver, which is proportional to velocity. Accuracies of about ± 15 percent of full scale may be achieved with the device over a flow range of about 10 to 1. Most devices require that the liquid contain at least 25 parts per million (ppm) of particles or bubbles having diameters of 30 μm or more.

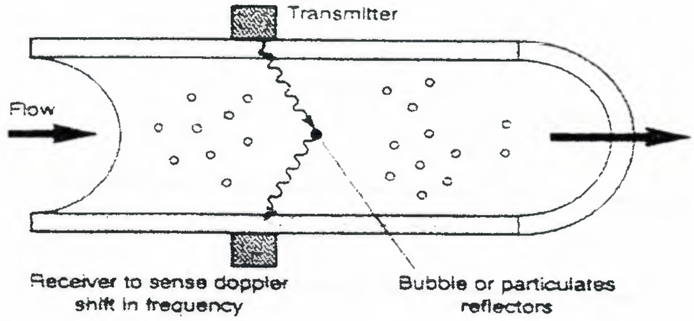

Fig 4.7 Ultrasonic Droppler flowmeter.

A microprocessor-based ultrasonic flowmeter has been developed which employs a [Doppler signal reflected from turbulent eddies in the flow. As a result, it is suitable for operation with clean low-viscosity liquids. Accuracy of 2 percent of full scale may be achieved and the meter may be installed as few as three-pipe diameters downstream from a 90°elbow. The price is quite high.

4.3 TLERMAL MASS FLOW METERS

A direct measurement of mass flow of gases may be accomplished using the principle illustrated in Figure 4.4. A precision tube is constructed with upstream and downstream externally wound resistance temperature detectors. Between the sensors is an electric heater. The temperature difference $T_1 - T_2$ is directly proportional to the mass flow of the gas and may be detected with an appropriate bridge circuit. The device is restricted to use with very clean gases. Calibration is normally performed with nitrogen and a factor applied for use with other gases. Another thermal mass flow meter for gases utilizes two platinum resistance temperature detectors. One sensor measures the temperature of the gas flow at the point of immersion. A second sensor is heated to a temperature 60°C above the first sensor. As a result of the gas flow, the heating of the second sensor is transferred to the gas by convection.

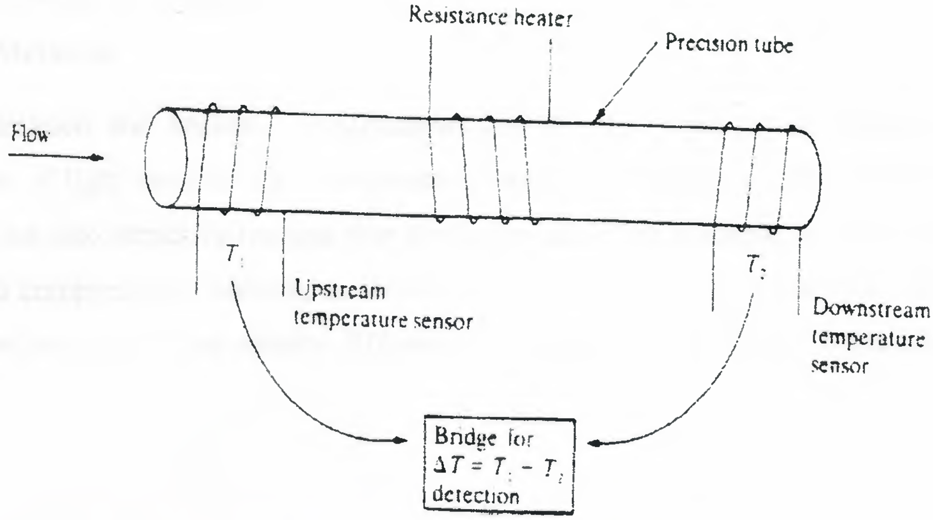

Figure 4.8 Mass flow meter based on thermal energy transfer

The heat transfer rate is propptional to the mass velocity of the gas, as defined;

Mass velocity = (density)*(velocity)

The two sensors are connected to a bridge circuit, which is called Weatston bridgeand the output voltage or current is required to maintain the 60°C temperature difference. It must be noticed that those kinds of meters measures the mass flow rate at the point of immersion only.

4.4 FLOW-VISULATION METHOD

Since fluid dynamics is a highly visual science, visualization methods are used extensively in the study of fluid phenomena. In this respect, concepts such as streamlines, streak lines, pathlnes, stream function, and velocity potential are very useful. In general, visualization methods provide qualitative information about fluid behavior. However, mote sophisticated techniques can use visual information for quantitative analysis as well.

Methods of visualizing streamlines, path lines and streamlines vary depending on the means used to produce them. For example, the simplest method is to inject into the flow stream either small particles or colored fluid and follow their trajectory through the flow field. Similarly, flow information can be obtained by injecting smoke into a flowing stream and by following its dynamics.

Optical Methods

Highly detailed and accurate visualizations can he also obtained by using the optical properties of light rays through compressible media. In addition to their accuracy. These methods are also attractive because they are noninvasive For example, a ray of light passing through a compressible medium, as shown in Figure 4.9,deflects in the direction shown in the figure because of the density differences. In terms of the density refraction index is given by

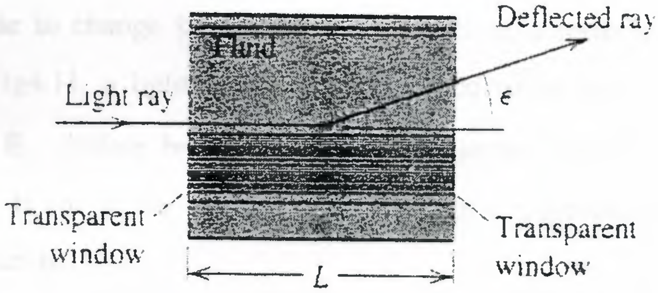

Fig 4.10 Light rays deflected due to density differences in a compressible medium.

$$n = \left(1 + \beta \frac{\rho}{\rho_s}\right) n_1$$

Where n : is the refraction index

β : a nondimensional constant

ρ : density

ρ_s : reference density

n_1 : the refraction index outside the flow

Therefore, using the deflection of a ray of light and upon integration. The density variation in the vertical variation can by obtain. Actually, This method provides a way to measure directly the density of a gas.

Slradowgraphs: The basis of shadowgraphs follows naturally from the deflection of liuht rays in a compressible medium; a beam of light passing through a compressible gases with variable density deflects the light in a manner consistent with the theory. The image of the beam projected on the other side of the flow produces areas of dark and tight colors indicating the density differences. This image, then, is a representation of the relative deflection of the light beam.

Scirliereir: This method is based on the Sclrlicivir effect,in which a beam of light focused on a sharp edge or a knife edge produces regions of light and dark areas that are proportional to the density gradient across the viewing area. This method is used quite extensively to produce pictures of the flow.

Interformetry: one of the most precise visualization methods is based on the change in the optical path due to change in the refractive index as a result of density variation.in the schematic of Fig4.11, a light sources is collimated using lens L_1 and then spilt into two beams, B_1 and B_2, before being merged and projected onto a screen with the help of a second lens L_2. If one of the beams travels through a compressible medium, the refractive index change that is,

$$\Delta L = L(n - n_0) = \beta \frac{\rho - \rho_0}{\rho_s}$$

as the result of the shift in the optical path, the image on the screen will form a series of fringes areas of dark and light shadows. The number of fringes N then is directly related to the density variation across the flow section

$$N = \frac{\beta L}{\lambda} \frac{\rho - \rho_0}{\rho_s}$$

measured relative to the density ρ_0 at the first fringe. Figure 4.11shows a typical flow representation using interferometry.

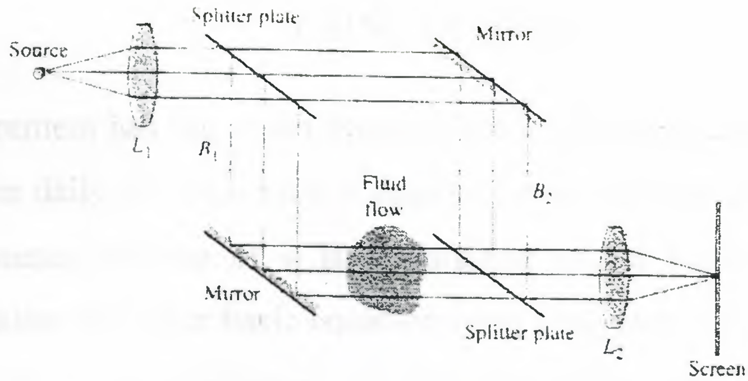

Fig 4.11 Basic principle of inerferometry.

Fluorescent Dyes: The fluorescent dye approach is a noninvasive, remote sensing method based on the excitation of fluorescent dyes mixed in the flow using a laser beam or sheet. The flow image is constructed from the sensing of the radiative energy from the dye. Consequently, this method captures simultaneously the flow field for large domains without affecting the flow.

4.5 CONCLUSION

The working principles of some commercially used flow measurement devices were represented in this chapter. The first section discussed the devices that use the positive displacement method for measurement of flow velocity and flow rate that are obtained directly by the use of digital registers. And hence, there was no need for further height measurements as the case with flow measurements using simple devices such as the pitot tube and the orifice meter. In addition, the working principle of the rotameter, which is used in various applications, is explained. Although the rotameter is working principle is based on the drag effects of the flow, it is considered to be an accurate device for flow rate measurement because every rotameter has its ready and tabulated meter constants. Thermal mass flow meter involves the use of electrical circuits for more accurate measurements. This device is used for the measurement of flow rate at a specified point on the flow thus it is suitable to be used for the measurement of compressible flows.

CONCLUSION

A measurement has important function for engineering and scientist, beside it is role in daily life. Mechanical engineer is greatly concerned of fluid flow measurements because of it is importance in his fields. The fluid flow classification and other basic equation were analyzed in the first chapter. To describe the fluid mechanics promote we must use the mathematical equation, which were, analyze in second chapter. Further more, we drive two of the most important equation in fluid fields Bernoulli's and continuity equation.

The flow velocity and static pressure were obtained for the orifice meter, then the flow velocity expression were derived for the flow rate measuring devices both for flow from the reservoir and in pipe (closed system). The working principle of the nozzle flow meter is almost the same as that of the orificer but it differs in that it has a converging extended section to control the declaration of flow while passing through the nozzle opening. The same thing can be for the venturi meter, which the diverging occurs after the fluid in pipe passing through the minimum cross section of the venturi meter. Some comparison was made between the flow measurements devices. More commercially flow measuring device were analyzed in chapter four which use more complicated method to determine the fluid flow.

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