NEAR EAST UNIVERSITY

FACULTY OF ENGINEERING

DEPARTMENT OF MECHANICAL ENGINEERING

FLUID FLOW MEASUREMENTS

GRADUATION PROJECT
ME-400

STUDENT: Ayman SIAM (981313)

SUPERVISOR: Ass. Prof. Güner ÖZMEN

LEFKOŞA- 2000

ACKNOWLEDGEMENT

I wish to thank very sincerely my parents and my family who supported and encouraged me at every stage of my education and who still being generous for me as they are ever.

My sincere thanks and appreciation for my supervisor Dr.Güner ÖZMEN who was very generous with her help, valiable advises and comments to accomplish this research. And who will be always my respectful teacher.

All my thanks goes to N.E.U. educational staff and mechanical engineering departmenets teaching team for their generuosity and special concern of me and all M.E. students.

I wuold like to thank the university's registration staff for their help and support. My special thanks goes to my advisors Mr.Tayseer and Mrs. Filiz Al shanabela for all their help.

Final aknowledgements goes to my class mates and friends who provided me with their valiable suggestions throughout my educational years.

Special thanks to Maher MERZA, Abdulfattah SIAM, my brother Ashraf, and my home mate Mahmoud .

Ayman SIAM
M.E. DEPARTMENT
N.E.U.

TABLE OF CONTENTS

CHAPTER IV FLOW MEASUREMENT DEVICES

NOMENCLATURE

A	area (m/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 , height (m)
h_f	frictional head (m)
h_s	shaft work per unit weight (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
μ	absolute viscosity
τ	shear stress (Pa)
ρ	mass density (kg/m^3)
γ	specific weight

SUMMARY

Fluids are of great importance in the engineering fields and engineers are of great concern of the fluid properties and hence their measurements. The main aim of this project is to present the subject of fluid flow properties measurements and the related measuring devices of the following properties;

- flow velocity of a fluid
- static and dynamic pressure of the flow
- flow rate measurements

The first chapter is an introductory chapter that includes definition of measurements and the measurement of the fluids and their importance in engineering fields. Also it includes definitions of some basic expressions that are used throughout the research. The second chapter explains the theoretical background and the mathematical formulations on which the working principles of the flow measuring devices are based. The third chapter analyses and describes the most common flow measuring devices with their working principles. A mathematical expression is derived for each measured flow property separately according to the measuring device. The fourth chapter introduces more flow measuring devices that are commercially used.

CHAPTER I
INTRODUCTION

The first section of this chapter explains the definition of measurement and its scientific meaning and its general functions in engineering. Whereas, the second section is a statement about the importance of fluid flow 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 flows. So that by assuming those cases, simplifications can be made to describe the flow with reasonable approximations.

1.1 MEASUREMENTS

Measurement has been of great importance to human civilisation 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 and 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 restricts obtaining the absolute results. Consequently, only 'good 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 behaviour 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 behaviour 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 flows in order to simplify the analyses of the measuring devices.

The types of fluid flows that are going to be used in the coming chapters can be classified as follows;

VISCOUS AND INVISCID FLOWS

Viscosity is the property of the fluid that indicates the relation between an applied shear stress and the rate of deformation of the fluid due to that shear

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

ζ : shear stress

μ : the viscosity

$\frac{du}{dy}$: rate of deformation

u : velocity of the flow

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

COMPRESSIBLE AND INCOMPRESSIBLE FLOWS

If the changes in the mass density of a flowing fluid are avoidable or if their contribution on the flow can be neglected, the flow is said to be incompressible. But if those density variations are not negligible their effects on the flow must be considered as well, and the flow is turned to be compressible. Measuring the properties such as velocity and flow rates for an incompressible fluid is easier than the measurement for compressible fluids.

INTERNAL AND EXTERNAL FLOWS

If the flow takes place inside a closed surface (e.g. pipes or conduits) it is named as internal flow. But if it occurs with one of its surfaces is in contact with another fluid it is named as external flow such as fluid flow in an open channel.

LAMINAR AND TURBULENT FLOWS

The viscous flows are further classified as being laminar or turbulent flows. In laminar flow, the fluid is moving smoothly and steadily taking the shape of laminae, whereas in the turbulent flow the fluid is moving randomly in three dimensions. Reynold's number is a dimensionless number that is used to determine the type of an internal flow to be laminar or turbulent.

$$\mathrm{Re} = \frac{\rho . V . d}{\mu}$$

Rynold's is a constant number based on the diameter of the pipe or conduit inside which the flow takes place, density of the fluid, viscosity and the velocity of the flow. If the Re turns to be greater than a specific number of flow then the flow turns to be turbulent, otherwise the flow is considered to be laminar.

1.4 CONCLUSION

Measurement has important functions for engineers and scientists beside its role in our daily life. Mechanical engineering is greatly concerned of fluid flow measurements because mechanical engineers frequently deal with fluids in their fields and it is almost impossible to find any mechanical system that operates without the contribution of fluids as the working substance or even as a coolant at least. In addition the fluid flows were classified as viscous, inviscid, compressible, incompressible, internal, external, laminar and turbulent flows. This classification helps in analysing the fluid flow measuring devices in the proceeding chapters because it makes it possible to determine the special cases that are usually encountered in the practical applications.

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 analyse the working principles of the measuring devices. Those equations are named as the Bernoulli equation and the continuity equation. The two equations are discussed in the second and the 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 the fluid system the mass it contains can not be changed. But the shape of the 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 analyse 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.

It is also helpful to show the direction of the flow at its every point this can be achieved by drawing continuous arrowed lines called 'streamlines' tangent to the velocity vector through out the flow. Thus, streamlines indicate only the direction of the velocity without giving the magnitude of it at every point.

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 .

2.1.1 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;

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

where $\dot{m}$: 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 surface (section)

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 (ie. fluid density is constant and uniform over the control volume's area) and steady conditions are assumed the mass flow rate equation reduces to

$$\dot{m} = \rho A V$$

where A : the cross section area of the flow

2.1.2 VOLUMETRIC FLOW RATE

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

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

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

$$Q = V.A$$

Here area A being normal to the flow direction since the velocity does not change over this control surface.The volumetric flow rate has units of (m^3/s) in the SI system.

2.1.3 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;

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

If the fluid is uncomprssible then the avarage velocity of the flow is reduced to

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

2.2 THE CONTINUITY EQUATION

The application of the principle of conservation of mass to a fluid flow yields an equation which is refered to as the quntinuity equation. Which states that the time rate of cahnge of the the mass of the system is zero. So by considering an infintesimal control volume of the flow a mathemetical formula can be derived as follows

$$m_s = \int_{m_s} \rho \, d\forall$$

For the fluid system

$$\frac{D}{dt}\int_{\forall} \rho \, d\forall = 0 \qquad \frac{D m_s}{dt} = 0$$

Which results in

$$\frac{D}{dt}\int_{\forall} \rho \, d\forall = \frac{\partial}{\partial t}\int_{\forall} \rho \, d\forall + \int_{A} \rho \, \vec{V}.\vec{n} \, dA = 0$$

where

$\left[\frac{\partial}{\partial t}\int_{\forall} \rho \, d\forall\right]$ is the rate of change of mass in the system

$\left[\int_{A} \rho \, \vec{V}.\vec{n} \, dA\right]$ is the net rate of the mass flux through the control surface

This equation simply indicates that the time rate of change of the mass of the fluid system is equal to the mass flux separating through the system bounderies added to the rate of change of the mass that the fluid system contains.

The continuity equation can be further simplified by considering the special cases that are usually encountered in the practical problems. So for steady flow the partial derivative with respect to time is zero.

$$\frac{\partial}{\partial t}\int_{\forall} \rho \, d\forall = 0$$

A : surface area of the control volume

$\forall$: volume of the conrtol volume

For one dimension steady flow

$$\int_{A_{inlet}} \rho V \cdot dA = \int_{A_{outlet}} \rho V \cdot dA$$

if the properties are uniform at the inlet and at the exit then the quntinuity equation is further reduced to

$$\sum (\rho v \cdot A)_{inlet} = \sum (\rho v \cdot A)_{outlet}$$

For an incompressible flow the density of the fluid is the same at the inlet and at the exit hence,

$$A.V = \text{constant} = Q \qquad Q \text{ is the volumetric flow rate}$$

This equation indicates that, for control volume in an incompressible, steady and one dimensional flow the mass and volumetric flow rates have to be constant.

2.3 THE BERNOULLI EQUATION

The Bernoulli equation gives a relationship between pressure, velocity and position or elevation in a flow field. Normally these properties vary considerably in the flow, so by the formulation of the conservation of energy principle on an infinetisimal control volume fo the fluid and by the help of Newton's seconed law of motion the Bernoulli's equation can be expreesed for a streamline as following;

$$\int \frac{\partial \forall}{\partial t} ds + \frac{V^2}{2} + \int \frac{dp}{\rho} + gz = B(t)$$

z : elevation
ds : infinetism al displacement in the direction of the flow
B(t) : a function of time results from the partial integration in the (s) direction

Similar to the siplifications applied to the continuityequation, the bernoulli equation can be further simplified to describe the practical conditions. So for steady and uniform conditions the derivative with respect to time is zero, hence;

$$\frac{D}{\partial t} = 0 \qquad \text{and}$$

$$\frac{V^2}{2} + \int \frac{dp}{\rho} + gz = \text{constant}$$

For steady and incompressible flow the density is constant with respect to pressure such that;

$$\frac{V^2}{2} + \frac{1}{\rho} \int dp + gz = \text{constant}$$

Hence:

$$\frac{V^2}{2} + \frac{p}{\rho} + gz = \text{constant}$$

For a streamline within the flow, the Bernolli equation is written as :

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

where the subscribts 1 and 2 indicates the properties at two points on the stream.

Deviding by g the gravitational acceleration

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

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. Therfore the quantities in the equation are named as the velocity head, pressure head and gravitational head. Moreover, if there exists a non conservative forces in the flow field and resulting in 'head losses', those losses represent the work done by the nonconservative forces againist 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;

$$\frac{V_1^{\ 2}}{2g}+\frac{p_1}{\rho g}+z_1-h_f+h_s=\frac{V_2^{\ 2}}{2g}+\frac{p_2}{\rho g}+z_2$$

where

h_s : head gained by the external work (e.g. pump work)

h_f : head loss due to non conservative forces (e.g. friction)

The following example is introduced to make the previous derived equations more clear and to show how can a flow property be calculated by their means.

EXAMPLE

An incompressible and inviscid fluid is flowing through a horizontal converging duct. The area at the inlet and the exit of the duct are knowen. 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, and the fluid densityare 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 a uhiform flow at the inlet and the exit of the converging duct, the continuity equation is

$$V_1A_1 = V_2A_2$$

So that the velocity at the inlet of the duct is

$$V_1 = \frac{V_2A_2}{V_2} = \frac{(50m/s)\times(0.02m^2)}{0.1m^2} = 10\ m/s$$

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 neglegted. Therefor the Bernoulli's equation between two points on a streamline in the direction of the flow

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

$$P_1 = P_2 + \frac{\rho}{2}(V_2^{\,2} - V_1^{\,2})$$

$$P_1 = 100000\ \text{N/m}^2 + \frac{1000\ \text{kg/m}^3}{2}\left[(50\text{m/s})^2 - (10\text{m/s})^2\right] = 1300\ \text{kPa}$$

Is the pressure st the inlet.

2.4 CONCLUSION

The mathematical equation which are used in describing the fluid mechanics problems have been analysed with thier simplified forms for special cases and types of fluid flows. The defination of the flow rate and the avarage velocity of a flow were also explained. Two important equations were derived the Quntinuity equation and the Bernouli's equation with thier simple forms to analyse steady,incompressible and one dimensional flows, which are the conditions encountered in the flow properties measurement

CHAPTER III

FLOW MEASUREMENT

In this chapter the working principles of the simple and the most commonlly used devices for the measurement of the flow properities are analysed. Furthermore, according to the flow properity 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 properperties and by considering the sources of errors and the assumptions made the measurements are obtained as accurate as possible.

3.1 FLOW VELOCITY MEASUREMENTS

The measurement of the velocity at a number of points over a cross section is often needed for determining the velocity profile. This velocity profile may then be integrated over the flow area in order to obtain the volumetric flow rate. At this point, it should be noted that, it is almost impossible to measure the flow velocity at a point practically, since the measuring device occupies a finite space. However, if the area of the flow occupied by the measuring element is very small compared with the total area of the fluid flow, then the measured velocity may be considered as the velocity at apoint. Therefore, it is essential that the presence of the measuring device in the flow stream should not affect the flow where the velocity measurements are to be made. Thus the size of the measuring device is required to be as small as posible in order to have more accurate data.

3.1.1 PITOT TUBE

The Pitot tube is a device, which does not measure the flow velocity directly, but yields a measurable quantity that can be related to the f]ow velocity. The Pitot tube which is operating on this principle, is one of the most accurate devices for the measurement of the flow velocity in open channels and pipes.

The simple Pitot tube is composed of a glass tube or a hypodermic needle with a right-angled bend in an open channel for the measurement of the flow velocity. When this Pitot tube is first inserted into the open channel with the tube opening being directed upstream, the fluid flows into it. As a result the fluid rises to a height of h above the free surface of the open channel in the vertical part of the tube, increasing the pressure sufficiently within the horizontal part of the tube to withstand the impact of the velocity against it.Therefore, the fluid in front of the tube opening is stagnant or at rest. Hence, the streamline passing through point x leads to point 0, which is known as the stagnation point ,that is the pointat which the fluids is at rest. as shown in Figure3.1, the Bernoulli equation for the steady flow of an incompressible fluid may is applied between points x and 0 along the streamline, in the direction of the flow such that;

$$\frac{P_X}{\rho}+\frac{V_X^{\ 2}}{2}=\frac{P_0}{\rho}+\frac{V_0^{\ 2}}{2}$$

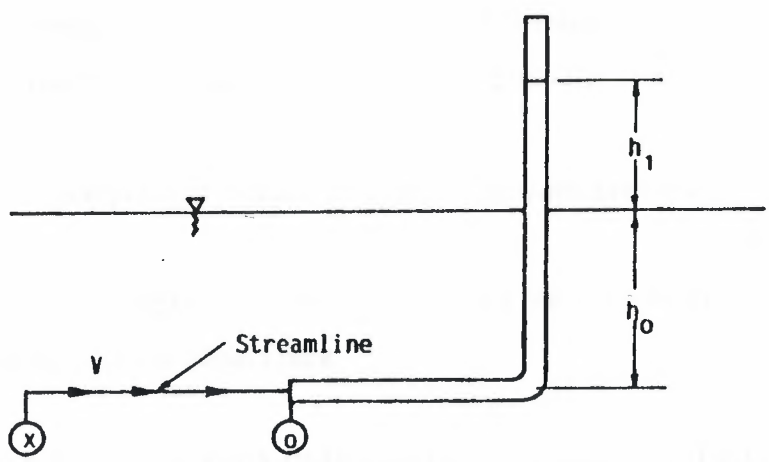

Figure 3.1 A sketch for the Pitot tube

Since both points are at the same elevation z is constant and thus drops from the equation .Otherwise its contribution to the flow must be considered by evaluating the gravitational head. As long as the flow in the open channel is exposed to the atmosphere, then the pressure distribution in the vertical direction corresponds to a static pressure distribution such that;

$$P_x = P_{atm} + \rho.g.h_0$$

But point 0, is just inside the simple Pitot tube, is a stagnation point so

$$P_0 = P_{atm} + \rho.g.(h_0 + h_1) \quad \text{and} \quad V_0 = 0$$

Therefore the flow velocity at any point x in the open channel is

$$V_x = V = \sqrt{(2.g.h_1)}$$

However, it is very difficult to read the height, h_1, from a free surface. Also one should observe that

$$P_0 = P_{atm} + \rho.g.(h_0 + h_1) = P + \rho.\frac{V^2}{2}$$

Therefore, the simple Pitot tube measures the total pressure or the stagnation pressure, which is composed of static pressure and dynamic pressure

Total pressure = Static pressure + Dynamic pressure

For this reason, the simple Pitot tube is sometimes the referred as the total head tube, the stagnation tube, or the impact tube.

3.1.2 PITOT TUBE MEASUREMENTS FOR INTERNAL FLOW

For the measurement of the flow velocity in a pipe or in a closed conduit, a simple Pitot tube and a piezometer should be used together. The Bernoulli equation for the steady flow of an incompressible fluid may be applied between points x and 0 along the streamline, as shown in Figure 3.2, as;

$$\frac{P_X}{\rho} + \frac{V_X^{\,2}}{2} = \frac{P_0}{\rho} + \frac{V_0^{\,2}}{2}$$

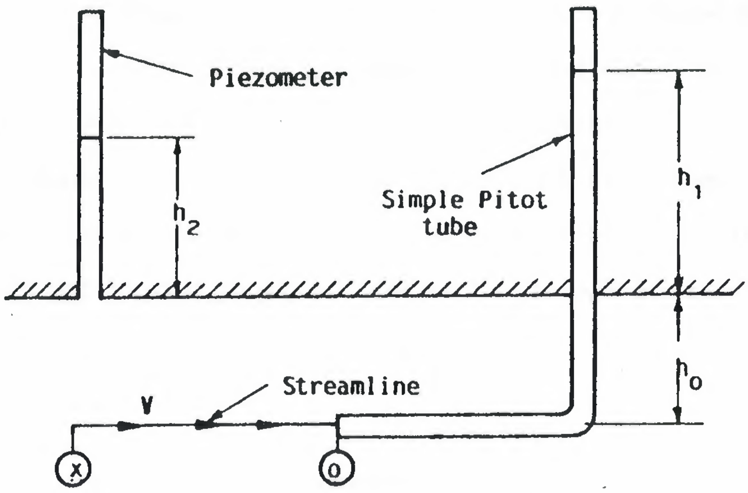

Figure 3.2 A simple Pitot tube and a piezometer

since both points are at the same elevation. As long as both the simple Pitot tube and the piezometer are exposed to the atmosphere, then the pressure distribution in them correspond to a static pressure distribution, so that

$$P_X = P_{atm} + \rho g(h_0 + h_2) \quad \text{and} \quad P_0 = P_{atm} + \rho g(h_0 + h_1)$$

At point 0, which is a stagnation point, the velocity is zero. Hence the flow velocity at any point x is $V_X = V = [2g(h_1 - h_2)]^{\frac{1}{2}}$

It should be noted that, using a simple Pitot tube and a piezometer for the measurement of flow velocities in a closed conduit with large pressures, is impractical, since very long vertical piezometer tubes will be necessary.

3.1.3 THE COMBINED PITOT TUBE

The static and the stagnation pressures in a closed conduit may be measured together by a combined Pitot static tube, to determine the flow velocity. A combined Pitot static tube consists of two circular concentric tubes one inside the other with an annular space in between.The static pressure is measured through two or more holes, which are through the outer tube into the annular space. For round nosed body of revolution with its axis parallel to the flow, the stagnation pressure is obtained at the tip, which is marked by point A. When the combined Pitot static tube is placed in the fluid stream, the flow along its outer surface gets accelerated, and causes the static pressure to decrease. But the effect of the stem, which is at right angles to the stream, is to produce an excess pressure head which diminishes upstream from the stem. If the piezometer hole located at the side of the outer tube, where the excess pressure produced by the stem equals to the decrease in pressure caused by the flow around the nose and along the tube, then the true static pressure will be obtained.

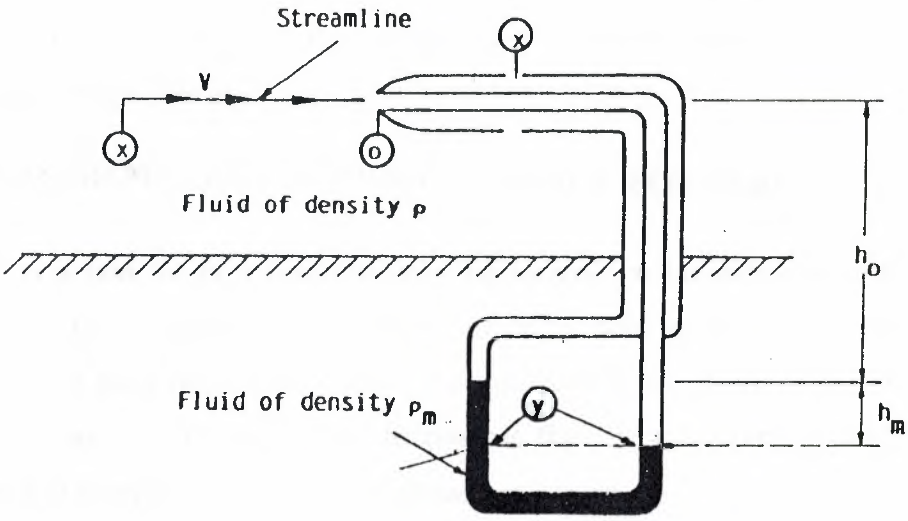

Figure 3.3 A combined Pitot static tube for the measurement of the flow velocity

Furthermore, considering the combined Pitot static tube for the measurement of the flow velocity in a closed conduit, The Bernoulli equation for the steady flow of an incompressible fluid may be applied between points x and 0 on the streamline, which gives;

$$\frac{P_X}{\rho}+\frac{V_X^{\ 2}}{2}=\frac{P_0}{\rho}+\frac{V_0^{\ 2}}{2}$$

since both points are at the elevation and using the principles of manometers

$$P_y = P_x + \rho g h_0 + \rho_m g h_m \qquad \text{and} \qquad P_y = P_0 + \rho g(h_0 + h_m)$$

At point 0, which is a stagnation point, the velocity is zero, that is $V_0 = 0$.Therefore, the flow velocity at any point may be obtained by solving the Bernoulli equation for V as;

$$V_x = V = \left[2gh_m\left(\frac{\rho_m}{\rho - 1}\right)\right]^{\frac{1}{2}}$$

3.2 FLOW RATE MEASUREMENTS

In this part of the chapter some simple devices for the measurement of flow rate from a reservoir, through a closed conduit or in an open channel. Firstly the flow rate from a reservoir may be measured with an orifice, which is an opening, usually round, through which the fluid flows. Then more flow measuring devices such as the nozzle flow meter and the venturi meter are analysed.

3.2.1 MEASUREMENT OF FLOW RATE FROM A RESERVIOR

An orifice in a tank or in a reservoir may be located on the side walls or on the bottom.usually. Considering the flow through an orifice with an area of A from a large reservoir under a head of ,h, that is, the elevation of the free surface of the fluid. The Bernoulli equation for the steady and frictionless flow of an incompressible fluid is written between points 1 snd 2 which are showen in Figure 3.4

$$\frac{P_2}{\rho} + \frac{V_2^{\,2}}{2} + gz_2 = \frac{P_1}{\rho} + \frac{V_1^{\,2}}{2} + gz_1$$

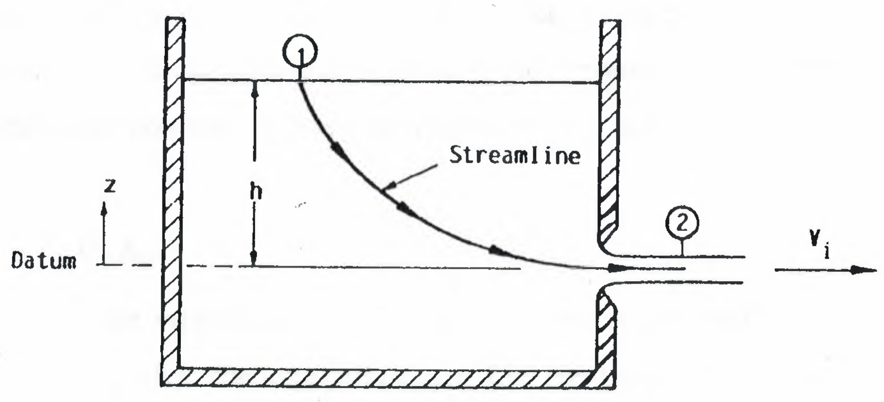

Figure 3.4 Flow from a reservoir through an orifice

As long as the area of the reservoir is very large when compared to the area of the orifice, then the velocity of the fluid in the reservoir may approximately be taken as *zero, that is* $V_1 = 0$. *Also points 1 and 2 on this streamline are both exposed to the* atmosphere, so that $P_1 = P_2 = P_{atm}$ Finally, $Z_1 = h$ and $Z_2 = 0$. Then, the velocity of the jet occuring just outside of the orifice, $V_i = V_2$, in the absence of friction is $V_i = [2gh]^{1/2}$

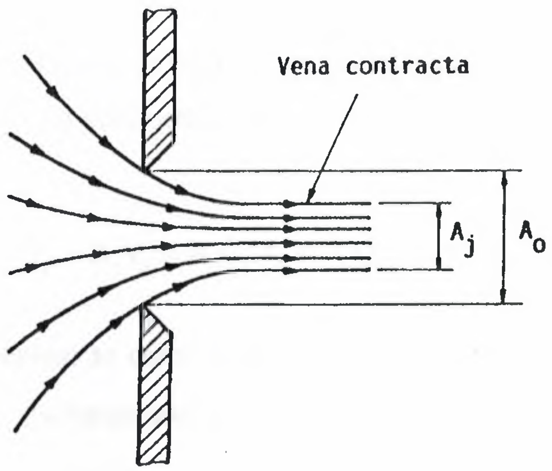

Figure 3.5 Flow through an orifice

During the flow in the vicinity of the orifice with sharp edges, the fluid jet contracts within a short distance from the opening. The portion of the flow that approaches to the orifice along the wall cannot make a right-angled turn at the opening and therefore maintains a radial velocity component which reduces the jet area. The section, where the area of the jet is minimum, is known as the vena contracta, Shown in Figure 3.5 . At the vena contracta, the streamlines are parallel and the pressure is atmospheric. The area of the jet at the vena contracta, A_j may be related to the area of the orifice by the relation;

$$A_j = C_C A_0$$

where C is called the contraction coefficient. The contraction coefficient C can be determined experimentally. The ideal volumetric flow rate through the orifice, Q_i, may be obtained by multiplying the ideal velocity of the jet with the jet area at the ven contracta as;

$$Q_i = A_j V_i = V_i C_C A_0 = C_C A_0 (2gh)^{1/2}$$

However, the velocity of the actual jet, V_a is less than the velocity of the ideal one due to the friction, and they may be related by

$$V_a = C_v A_i = C_v (2gh)^{1/2}$$

where Cv is known as the velocity coefficient and should be determined experimentally. Then the actual volumetric flow rate through the orifice is written as;

$$Q_a = A_j V_a = A_j C_v A_i = C_v Q_i = C_v C_c A_0 (2gh)^{1/2}$$

It is convenient to combine the velocity coefficient and the contraction coefficient by defining a discharge coefficient, C_d as $C_d = C_c C_v$ Then the actual volumetric flow rate through the orifice becomes;

$$Q_a = C_d A_0 (2gh)^{1/2} = C_d A_0 V_i$$

it is important to say that a velocity coefficient, which is less than unity, implies the existence of the friction and therefore a loss of head. When the head loss is to be determined, it is more convenient to introduce the concept of a head loss coefficient instead of working with a velocity coefficient. The head loss for the orifice may be expressed as;

$$h_f = k \frac{V_a^2}{2g}$$

Where k is known as the head loss coefficient. The actual jet velocity may then be determined by applying the extended Bernoulli equation between 2 and 1 along the streamline.(as illustrated in Figure 3.4) as;

$$h_{t2} = h_{t1} - h_{f1-2}$$

As long as the frictional effects are considered in the extended Bernoulli equation, then the velocity at the downstream of the orifice is the actual jet velocity, that is; $V_a = V_2$

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

also

$$h_{t2} = \frac{P_2}{\rho g} + \frac{V_2^2}{2g} + Z_2 = \frac{P_{atm}}{\rho g} + \left(\frac{V_a^2}{2g}\right)$$

Hence the extended Bernoulli equation becomes as follows;

$$\frac{P_{atm}}{\rho g} + \frac{V_a^2}{2g} = \frac{P_{atm}}{\rho g} + h - k\frac{V_a^2}{2g}$$

which may be solved for the actual jet velocity as

$$V_a = \left(\frac{2gh}{1+k}\right)^{1/2}$$

As a result it is possible to tbtain a relation between the head loss coefficient and the velocity coefficient as ;

$$k = \frac{1}{C_v^2}$$

It is importanat to note that the head loss coefficient given by the above equation is only valid between two points on the same streamline, which are both exposed to the atmosphere.

3.2.2 ORIFICE METER

The orifice meter is a thin plate with an opening which is usually circular. The fluid stream, which is accelerated through the orifice, causes flow separation at the sharp edge of the orifice meter. As a result, a recirculation zone is formed at the downstream of the orifice meter,see Figure 3.6. The main stream flow continues to accelerate after the throat of the orifice meter to form a vena contracta and then decelerates again to fill the pipe. At the vena contracta the flow area passes through a minimum, the streamlines are essentially straight, and the pressure is uniform across the cross section. Applying the continuity equation for the steady flow of an incompressible fluid to the control volume, it is possible to obtain $V_{1i}A_1 = V_{2i}A_2$ where V_{1i} represents the ideal velocity at section 2.

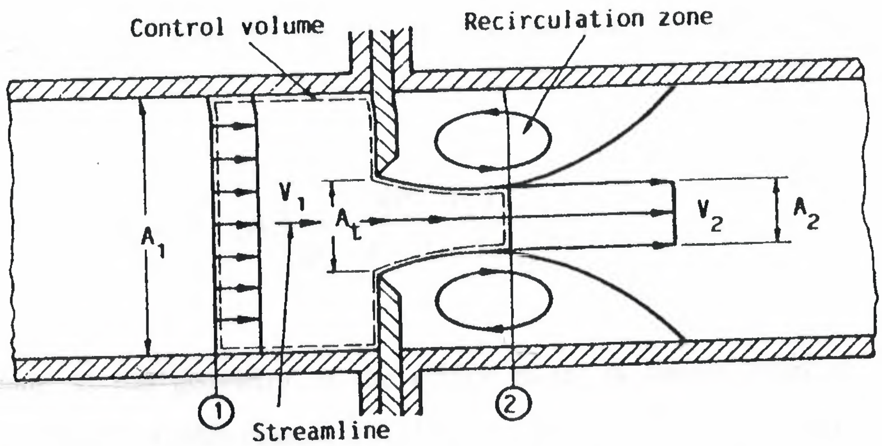

Figure 3.6 Construction of an Orifice meter

applaying Bernoulli equation between points 1 and 2 gives;

$$\frac{P_1}{\rho}+\frac{V_{1i}^{\ 2}}{2}=\frac{P_2}{\rho}+\frac{V_{2i}^{\ 2}}{2}$$

It is possible to obtain

$$V=\left[\frac{2(P_1-P_2)}{\rho\left(1-(A_2/A_1)^2\right)}\right]^{1/2}$$

This ideal velocity may now be expressed in terms of the throat area of the orifice meter A_t by defining a contraction coefficient, C_c as $C_c = \frac{A_2}{A_t}$ Then the ideal velocity at the section 2 can be expressed as;

$$V = \left(\frac{2(P_1 - P_2)}{\rho\left(1 - C_c^{\,2}\left(\frac{A_t}{A_1}\right)^2\right.} \right)^{1/2}$$

As a result of friction, the actual velocity at the vena contracta will be less than the ideal velocity. Frictional effects are taken into account by defining a velocity coefficient, C_V, so that $C_v = \frac{V_{2a}}{V_{2i}}$ Then the actual volumetric flow rate, through the orifice meter is

$$Q_a = C_v C_c A_t \left(\frac{2(P_1 - P_2)}{\rho(1 - C_c^{\,2}(A_t / A_1)^2} \right)^{1/2}$$

As long as the geometry of the orifice meter is simple, then it is quiet easy to manufacture. For this reason, it is low in cost. Also the orifice meter can be installed or replaced easily .The main disadvantage of the orifice meter is the high head loss due to the uncontrolled expansion at the dowenstream of the metering element.

3.2.3 THE NOZZLE FLOW METER

A nozzle flowneter, which is placed in a pipe, has a well rounded entrance. The fluid stream, which is accelerated through the converging nozzle flowmeter, causes flow separation at the downstream of the nozzle. As a result, a recirculation zone is formed at the downstream of the nozzle flow meter, the jet does not continue to contract at the downstream of the nozzle opening, so that the minimum area of the jet is approximately the same as the area of the nozzle opening. Therefore, the contraction coefficient of the nozzle flowneter is unity. At the downstream of the nozzle opening, the jet decelerates to fill the pipe again. however, this is an uncontrolled deceleration due to the lack of guidance of the jet at the downstream of the jet. The actual volumetric flow rate through a nozzle flowneter may be determined by following the same procedure, which is used

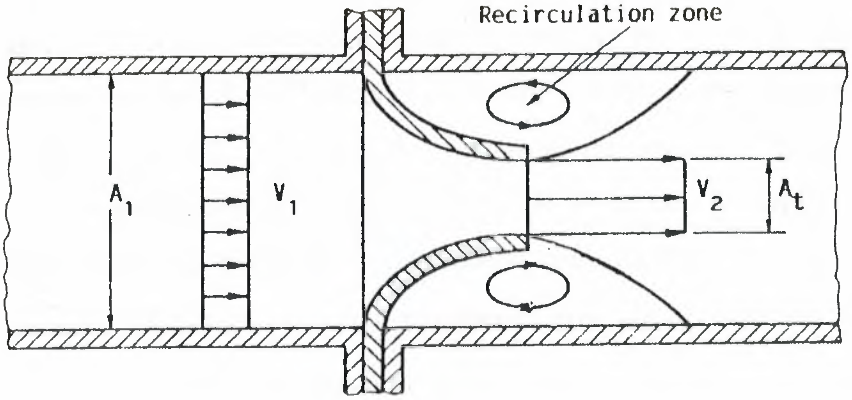

Figure 3.6 flow in the nozzle flow meter

during the evaluation of the actual volumetric flow rate through an orifice meter. However, one should note that the contraction coefficient is unity for a nozzle flowmeter, that is $C_c = 1$, Therefore, the actual volumetric flow rate through a nozzle flowmeter may be written as

$$Q_a = C_v A_t \left(\frac{2(P_1 - P_2)}{\rho\left(1 - (A_t / A_1)^2\right)} \right)^{1/2}$$

Since the geometry of the nozzle flowmeter is more complex than the geometry of the orifice meter, then its cost of manufacturing is higher. It may be installed between the flanges of a pipeline. The nozzle flowmeter with its smooth rounded entrance convergence, practically eliminates the 'vena contracta' and gives discharge coefficients nearly unity. However, the nonrecoverable head loss is still large, because there is no diverging section provided for gradual expansion. Hence the head loss in a nozzle flowmeter is lower than the one in an orifice meter.

Page Set-up.

3.2.4 VENTURI METER

the Venturi meter is of a conical contraction, a straight throat and a conical expansion,The fluid stream, which is accelerated through the converging'nozzle, reaches to its minimum area at the throat of the Venturi meter. At the downstream of the throat of the Venturi meter, the fluid jet decelerates through the diverging diffuser to fill the pipe again. However, this is a controlled deceleration due to the guidence of the jet in the diverging section of the Venturi meter. The actual volumetric flow rate through a Venturi meter may be determined by following the same procedure, which is used during the evaluation of the actual volumetric flow rate through an orifice meter. However, one should note that the contraction coefficient is unity for a Venturi meter, that is $C_c = 1$ Therefore the actual volumetric flow rate through a Venturi meter may be obtained by setting the contraction coefTicient in to unity as in the case of a nozzle flowmeter to yield the volumetric flow rate as;

$$Q_a = C_v A_t \left[\frac{2(P_1 - P_2)}{\rho\left(1 - (A_t / A_1)^2\right)} \right]^{1/2}$$

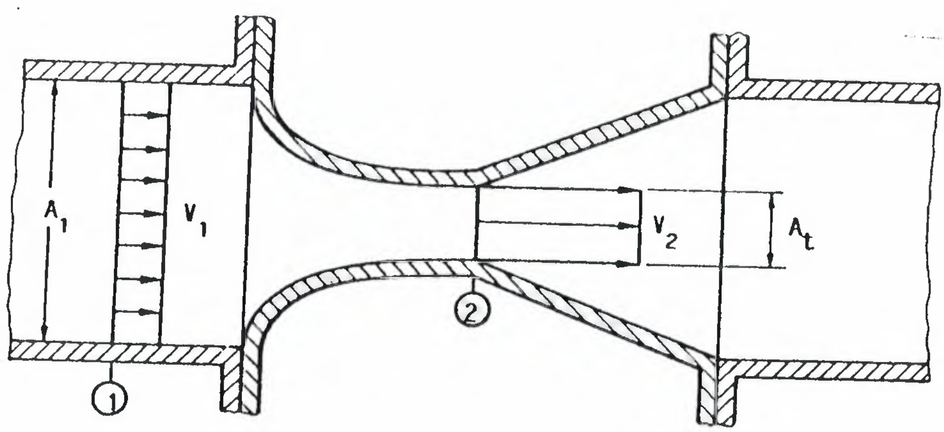

Figure 3.7 Schemetic of the venturi meter

Since the geometry of the Venturi meter is much more complex than the geometries of an orifice meter and/or a nozzle flowmeter, then its cost of manufacturing is much higher than the ones that are previously mentioned. A Venturi meter may be installed between the flanges of a pipeline. The Venturi meter, with its smooth diverging nozzle, practically eliminates the vena contracta, and gives discharge coefficients nearly unity. However, the nonrecoverable head loss is minimum due to the diverging diffuser, which is provided for gradual expansion. Therefore the head loss in a Venturi meter is much more lower than the ones in a orifice meter and/or a nozzle flowmeter.

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

Flowmeter	Cost	Head Loss
Orifice meter	Low	High
Nozzle flowmeter	Medium	Medium
Venturi meter	High	Low

3.3 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 3.8. If the deflection of mercury in the manometer is 0.1 m, then determine the velocity of water at the centre of the pipe. The densities of water and mercury are 1000 kg/m^3 and 13600 kg/m^3 respectively.

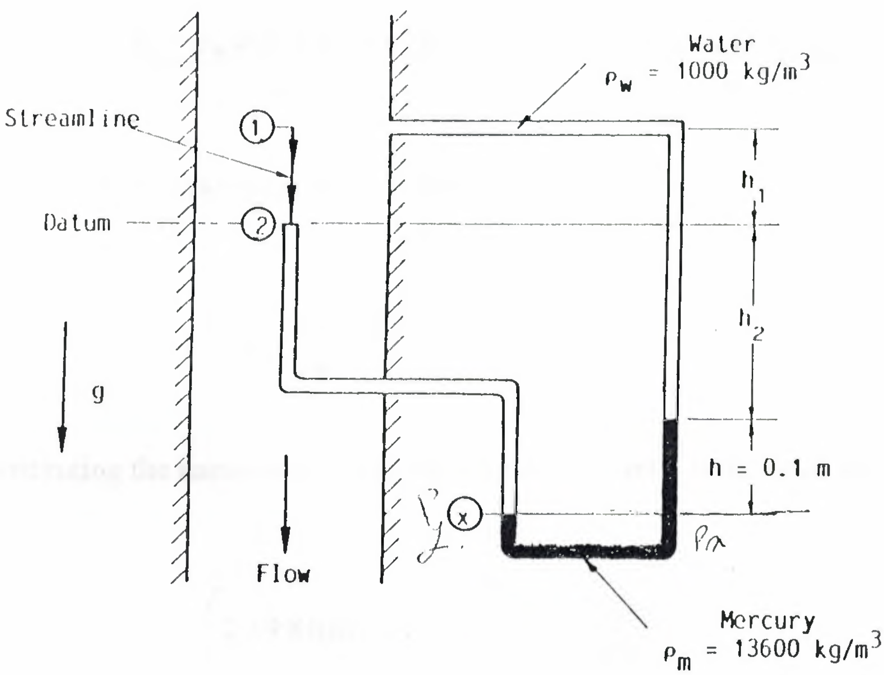

Figure 3.8 sketch for example 3.1

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 3.8 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 3.8 $Z_1=h_1$ 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 for the velocity at point 1results in;

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

Substituting the numerical values the velocity at point 1 is obtained as;

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

$$v_1 = 4.97 \quad m/s$$

Example 3.2

A fire nozzle; which is to be used at an elevation of 10 m above the level of a reservoir as shown in Figure 3.9. The velocity of the jet is to 15 m/s. The cross section areas of the hose and the nozzle are 0.004 m^2 and 0.001 m^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 net head to be supplied by the pump
b) the power required to derive the pump, if the pump efficiency is 70 percent

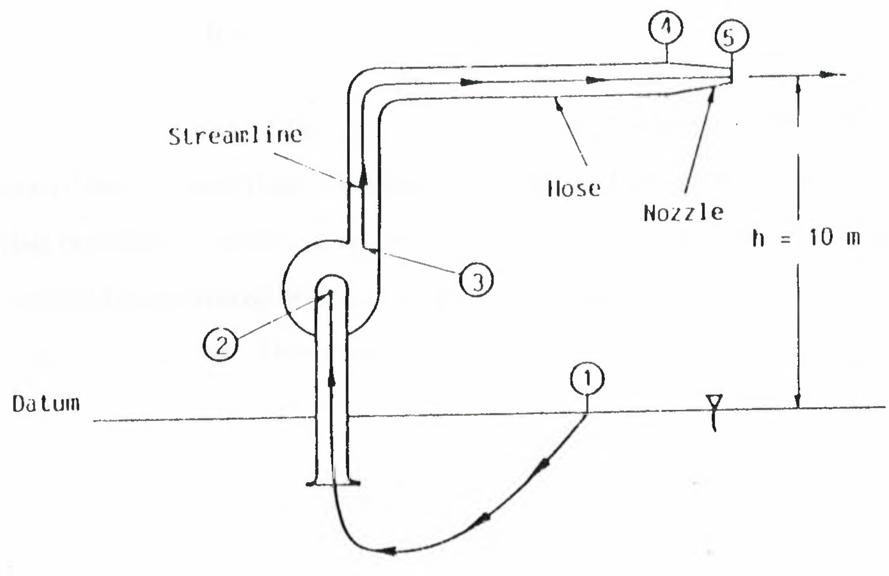

Figure 3.9 Sketch for example 3.2

Solution

The velocity of the fluid in the inlet 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;

$$V_4A_4 = V_5A_5$$

Also $A_1 = A_3 = A_4$ 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 streamline that is shown in Figure 3.9 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

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

As long as the area of the reservoir is very large when compared to 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 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 3.9, $Z_{10}=0$. Therefore;

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

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

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

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

And for the nozzle;

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

The required pump head is obtained as;

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

The volumetric flow rate may now be determined as;

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

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

$$P_f = \rho g Q h_s = 1000(\text{kg/m}^3)\times 9.81(\text{m/s}^2)\times 0.015(\text{m}^3/\text{s})\times 32.03(\text{m})$$
$$P_f = 4.71(\text{kW})$$

Thus the power required to derive the pump is

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

Example 3.3

A sharp edged orifice with an area of 0.01 m^2 is installed in a vertical pipe with an area of 0.04 m^2 as shown in Figure 3.10 The velocity and the contraction coefficients for the orifice are 0.98 and 0.61 respectively. The mercury manometer indicates a deflection of 0.1 m. The densities of water and mercury are 1000 kg/m^3 and 13600 kg/m^3 respectively. Determine the volumetric flow rate through the pipe.

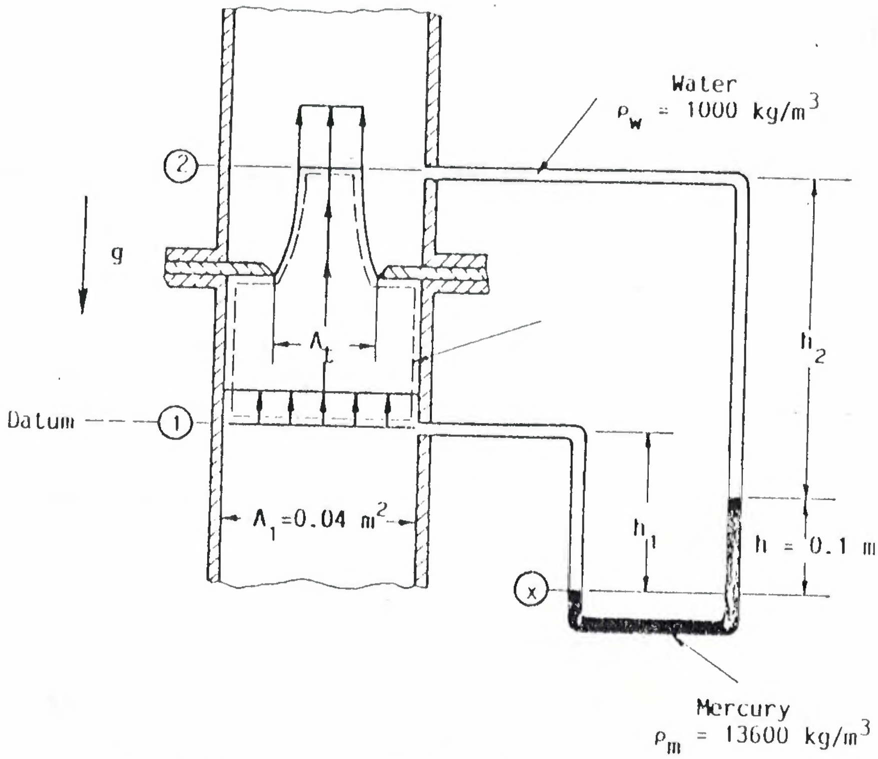

Figure 3.10 Sketch for example 3.3

Solution

Applying the continuity equation for steady flow of an incompressible fluid to the control volume, which is shown in Figure 3.10 it is possible to obtain;

$$V_1A_1 = V_{2i}A_2$$

Where V_{2i} represents the ideal velocity at section 2. The Bernoulli equation for the steady flow of an incompressible fluid may be applied between point 1 and 2 along the chosen streamline 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

$$P_1 = P_X - \rho_W g h_1$$

And

$$P_2 = P_X - \rho_m g h - \rho_W g h_2$$

Also, according to the chosen datum $Z_1 = 0$ and $Z_2 = h_2 - h_1 + h$ then the Bernoulli equation may be written as;

$$\frac{P_X - \rho_w g h_1}{\rho_w} + \frac{(V_{2i}A_2 / A_1)^2}{2} = \frac{P_X - \rho_m g h - \rho_W g h_2}{\rho_w} + \frac{V_{2i}^{\ 2}}{2} + g(h_2 - h_1 + h)$$

Solving for V_{2I} and noting that $A_2 = C_C A_t$

$$V_{2i} = \left(\frac{2 \times 9.81(m/s^2) \times 0.1(m) \times \dfrac{13600(kg/m^3)}{1000(kg/m^3)}}{1 - \left(\dfrac{0.61 \times 0.01(m^2)}{0.04(m^2)} \right)^2} \right)^{1/2} = 5.03 m/s$$

Then the actual velocity at section 2 , V_{2a} is

$$V_{2a} = C_V V_{2i} = 0.98 \times 5.03(m/s)$$

Now the actual volumetric flow rate through the pipe is;

$$Q = V_{2a} A_2 = C_C V_{2a} A_t = 0.61 \times 4.93(m/s) \times 0.01(m^2) = 0.0301(m^3/s)$$

3.4 CONCLUSION

This chapter analysed the flow measuring devices. The equations that govern their working principles were accomplished. The flow velocity and the static pressure were obtained firstly for the Orifice meter. Then the flow velocity expressions were derived for the flow rate measuring devices both for flow from a reservoir and for flow in closed conduits. Further more, a comparison was held among the three main devices for measuring flow rates. The comparison was from an economical point of view beside the accuracy of the devices themselves. Moreover, because of the errors of measurement of flow velocity and flow rate it was necessary to develop correction coefficients to help in obtaining more accurate measurements.

CHAPTER IV

FLOW MAESURMENT DEVICES

The objet of this chaoter is to present a discussion of more flow measuring devices that are used commercially and to indicate their principles of operation. Also to give simplified calculations beside the descibtion of the components of each device.

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 neceassery 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 avarage flow rate is thus calculated very easily. Improved accuracy may be obtained by using longer or more exact timing or more precise weghit measurement . The direct-weighing technique is frequently used for calibration of flow meters, and thus may be taken as a standard calibration technique.

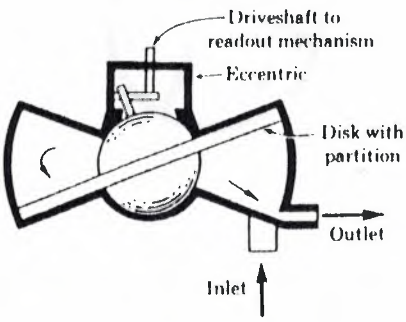

Figure 4.1 a nutating meter

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 schemetically in Figure 4.1. This meter operates on the nutating-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 seperates the inlet and the out let chamber of the disk. As the disk nutates, it gives direct indication of the volume of the liquid whice 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 percrnt deviation.

An other tyoe 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 uncertainities 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.

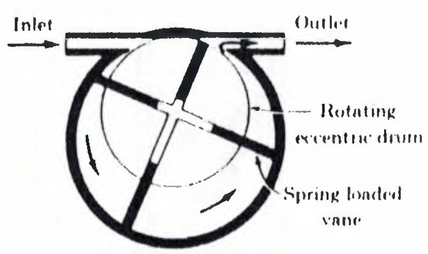

Figure 4.2 components of a rotary vane flow meter

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.

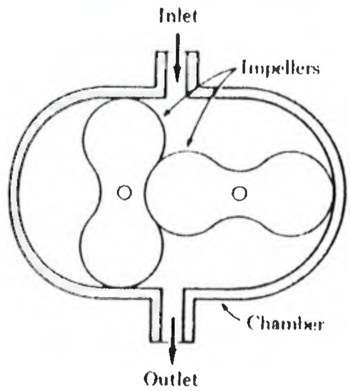

Figure 4.3 Schemetic of lobed-impeller flow meter

4.2 ROTAMETER

A rotameter is composed of a tapered tube and a float 'or a bob' inside it. As shown in figure 4.4 the fluid enters the vertical tapered tube causing the float to move upward.

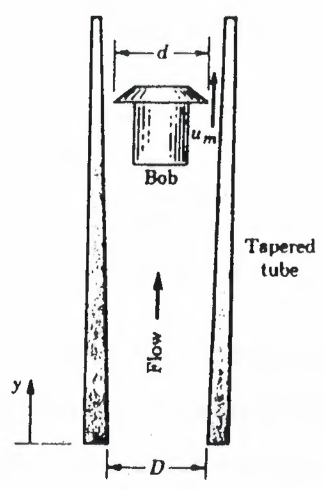

Figure 4.4 the rotameter

The float will rise to a point will rise in the tube to the point where the drag forces are balanced by the weight and the bouyancy forces. The device is also called an area meter because the elevation of the float is dependent on the annular area between it and the tapered glass tube.

4.3 THERMAL 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 flowmeter 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 $60\,^0\mathrm{C}$ above the first sensor. As a result of the gas flow, the heating of the second sensor is transferred to the gas by convection.

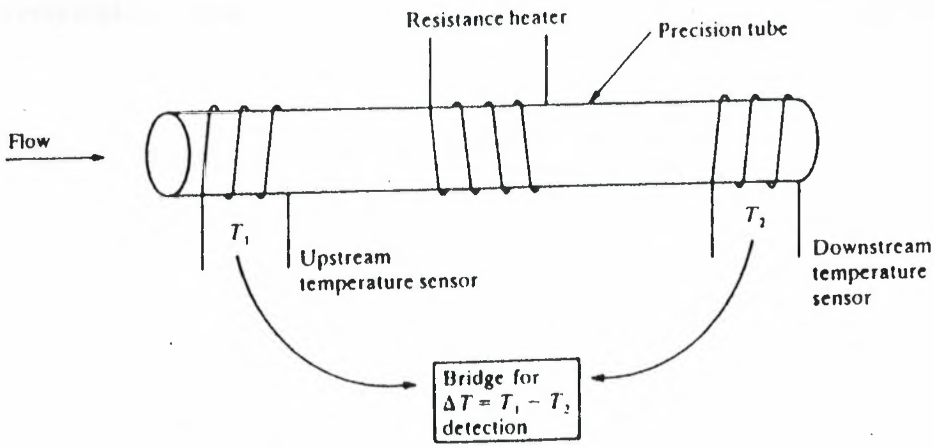

Figure 45 Massflow meter based on thermal energy transfer

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 maitain the $60\,^0\mathrm{C}$ tempereture difference. It must be noticed that those kind of meters measures the mass flow rate at the point of immersion only.

4.4 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 hight 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

Throughout this project the fluid flow properties measurements were analyzed by introducing classification of the fluid flow in the first chapter. This classification is important for the study of the properties of the fluid flows. In the second chapter the definitions of the mass flow rate and the volumetric flow rates were presented with their mathematical expression. In addition, two important equations were derived from the principles of conservation of mass and conservation of energy. Those two useful formulas are named as the continuity equation and Bernoulli equation respectively, and by their means it is possible to calculate the flow velocity and the flow rates of a fluid be considering a streamline in the direction of the flow.

The working principles of the most common flow measuring devices were represented. First some velocity measuring devices such as the pitot tube and the combined pitot tube were explained with the proper illustrating figures. The flow rate measurements using simple devices were discussed. Firstly measurement of flow rate from a reservoir using an orifice opening is studied and the necessary corrections were made to achieve the flow rate as accurate as possible. This resulted in some corrective coefficients such as contraction coefficient that can be determined experimentally. The orifice meter device is further used for the measurement of flow rates in closed conduits with a reasonable deviations which can be minimized by calculation of the effect of friction force and it contribution to the flow that results in head losses. Velocity coefficient was also discussed and combined with the contraction coefficient to result a total head loss coefficient that improves the accuracy of the measurements. The working principles of the nozzle flow meter is almost the same as that of the orifice but it differs in that it has a converging extended section to control the deceleration of the flow while passing through the nozzle opening. The same thing can be said about the venturi meter, which has an additional diverging section that controls the expansion of the fluid in the pipe after passing through the minimum cross section of the venturi meter. Moreover a comparison among the devices was held considering the economical point of view too. The third chapter included some numerical examples which were chosen from the practical life to further explain the usage of the flow measuring devices and to make their working principle more clear.

The fourth chapter included more complex flow measuring devices, which are commercially used. Brief explanations of their components were made. The advantage of these devices is that they can measure the flow properties directly by indicating the measurements by register. Moreover, they have good accuracy and less measurement errors.

Since the fluid measurements are of great important to both scientists and engineers, there are more complex and advanced measuring devices than those represented in this project. In addition, the flow measurements are rapidly developing nowadays and more advanced techniques are involved with the aid of computers and digital registers which makes the measurement more precise and accurate.

REFERENCES

WILLIAM S. JANNA. Introduction to Fluid Mechanics, PSW Engineering BOSTON

JOSEPH B. FRANZINI. Fluid Mechanics. Mc Graw Hill 1997

J. P. HOLMAN. Experimental Methods For Engineers. Mc G raw Hill sixth edition

HALUK AKSEL. Fluid Mechanics. M.E.T.U 1994