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FACULTY OF ENGINEERING

DEPARTMENT OF MECHANICAL ENGINEERING

PRESSURE LOSSES IN PIPE FLOWS

GRADUATION PROJECT ME-400

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Firstly thanks for God who guide me in my life…..

I want to dedicate this project to my university N.E.U.

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*Your's **AMER ISMAEEL.***

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CHAPTER 4 CALCULATION OF THE EXPERIMENT & RESULTS

Chapter 1

Introduction to Fluid Mechanics

Introduction

This chapter gives an introduction for fluid mechanics, including the development of fluid mechanics to be discussed, fluids, some of its properties and the way we measure them. Then the basic equations for fluid mechanics were discussed; including the continuity equation, beside Bernolli's equation (energy equation).

Reynold's number is introduced, also the flow, flow types were discussed. Then the equations used in experiment were classified, such as the pressure, the velocity, the flow rate, figures and tables were combined also.

1.1 The Development of Fluid Mechanics

From time to time we discover more about the knowledge that ancient civilization had about fluids, particularly in the areas of irrigation channels and sailing ships. The Romans are well known for their aqueducts and baths, many of which were built in the fourth century B.C, with some still operating today. The Greek are known to have made quantified measurements, the best known being those of Archimedes who discovered and formulated the principles of buoyancy in the third century B.C.

We know of no basic improvement to the understanding of flow until Leonardo da Vinci (1452-1519), who performed experiments, investigated, and speculated on waves and jets, eddies and streamlining, and even on flying. He contributed to the one-dimensional equation for conversion of mass.

Isaac Newton (1642-1727), by formulating his laws of motion and his law of viscosity, in addition to developing the calculus, paved the way for many great developments in fluid machines. Using Newton's laws of motion, numerous 18^{th} century mathematicians solved many frictionless (zero-viscosity) flow problems. However, most flows are dominated by viscous effects, so engineering of the 17^{th} and 18^{th} centuries found the inviscid flow solution unsuitable, and by experimentation they developed empirical equations, thus establishing the science of hydraulics.

In 1904 Ludwig Prandtl published a key paper, proposing that the flow fields of low-viscosity fluids be divided into two zones, namely a thin, viscosity-dominated boundary layer near solid surface, and an effectively inviscid outer zone away from the boundaries. This concept enabled subsequent engineers to analyze far more complex flows. However, we still have no complete theory for the nature of turbulence, and so modern fluid mechanics continues to be a combination of experimental results and theory.

1.2 Fluids

Fluids, as the other forms of matter, such as solids, are discontinuous in nature, consisting of molecules. However in contrast to solids, fluid molecules posses a high degree of motion freedom, such that they tend to assume the shape and occasionally occupy the volume of their containers. Fluids may include (1) gases: of the highest degree of molecular motion freedom and lightest molecular weight such that they occupy the volume of their containers; (2) liquids: enough molecular motion to assume the shape but not the occupy the entire volume of their container under gravity; (3) any other form of matter that can be made to behave as a fluid, for example, molten metals and polymer melts and granular solids(e.g., sands, wheat, etc.), in which case making unit in the grain; (4) mixtures of two or more of the foregoing three. All of these forms of discontinuous matter are characterized by the ability of each of the constituting units to change its position with respect to its neighbors, which distinguishes them from plain solids. Due to these properties, fluids are defined as matter that cannot support shear forces of any magnitude without continuous deformation and flow (i.e., relative motion). Of course, fluids deform and flow under normal forces as well, but so do solids, which, in contrast, can resist shear forces without any continuous deformation or flow, up to a certain level of shear force of structure collapse.

1.3 Fluid Properties

Properties are conditions that characterized a state. Fluids exhibit extensive and intensive properties. Extensive properties depend on the amount of fluid: for example, mass, weight, volume, internal energy, and enthalpy. Intensive properties do not depend on the amount of fluid: for example, pressure, density, temperature, concentration, and specific heat.

After all I will mention some of these properties; as follows:

1. Density.
2. Specific volume.
3. Specific weight.
4. Viscosity (Dynamic, Kinematic)

1.3.1 Density

A fundamental property of continuum is the mass density. Density, symbolized by ρ, is the ratio of the mass m to the volume V, occupied by a fluid. The density is given by :

$$\rho = \frac{M}{V}$$

Where;

ρ : density, [kg/m^3]**Table 1.1**

M : mass, [kg]

V : volume, [m^3]

Fluid	**Density** ρ [kg/m^3] (at 25C)
Water	997
Mercury	13580
Oil	885

1.3.2 Specific Volume

Specific volume υ, is the volume occupied by a unit mass of fluid. Specific volume is the reciprocal of density thus it is considered to be a fluid property, and given by this equation:

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

Where;

v : specific volume, [m^3/kg]

ρ : density, [kg/m^3]

1.3.3 Specific Weight

Specific weight of some common liquids at (20°C) and standard sea-level atmospheric pressure with g =(9.81 m/s^2) are given in table coming table the specific weight of liquids varies only slightly with pressure, depending on the bulk modulus of the liquid; it is also depends on temperature, and the variation may be considerable. Since specific weight γ is equal to ρg , the specific weight of fluid depends on the local value of the acceleration of gravity in addition to the variations with temperature and pressure. The presence of dissolved air, salts in solution, and suspended matter will increase these values a very slight amount. Ocean water may ordinarily be assumed to weigh (10.1 KN/m^3). Unless otherwise specified or implied by some specific temperature being given, the value to use for water in the problems in the text is γ = (9.81 kN/m^3). Under extreme conditions the specific weight of water is quite different. The specific weight is given by this equation:

$\gamma = (M/V).(g) = \rho.g$ Where;

γ : specific weight, [N/m^3]

M : mass, [kg]

V : volume, [m^3]

ρ : density, [kg/m^3]

Table 1.2 Specific weight for some liquids at 20°C, with g = (9.81m/s²)

Fluid	kN/m³
Motor oil	8.5
Water	9.81
Seawater	10.05

Ideal fluid may be defined as a fluid in which there is no friction; it is inviscid (its velocity is zero). Thus the internal forces at any section within it are always normal to the section, even during motion. So these forces are purely pressure forces. Although such a fluid does not exist, many fluids approximate frictionless flow at sufficient distance from solid boundaries, and so their behaviors can often be conveniently analyzed by assuming an ideal fluid.

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

1.3.4 Viscosity

Viscosity is a measure of the stickiness of the fluid. High viscosity fluids stick together and produce large friction on surroundings. The viscosity of a fluid changes with temperature. For liquid it decreases with temperature whereas for gases viscosity increases with temperature.

Viscosity μ is the property of a fluid, which offers resistance to shear deformation. Different fluids deform at different rates under the same shear stress. Fluid with a high viscosity such as syrup deforms more slowly than fluid with a low viscosity such as water. Viscosity can be calculated from this equation;

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

Where;

μ : viscosity, [N/Kg]

γ : specific weight, [N/m^3]

ρ : density, [kg/m^3]

Kinematic Viscosity

Kinematics Viscosity is the ratio of dynamic viscosity to the density of the fluid.

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

Where,

ϑ : viscosity, [m^2/s]

μ : dynamic viscosity, [N/Kg]

1.4 Basic Equation of Fluid Mechanics

There are two basic equations that discuss the flow of the fluids, one of them is the continuity equation, and the other one is the energy equation, I will discuss these equations as follows:

1.4.1 Continuity Equation

The application of the principle of conservation of mass to a fluid flow yields an equation which is refered to as the continuity equation. This equation tells the mass flow rate m°, or the weight flow rate. As the volumetric flow Q° do not change throughout a single pipe or pipes in series, then we will have the same mass flow rate all over the system (single pipe or pipes in series).as seen in fig. (1.1)

$$\text{Mass Flow Rate} = \frac{\Delta m}{\Delta t}$$

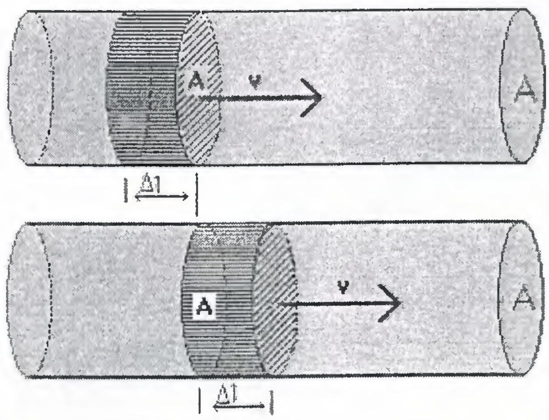

Figure 1.1 Flow Rate Inside of Pipe

The derivation of the mass flow rate, using a differential element, as follows:

$$\Delta V = A \Delta l$$

$$\Delta l = V \Delta t$$

$$\Delta m = \rho \Delta V = \rho A \Delta l = \rho A V \Delta t$$

$$\text{Mass Flow Rate} = \frac{\Delta m}{\Delta t} = \rho A V$$

Where,

Q° : discharge, $[m^3/s]$.

A : cross sectional area, $[m^2]$.

V: velocity, $[m/s]$.

Δl: length $[m]$.

But in the case of different diameter system (different volumetric flow rate, as seen in Figure1.2):

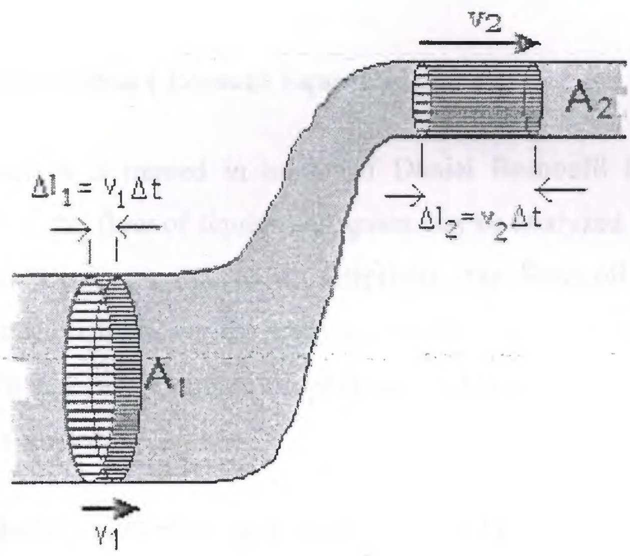

Figure 1.2 Flow Rate In Different Section Areas

$\Delta m^{\circ}_1 = \rho_1 A_1 V_1 \Delta t$

$\Delta m^{\circ}_2 = \rho_2 A_2 V_2 \Delta t$

The mass Δm_1 that flows into a region must equal the mass Δm_2 that flows out of the region. That is;

$\Delta m^{\circ}_1 = \Delta m^{\circ}_2$

$\rho A_1 V_1 \Delta t = \rho A_2 V_2 \Delta t.$

$\rho A_1 V_1 = \rho A_2 V_2.$

Where ;

ρ : density, [kg/m^3].

A : cross sectional area, [m^2].

V : velocity, [m/s].

1.4.2 The Energy Equation (Bernolli Equation)

The Bernoulli equation is named in honor of Daniel Bernoulli (1700-1782). Many phenomena regarding the flow of liquids and gases can be analyzed by simply using the Bernoulli equation. However, due to its simplicity, the Bernoulli equation may not provide an accurate enough answer for many situations, but it is a good place to start. It can certainly provide a first estimate of parameter values. The resulting equation is called the "energy equation".

The Bernoulli equation assumes that your fluid and device meet four criteria: 1. Fluid is incompressible, 2. Fluid is inviscid, 3. Flow is steady, 4. Flow is along a streamline.

The Bernoulli equation is used to analyze fluid flow along a streamline from a location 1 to a location 2. Most liquids meet the incompressible assumption and many gases can even be treated as incompressible if their density varies only slightly from 1 to 2. The steady flow requirement is usually not too hard to achieve for situations typically analyzed by the Bernoulli equation. Steady flow means that the flow-rate (i.e. discharge) does not vary with time. The in-viscid fluid requirement implies that the fluid has no viscosity. All fluids have viscosity; however, viscous effects are minimized if travel distances are small.

Bernoulli equation is one of the most important equations in fluid mechanics. It may be written;

$P_1/\gamma + V_1^2 / 2g + h_1 = P_2/\gamma + V_2^2 / 2g + h_2$.

Where ;

P : pressure, $[N/m]$.

γ : specific weight, $[N/m^3]$.

V : velocity, $[m/s]$.

g : gravity acceleration, $[m/s^2]$.

h: elevation, $[m]$.

The Bernoulli equation applies to conditions along a streamline. It can be applied between two points, 1 and 2, on the streamline as shown in Figure 1.3:

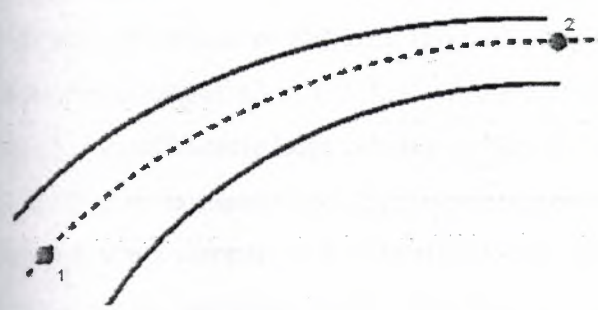

Figure 1.3 Two Points Joined by a Streamline.

Total head at 1 = Total head at 2.

$$P_1/\gamma + V_1^2 / 2g + h_1 = P_2/\gamma + V_2^2 / 2g + h_2$$

1.4.3 Reynold's Number

In 1883, Osborne Reynolds, he injected a fine, threadlike stream of colored liquid having the same density as water at the entrance to a large glass tube through which water was flowing from a tank. A valve at the discharge end permitted him to vary the flow. When the velocity in the tube through which water was small, this colored liquid was visible as a straight line throughout the length of the tube, thus showing that the particles of water moved in parallel straight lines. As the velocity of the water was gradually increased by opening the valve further, there was a point at which the flow changed. The line would first become wavy, and then at a short distance from the entrance it would break into numerous vortices beyond which the color would be uniformly diffused so that no stream lines could be distinguished, this famous experiment results in two flow types:
Laminar flow and turbulent flow.

Reynold's no. is the ratio of inertia to viscous forces in the velocity to boundary layer, F_I/F_S *=inertia force/ viscous force,* this dimensionless parameters, determine the existence of laminar or turbulent flow, in many flow types there exist small disturbances that can be amplified to produce turbulent conditions. For small Re; however, viscous forces are sufficiently large relative to inertia forces to prevent this amplification. Hence laminar flow is maintained. But, with increasing Re, viscous effects become relatively less important comparing with inertia effects, and small disturbances may be amplified to a point where transition occurs. The type of flow will be discussed later in this chapter, for now the Reynold's no. relations is explained as follows;

$$Re = \frac{V.D.\rho}{\mu}$$

Where,

V: velocity

D: diameter of pipe

μ: dynamic velocity

The measuring of Re, came from this Equation;

$\mu = \gamma \rho$

Where,

μ: dynamic velocity, [N/Kg]

γ: specific weight, , [N/m^3]

$Re = \frac{V.D}{\gamma}$.

There is a critical Reynolds number above which laminar flow is disrupted and turbulence occurs. Therefore, as blood flow velocity increases in a blood vessel or across a heart valve, there is not a gradual increase in turbulence as the Reynolds number increases. Instead, laminar flow will continue until a critical Reynolds number is reached, at which point, turbulence will develop.

1.5 Flow Types

There are many different fluid flow classifications; laminar flow, turbulent flow and transition flow, will be discussed as follows:

1.5.1 Laminar Flow

For low flow rates, the pressure gradient is linearly proportional to the flow rate, and the flow is **laminar,** as characterized by the famous Reynold's experiment. In this type of flow the particles in the fluid move in definite and observable paths or streamlines as seen in fig. 1.3 , and also that the flow is characteristic of a viscous fluid or is one in which viscosity plays a significant part.

The Friction Coefficient for Laminar Flow

For fully developed laminar flow the roughness of the duct or pipe can be neglected, the laminar flow is described in Figure 1.4. The friction coefficient depends only the Reynolds Number - Re - and can be expressed as follows:

$f = 64 / Re$

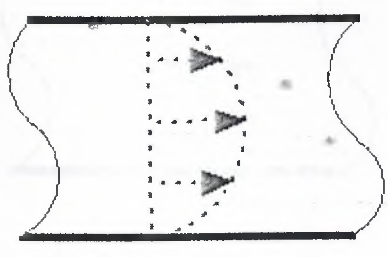

Figure 1.4 Laminar Flow.

1.5.2 Transition Flow

For intermediate flow rates, there is no unique relation between flow rate and pressure drop, and the response alternates randomly. Large swirls and irregular movements of large particles of fluid, which can be traced to obvious sources of disturbance, do not constitute turbulence, but may be described as disturbed flow.

The Friction Coefficient for Transient Flow

If the flow is transient - 2300 < Re < 4000 - the flow varies between laminar and turbulent flow and the friction coefficient is not possible to determine.

1.5.3 Turbulent Flow

For high flow rates, the pressure gradient is roughly proportional to the square of the flow rate, where the flow is characterized as **turbulent**. turbulence may be found in what appears to be a very smoothly flowing stream and one in which there is no source of disturbance as seen in Figure 1.4. Turbulent flow is characterized by fluctuation in velocity at all points of the flow field. These fluctuations arise because the fluid moves as a number of small, discrete particles or packets called eddies, jostling each other around in a random manner.

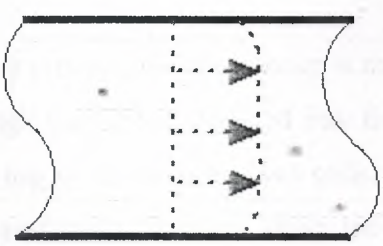

Figure 1.5 Turbulent Flow.

The Friction Coefficient for Turbulent Flow

For turbulent flow the friction coefficient depends on the Reynolds Number and the roughness of the duct or pipe wall. On functional form this can be expressed as:

$f = f(Re, \varepsilon / D_h)$

Where ;

ε : relative roughness of tube or duct wall, $[mm]$

ε / D_h : the roughness ratio.

D_h : hydraulic diameter $[m]$.

1.6 Fluid Measurements:

1.6.1 Measurement of Viscosity

Viscosity is the property of a fluid that resists the action of a shear force. Viscosity results from molecular action and cohesion in the fluid, one of the ways to measure the viscosity is:

The patented CAS electromagnetic viscometer:

Its design is very simple. In a process, the viscometer is mounted in a pipeline as shown above. Fluid traveling through the pipe is diverted into the measurement chamber by a flow deflector mounted on top of the sensor. Two coils, imbedded in the body of the viscometer, around the measurement chamber, drive the magnetic piston through the fluid, as seen in Figure 1.6.

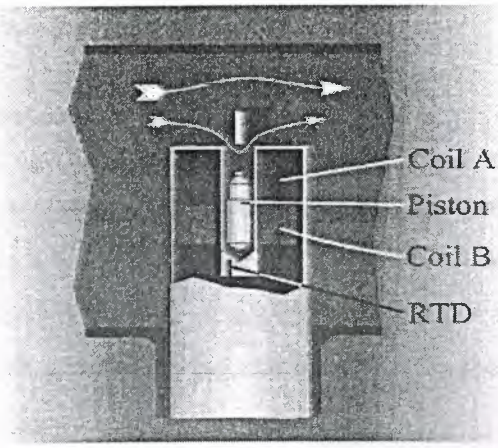

Fig 1.6 The Patented CAS Electromagnetic Viscometer.

When the lower "B" coil is activated the magnetic force on the piston pulls it down toward the base of the chamber. Excess fluid trapped behind the piston is forced out while fresh sample is drawn in. When the piston reaches the bottom of its stroke, coil "B" is turned off and coil "A" is activated, changing the direction of piston travel.

The force driving the piston is constant. The more viscous the fluid the longer it will take the piston to move through the measurement chamber and the less viscous the fluid, the more rapidly the piston will travel. The total two-way travel time of the piston is a very accurate measure of the fluid's absolute viscosity (cP). Our systems are guaranteed to meet a repeatability specification of 0.8% and an accuracy of +/-1.0%.The sensor is not sensitive to flow, vibration or changes in orientation. New data is updated on average, every 10-15 seconds. Fluid temperature is constantly measured using a platinum RTD mounted at the base of the chamber. The data provided by the system includes Temperature, Viscosity and Temperature Compensated Viscosity (TCV).

1.6.2 Measurement of Density

Hydrometer

Density are typically measured with a hydrometer. A hydrometer works on the principle that when a body is immersed in a liquid it is buoyed up with a force equal to the weight of the liquid displaced. The hydrometers used in this lab have been calibrated such that the specific gravity can be read directly from the paper scale located inside the glass neck. As seen in the fig. 1. below.

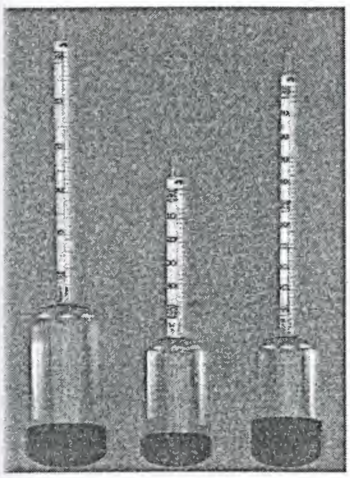

Fig. 1.7 Hydrometer.

1.6.3 Measurement of Static, Stagnation Pressure

Pressure

Pressure is always directed toward the surface (i.e., it is a normal stress), which is defined as equal to the magnitude of the force divided by the area of the surface.

Under equilibrium conditions, pressure results from random molecular collision with the surface and is also called thermodynamic pressure. Under flow conditions the resulting pressure, due to directed molecular collisions with the surface, is different from the thermodynamic pressure and is called mechanical pressure.

1.6.3.1 Static Pressure

The pressure at any point in a static fluid depends only on the pressure at the top of the fluid and the depth of the point in the fluid. If point 2 lies a vertical distance h below point 1, there is a higher pressure at point 2 as seen in fig. 1. , the pressure at the two points is related by the equation:

$$P_2 = P_1 + \rho g h$$

Where ;

P_1: atm. pressure, $[N/m^2]$.

ρ : density, $[kg/m^3]$.

g : gravity acceleration, $[m/s^2]$.

h: elevation, $[m]$.

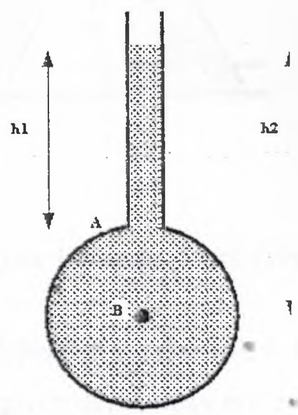

Figure 1.8 Pressure Depth in a Static Fluid

In Figure 1.1 that Point 2 does not have to be directly below point 1. it is simply a vertical distance below point Point 1. This means that every point at a particular depth in a static fluid is at the same pressure.

The pressure exerted by a static fluid depends only upon the depth of the fluid, the density of the fluid, and the acceleration of gravity. The pressure in a static fluid varises from the weight of the fluid and is given by the expression.

$P_{static\,fluid} = \rho g h$

Where,

ρ: density, $[kg/m^3]$.

g : gravity acceleration, $[m/s^2]$.

h : Depth of Fluid, $[m]$.

The pressure from the weight of a column of liquid of area A and height h is

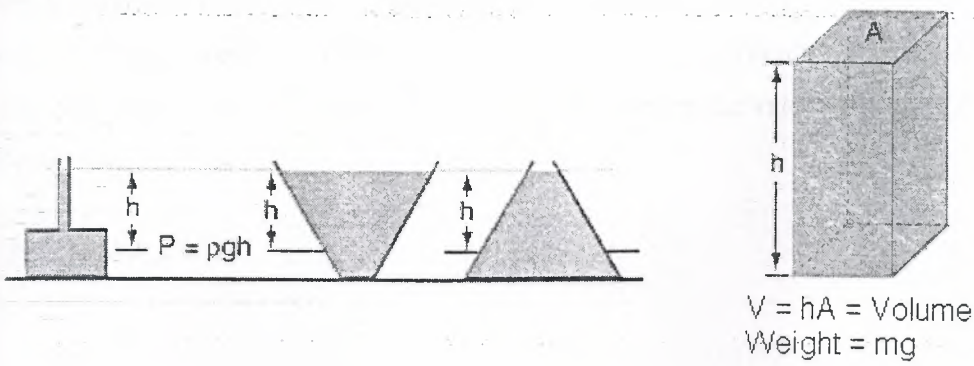

Figure 1.9 Static Fluid Pressure.

Static fluid pressure does not depended on the shape, total mass, or surface area of the liquids, The fluid pressure at a given depth does not depend upon the total mass or total volume of the liquid.

1.6.3.2 Stagnation Pressure

If a stream of uniform velocity flows into a blunt body, the stream lines take a pattern similar to this:

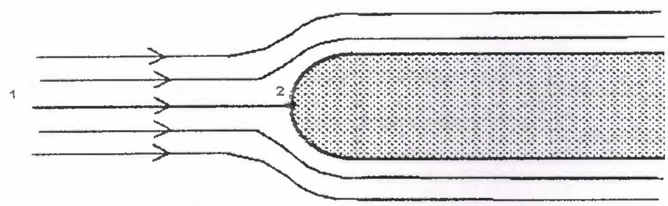

Fig.1.10 Streamlines around a blunt body.

Note how some move to the left and some to the right. But one, in the centre, goes to the tip of the blunt body and stops. It stops because at this point the velocity is zero - the fluid does not move at this one point. This point is known as the *stagnation point.*

From the Bernoulli equation we can calculate the pressure at this point. Apply Bernoulli along the central streamline from a point upstream where the velocity is V_1 and the pressure P_1 to the stagnation point of the blunt body where the velocity is zero, $V_2 = 0$. Also $h_1 = h_2$.

$$P_2 = P_1 + 1/2\ \rho V^2_1$$

V: velocity, $[m/s]$

ρ: density, $[kg/m^3]$.

This increase in pressure which bring the fluid to rest is called the *dynamic pressure*.

Dynamic pressure = $1/2\ \rho V^2_1$

or converting this to head (using $h = \dfrac{p}{\rho g}$)

Dynamic head = $V_1^2 / 2g$

The total pressure is know as the *stagnation pressure* (or *total pressure*)

Stagnation pressure = $P_1 + 1/2\ \rho V^2_1$

or in terms of head

Stagnation head = $P_1/\gamma + V_1^2 / 2g$.

1.6.4 Measurement of Velocity

Pitot Static Tube

The *Pitot static* tube combines the tubes and they can then be easily connected to a manometer. A Pitot static tube is shown below. The holes on the side of the tube connect to one side of a manometer and register the *static head, (h_1)*, while the central hole is connected to the other side of the manometer to register, as before, the *stagnation head (h_2)*. As seen in the fig. below.

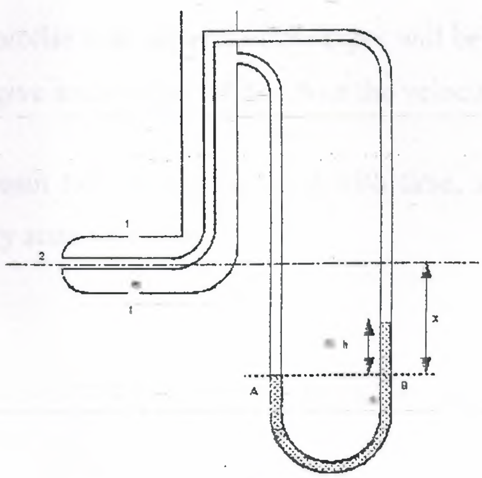

Figure 1.11 A Pitot-static Tube.

Consider the pressures on the level of the centre line of the Pitot tube and using the theory of the manometer,

$P_A = P_B.$

$P_A = P_2 + \rho gx.$

$P_B = P_1 + \rho g(x\text{-}h) + \rho_{mer.} gh.$

$P_2 + \rho gx = P_1 + \rho g(x\text{-}h) + \rho_{mer.} gh.$

Stagnation pressure = $P_1 + 1/2\ \rho V^2_1$

$P_1 + hg(\rho_{mer.} - \rho) = P_1 + 1/2\ \rho V^2_1$

Substituting these equations it results in the velocity, which is calculated by this equation:

$V^2_1 = 2\ hg\ (\rho_{mer.} - \rho) / \rho.$

Velocity of the flow is the average speed of all molecules at a point in the flow at a given time. Velocity is a vector quantity and can be constructed from three scalar components, (horizontal, and vertical, forward).

The variation of velocity profile with different flow types will be discussed later in this project, so for now I will give some information about the velocity in pipes.

If the mass inside the stream tube is not changing with time, so that the fluid is either incompressible or in steady state we have;

$\rho V_1 A_1 = \rho V_2 A_2$

Where;

ρ : density, [kg/m^3].

V : velocity of the fluid, [m/s].

A : cross sectional area, [m^2].

And here are some of measuring procedure of velocity, as follows in Figure. 1.4 :

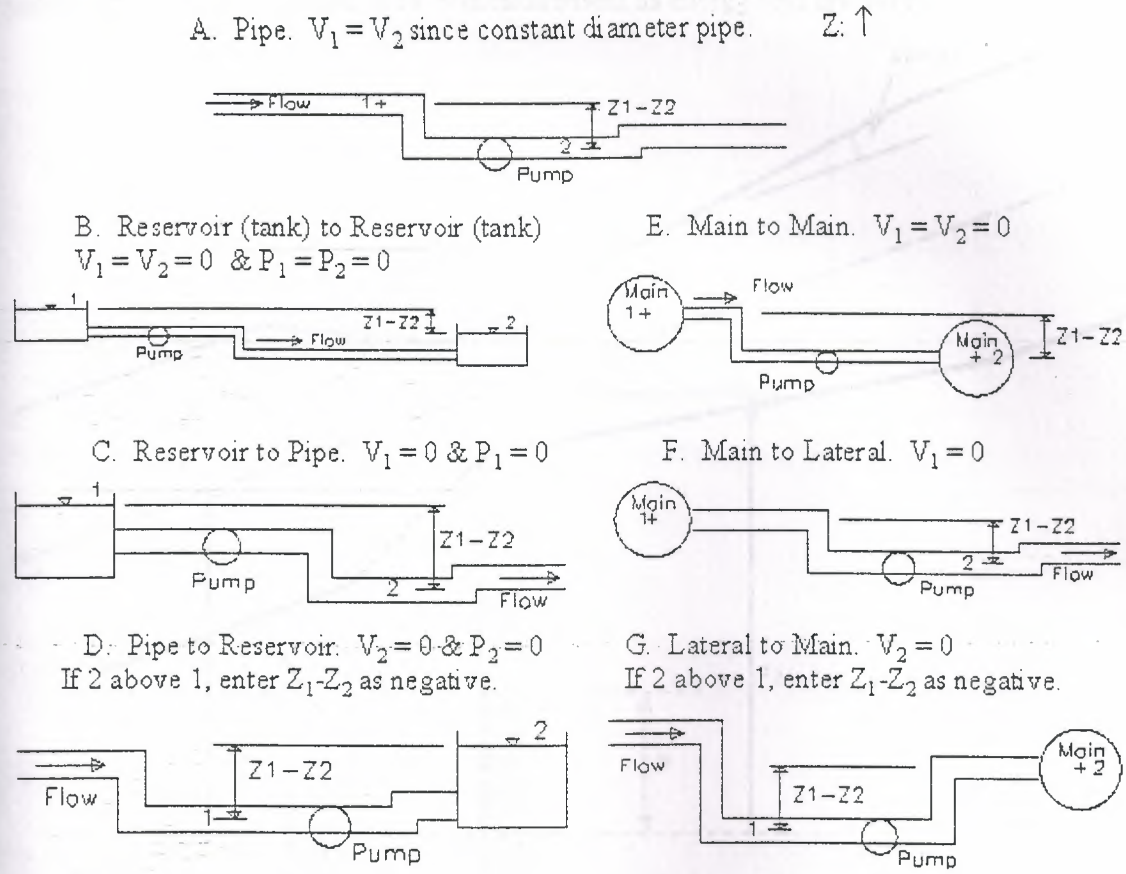

Figure 1.12 Velocity Measurement.

1.6.5 Measurement of Flow Rate

To measure the rate at which water is flowing along a pipe, a very simple way of doing this is to catch all the water coming out of the pipe in a tank over a fixed time period. Measuring the weight or volume of the water in the tank and dividing this by the time taken to collect this water gives a rate of flow rate.

The Venturi meter is a device for measuring discharge in a pipe. It consists of a rapidly converging section which increases the velocity of flow and hence reduces the pressure.

It then returns to the original dimensions of the pipe by a gently diverging 'diffuser' section. By measuring the pressure differences the discharge can be calculated. This is a particularly accurate method of flow measurement as energy loss are very small.

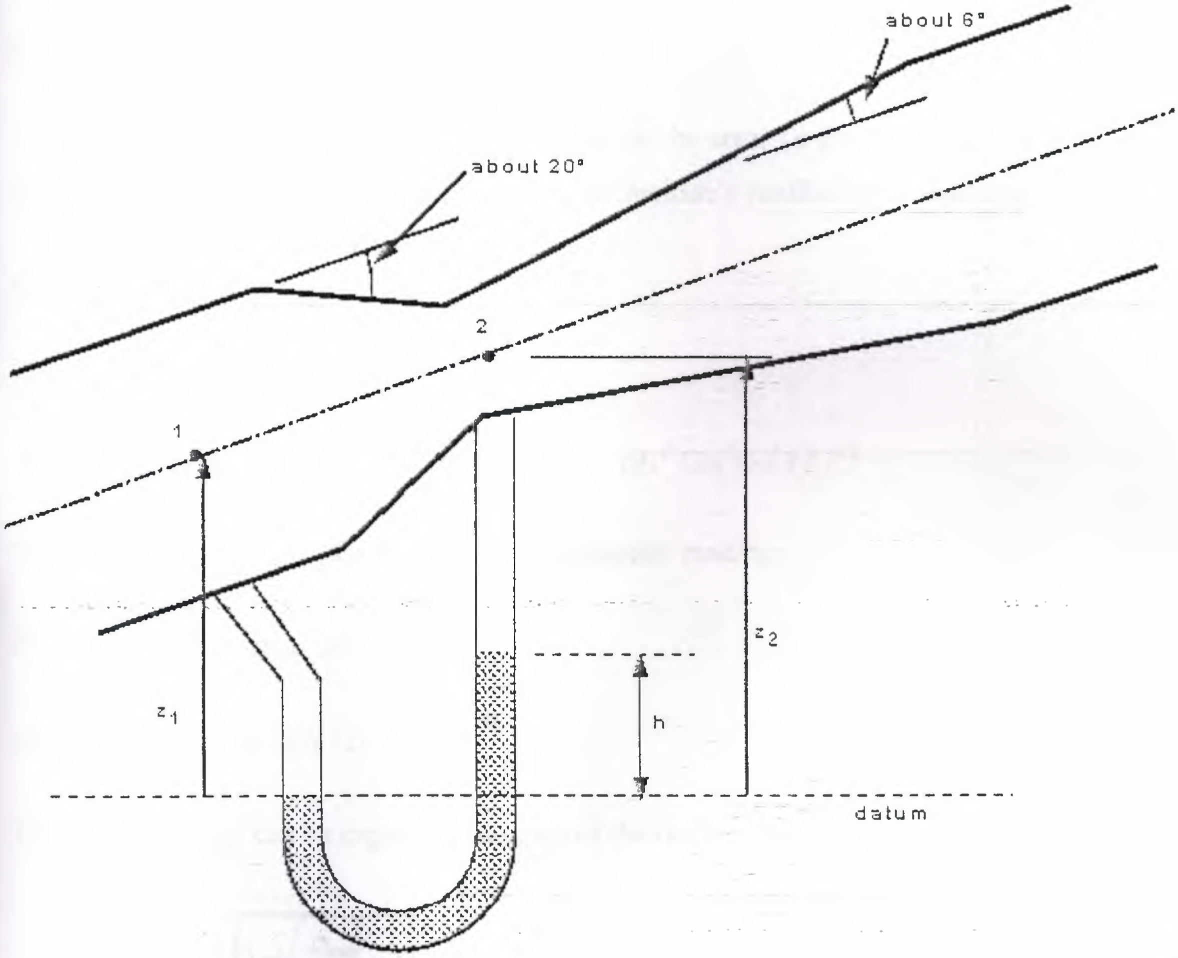

Fig. 1.13 A Venturi Meter

Applying Bernoulli along the streamline from point 1 to point 2 in the narrow *throat* of the venturi meter we have

$$P_1/\gamma + V_1^2 / 2g + z_1 = P_2/\gamma + V_2^2 / 2g + z_2.$$

By the using the continuity equation we can eliminate the velocity V_2,

$$Q = A_1 V_1 = A_2 V_2.$$

$$V_2 = A_1 V_1 / A_2.$$

Substituting this into and rearranging the Bernoulli equation we get

$(P_1 - P_2)/\gamma + z_1 - z_2 = (V_1^2 / 2g)((A_1^2 / A_2^2) - 1).$

$V_1^2 = 2g\,[((P_1 - P_2) / \gamma) + z_1 - z_2) / ((A_1^2 / A_2^2) - 1)].$

To get the theoretical discharge this is multiplied by the area. To get the actual discharge taking in to account the losses due to friction, we include a coefficient of discharge

$Q_{ideal} = A_1 V_1.$

$Q_{actual} = C_d\, Q_{ideal} = C_d\, A_1 V_1.$

$Q_{actual} = C_d\, A_1 A_2 (2g\,[((P_1 - P_2) / \gamma) + z_1 - z_2) / ((A_1^2 / A_2^2) - 1)])^{1/2}$

This can also be expressed in terms of the manometer readings

$P_1 + \rho g z_1 = P_2 + \rho_{mer.} gh + \rho g(z_2 - h).$

$(P_1 - P_2)/\gamma + z_1 - z_2 = (h)((\rho_{mer.} / \rho) - 1).$

Thus the discharge can be expressed in terms of the manometer reading :

$$Q_{actual} = C_d A_1 A_2 \sqrt{\frac{2gh\left(\frac{\rho_{man}}{\rho} - 1\right)}{A_1^2 - A_2^2}}$$

Notice how this expression does not include any terms for the elevation or orientation (z_1 or z_2) of the venturi meter. This means that the meter can be at any convenient angle to function.

The purpose of the diffuser in a venturi meter is to assure gradual and steady deceleration after the throat. This is designed to ensure that the pressure rises again to something near to the original value before the venturi meter. The angle of the diffuser is usually between 6 and 8 degrees. Wider than this and the flow might separate from the walls resulting in increased friction and energy and pressure loss. If the angle is less than this the meter becomes very long and pressure losses again become significant. The efficiency of the diffuser of increasing pressure back to the original is rarely greater than 80%.

1.7 Conclusion

In this chapter; the fluids, their properties; such as viscosity, density, specific weight and specific volume were discussed.

Then the basic equations of fluid mechanics were explained, such as the continuity equation, and the energy equation (Bernolli's equation). And the relation between the pressure, velocity, density and the fluid elevation.

The Reynold no. and its relation with laminar, transition and turbulent flow was explained, beside the flow types.

The devices we use for the measurement of the viscosity (Hydrometer), the measurement of density (CAS viscometer), the measurement of the static and the stagnation pressure, the velocity (pitot tube), the flow rate (venturi meter). Were also discussed and the governing equations.

Chapter 2

Head Losses in Pipes

Introduction

In this chapter, the aim is to explain the head losses, the major losses, the minor losses, the friction coefficient for different flow types also were explained, the losses due to sudden contraction and enlargement were given in equations.

The velocity effects, the roughness table, and k values for pipes, bends and fittings were given in two tables.

2.1 Head Losses in Pipe

The Energy equation can be expressed in terms of head and head loss by dividing each term by the specific weight of the fluid. The total head in a fluid flow in a tube or a duct can be expressed as the sum of elevation head, velocity head and pressure head.

$$P_1/\gamma + V_1^2 / 2g + h_1 = P_2/\gamma + V_2^2 / 2g + h_2 + ht_{loss}$$

The head loss of a pipe, tube or duct system, is the same as that produced in a straight pipe or duct whose length is equal to the pipes of the original systems plus the sum of the equivalent lengths of all the components in the system. This can be expressed as:

$$ht_{loss.} = \Sigma\, h_{major\_losses} + \Sigma\, h_{minor\_losses}$$

Where ;

h_t ; total head loss in the pipe or duct system.[m]

h_{major_losses} ; major loss due to friction in the pipe or duct system, or h_f. [m]

h_{minor_losses} ; minor loss due to the components in the system, or h_L. [m]

2.1.1 Major Losses

The major head loss for a single pipe or duct can be expressed as:

$$h_f = f \, (L / D_h) \, (V^2 / 2g)$$

where ;

h_f : head loss [m].

f : friction coefficient.

L : length of duct or pipe [m].

D_h : hydraulic diameter [m].

V : flow velocity [m/s].

g : acceleration of gravity [m/s^2].

The friction coefficient f depends on the flow - if it is laminar, transient or turbulent - and the roughness of the tube or duct.

To determine the friction coefficient we first have to determine if the flow is laminar, transient or turbulent - then use the proper formula or diagram.

With the Moody diagram we can find the friction coefficient if we know the Reynolds Number - Re - and the Roughness Ratio - ε / D_h.

In the diagram we can see how the friction coefficient depends on the Reynolds number for laminar flow - how the friction coefficient is undefined for transient flow - and how the friction coefficient depends on the roughness ratio for turbulent flow.

For hydraulic smooth pipes - the roughness ratio limits zero - and the friction coefficient is more or less depending of the Reynolds number only.

For fully developed turbulent flow the friction coefficient more or depends on the roughness ratio only.

The Friction Coefficient for Laminar Flow

For fully developed laminar flow the roughness of the duct or pipe can be neglected. The friction coefficient depends only the Reynolds Number - Re - and can be expressed as:

$f = 64 / Re$

Where ;

f : friction factor.

Re : Reynolds number

The Friction Coefficient for Transient Flow

If the flow is transient - 2300 < Re < 4000 - the flow varies between laminar and turbulent flow and the friction coefficient is not possible to determine.

The Friction Coefficient for Turbulent Flow

For turbulent flow the friction coefficient depends on the Reynolds Number and the roughness of the duct or pipe wall. On functional form this can be expressed as:

$f = f(Re, \varepsilon / D_h)$

Where ;

ε : relative roughness of tube or duct wall, $[mm]$

ε / D_h : the roughness ratio.

D_h : hydraulic diameter $[mm]$.

The relative roughness of the pipe is given in table 2.1.

Table 2.1 Usual Value Index of Roughness (ε) in mm.

Surface	**Roughness - ε**
	millimeters
Copper, Lead, Brass, Aluminum (new)	0.001 - 0.002
PVC and Plastic Pipes	0.0015 - 0.007
Epoxy, Vinyl Ester and Isophthalic pipe	0.005
Stainless steel	0.015
Weld steel	0.045
Galvanized steel	0.15
Rusted steel (corrosion)	0.15 - 4
New cast iron	0.25 - 0.8
Worn cast iron	0.8 - 1.5
Rusty cast iron	1.5 - 2.5
Ordinary concrete	0.3 - 1

2.1.2 Minor Losses

Minor losses, h_l, can be determined by the following equation;

$$h_L = k\frac{V^2}{2g}$$

Where;

h_l : minor loss, $[m]$.

k : minor head loss coefficient.

The coefficient of minor head loss can also be determined from tables of fluids mechanics book. There are values for every type of valve, elbows, tees, bends, and sudden and gradual expansions and contractions coefficient, the k values are given in tables 2.2, 2.3

Table 2.2 K Factor for Fitting

K Factor of fitting								
	Nominal Diameter, in							
	1/2	3/4	1	1 1/2	2	3	4	5
Gate Valve (open)	0.22	0.2	0.18	0.16	0.15	0.14	0.14	0.13
Globe Valve (open)	9.2	8.5	7.8	7.1	6.5	6.1	5.8	5.4
Standard Elbow (screwed) 90	0.8	0.75	0.69	0.63	0.57	0.54	0.51	0.48
Standard Elbow (screwed) 45	0.43	0.4	0.37	0.34	0.3	0.29	0.27	0.26

Table 2.3 Minor Loss Coefficients.

Fitting	**k**	**Fitting**	**k**
Valves:		*Elbows:*	
Globe, fully open	10	Regular 90°, flanged	0.3
Angle, fully open	2	Regular 90°, threaded	1.5
Gate, fully open	0.15	Long radius 90°, flanged	0.2
Gate 1/4 closed	0.26	Long radius 90°, threaded	0.7
Gate, 1/2 closed	2.1	Long radius 45°, threaded	0.2
Gate, 3/4 closed	17	Regular 45°, threaded	0.4
Swing check, forward flow	2		
Swing check, backward flow	infinity	*Tees:*	
		Line flow, flanged	0.2
180° return bends:		Line flow, threaded	0.9
Flanged	0.2	Branch flow, flanged	1.0
Threaded	1.5	Branch flow, threaded	2.0
Pipe Entrance (Reservoir to Pipe):		*Pipe Exit (Pipe to Reservoir)*	
Square Connection	0.5	Square Connection	1.0
Rounded Connection	0.2	Rounded Connection	1.0
Re-entrant (pipe juts into tank)	1.0	Re-entrant (pipe juts into tank)	1.0

2.1.3 Losses due to Sudden Enlargement

Consider the flow in the sudden enlargement, shown in Figure below, fluid flows from section 1 to section 2. The velocity must reduce and so the pressure increases this follows from Bernoulli. At position 1' turbulent eddies occur which give rise to the local head loss.

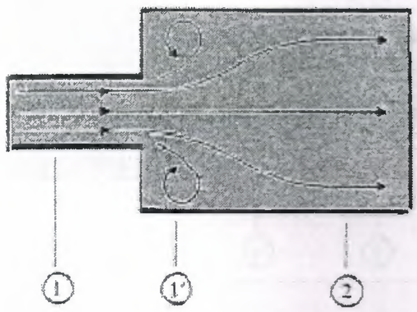

Figure 2.1 Sudden Expansion.

$$k_L = \left(1 - \frac{A_1}{A_2}\right)^2$$

Where,

K_L : Losses at Sudden Friction

A_1: Section area one

A_2: Section area two

So h_L:

$$h_L = \left(1 - \frac{A_1}{A_2}\right)^2 V^2/2g$$

2.1.4 Losses Due to Sudden Contraction

In a sudden contraction, flow contracts from point 1 to point 1'. It is possible to assume that energy losses from 1 to 1' are negligible no separation occurs in contracting flow but that major losses occur between 1', 2 as the flow expands again. As shown in Figure 2.6

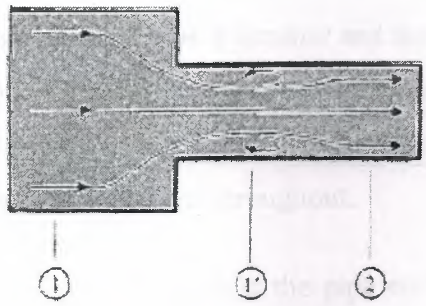

Figure 2.2 Sudden Contraction

$h_L = 0.44\ V_2^2 / 2g$

Where,

h_L : Sudden friction

V_2 : Velocity in pipe 2

2.2 Pipe Bends And Fittings

The pipe Bends and Fittings Apparatus enables friction losses in various types of pipe fittings to be determined experimentally. The apparatus consists of a test length of pipe work fitted to a vertical panel on a movable base. In the pipe run are a pipe union, globe, valve, gate valve and pipe fitting are manometer each fitted with stopcock. Manometer tubes which can be connected by means of flexible rubber to the manometer on both sides of the fitting under test are mounted on the panel. The difference in manometer heights will then indicate the loss in head of water caused by the fitting. If a higher pressure flow rate is required to test the fitting the manometer can be pressurized by the use of the cycle tire type air pump supplied with the apparatus.

2.3 The Velocity Effects

At low speeds the whole flow across a pipe is laminar and the fluid slides over itself. As the speed becomes faster eddies start to form and cross the fluid layers. A transition from laminar to turbulent flow develops. At still higher velocities the flow in the core of the pipe becomes turbulent with swirling eddies throughout.

The laminar sub layer is always present against the pipe wall. But as the velocity rises the energetic swirling eddies begin to impact more deeply and the sub layer begins to thin. At still higher velocities the sub layer thins further and the taller roughness peaks stick into the turbulent region. Where the sub layer covers the roughness projections the wall is considered smooth. When the wall roughness pokes out of the sub layer the wall is considered rough. This means the same wall can be both smooth and rough depending on the fluid's velocity.

The pipe system designer has to strike a practical balance between increasing the pipe diameter to reduce energy loss and keeping the diameter small to lower installation costs.

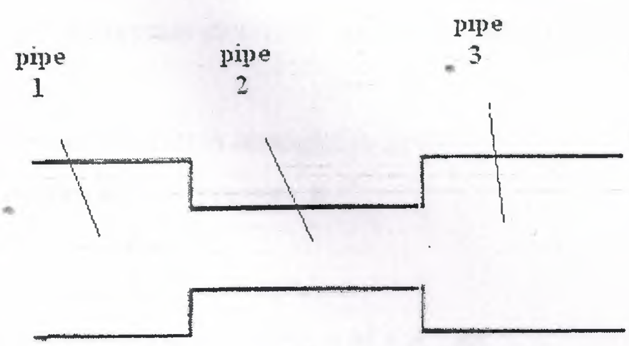

Fig. 2.7 Different diameter pipe

2.4 Measurement of Pressure Difference Using a "U"-Tube Manometer

If the "U"-tube manometer is connected to a pressurised vessel at two points the *pressure difference* between these two points can be measured.

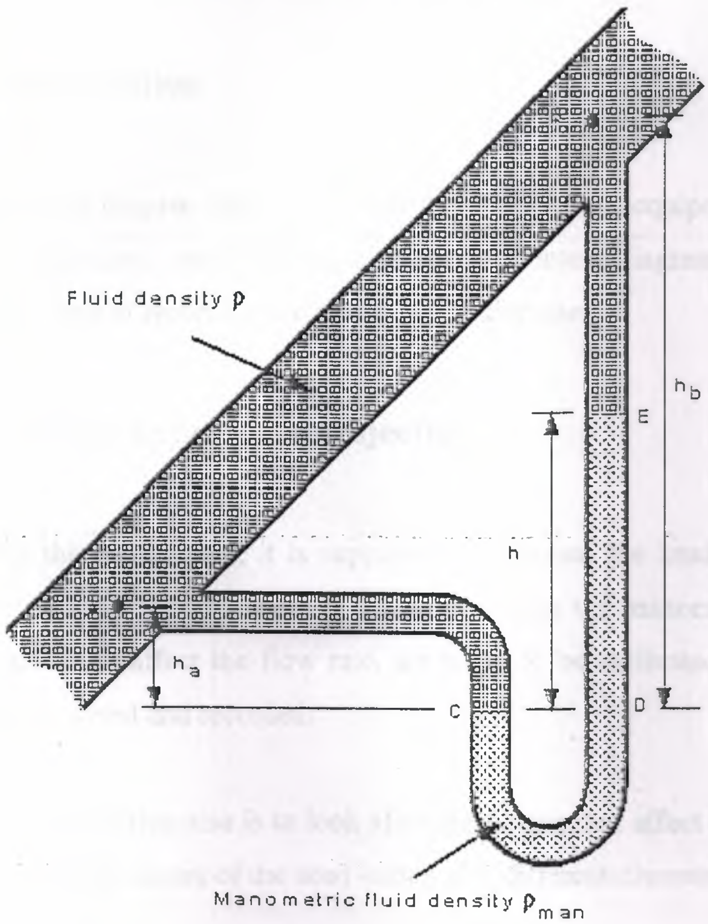

Fig. 2.8 Pressure difference measurement by the "U"-Tube manometer

If the manometer is arranged as in the figure 2.8, then

pressure at C = pressure at C

$$p_C = p_D$$

$$p_C = p_A + \rho g h_a$$

$$p_D = p_B + \rho g(h_b - h) + \rho_{man} g h$$

$$p_A + \rho g h_a = p_B + \rho g(h_b - h) + \rho_{man} g h$$

Giving the pressure difference $p_A - p_B = \rho g(h_b - h_a) + (\rho_{man} - \rho) g h$

Chapter 3

Experimental Setup

Introduction

In this chapter, the aim of this experiment, the equipments assembly, the equipments dimensions, specifications, also the experiment diagram, the experiment procedure and the way of recording the results, were discussed.

3.1 The Experiment Objective

In this experiment, it is supposed to calculate the head losses, by measuring the mass flow rate, and the pressure difference using the manometer U tube, and how the water elevation affect the flow rate, the valve to be calibrated, and the time interval must be considered and recorded.

The objective also is to look after the factors that affect the steady state flow rate, and to know the causes of the head losses, in a different diameter pipe.

3.2 Equipments

In this experiment as seen in Figure 3.1 ; a small water tank were used, that is connected by 90° elbow to a different diameter pipe, U tube manometer is attached to the large diameter portions of the pipe in order to measure the pressure difference, at the end of the mentioned pipe a valve has been connected to control the flow rate, the water flows through the valve into another tank that is connected to a pump, pushes up the water to the first tank, and so on.

3.3 Experiment Setup

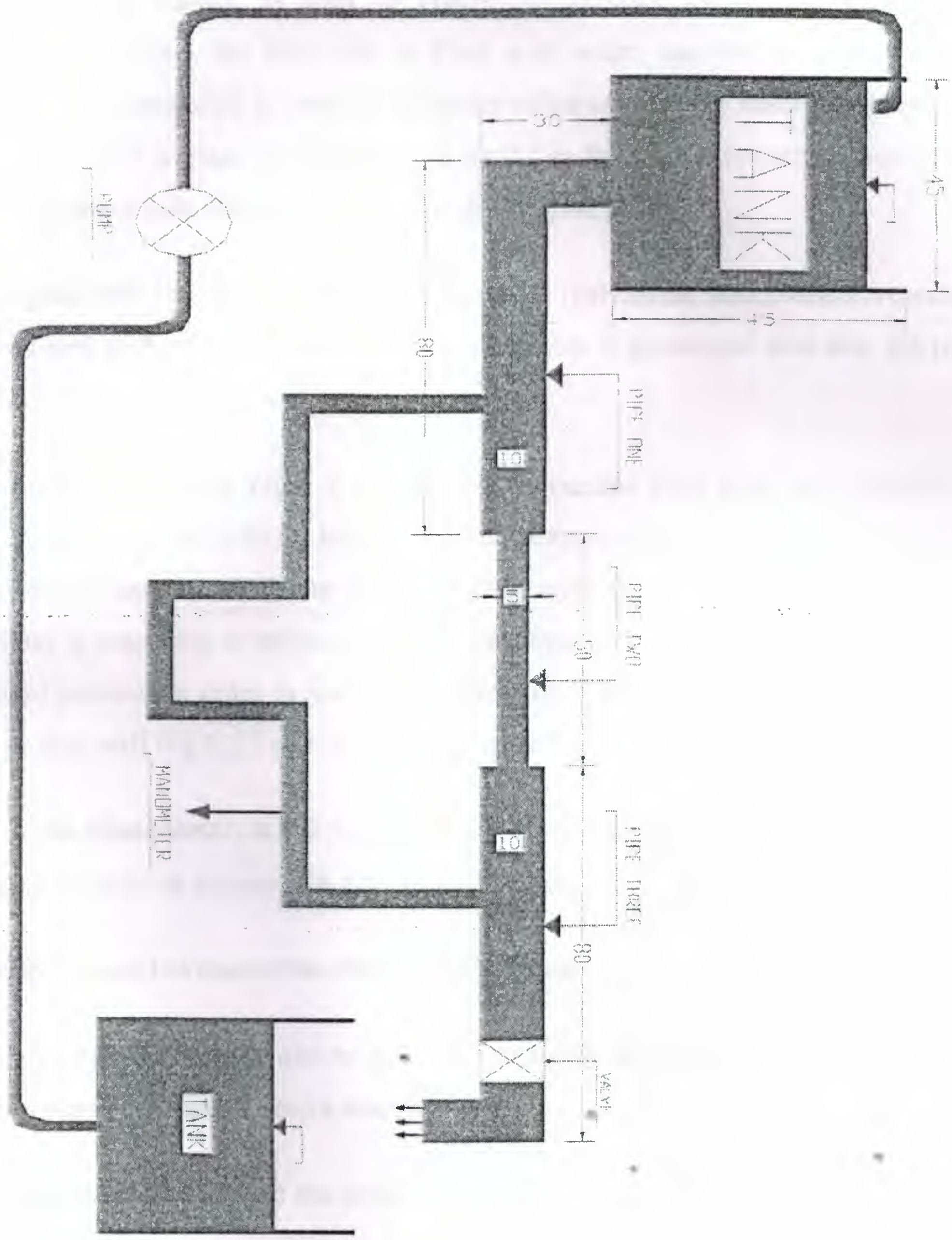

Figure 3.1 Experiment Setup

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The equipments were used are described as follows:

- **Two Water Tanks**, as seen in Figure 3.1.both are galvanized, the volume is ($42cm \times 45cm \times 45cm$), the first tank is filled with water, and the water elevation was measured and controlled in order to study the effect of different water elevations on the head losses. The k value is considered to be 0.2 as the case is re-entrant (pipe just into tank). The other tank was used to keep the water cycle going on.

- **Regular 90° Threaded Elbow** (k=1.5), that is (galvanized steel) which is connecting the first tank to the different diameter pipe, the elbow is galvanized steel also, the relative roughness of tube or duct wall is ε =.15 *mm*.

- **Different Diameter Pipe,** it is a 210 *cm* galvanized steel tube, let's consider three portions, the first one is 80 *cm* long with 10 *cm* diameter, the second is 50 *cm* long with 5 *cm* diameter and the third one is 80 *cm* long with 10 *cm* diameter. All pipes (three portions) is connected in series. A U tube manometer is connected between the first and the third portions in order to measure the pressure difference. The relative roughness of tube or duct wall is ε = .15 *mm*. As seen in Figure 3.1.

- **U-Tube Manometer,** that is using mercury is connected between the first and the third portions, in order to measure the pressure difference.

- **Valve**, is used to control the flow rate of the water.

- **Water Pump**, was used also to push the water into the first tank as seen in Figure 3.1, the pump was efficient to keep a steady state flow.

- **Ruler,** was used to read the level of mercury and the depth of the water in the first tank.

- **A digital stop watch** was while filling the bucket.

3.4 The Experiment Procedure

Measuring The Flow Rate

While applying this experiment, the following steps were followed;

- The water tank is to be filled using the pump until the desired water elevation.

- The water elevation is measured, while pump is working, the out let valve was opened gradually, until the flow is steady.

- Then the out let water was filled into a bucket, and the bucket weight was recorded, over a certain time interval.

These 3 three steps were done for different elevations.

Measuring the Pressure Difference

While measuring the pressure difference using the U tube manometer, the same as the 1^{st} and the 2^{nd} steps above.

- Then the manometer readings to be recorded.

3.5 Conclusion

In this chapter, the experiment was discussed; the objective of this experiment is to measure the flow rate and the head losses in pipes

The experiment diagram and all of its components were classified, and the usage of each component, the assembly of the equipments, the equipment specification and the water cycle was explained.

The experiment procedure, in measuring the flow rate and the pressure difference using the manometer was discussed also.

Chapter 4

Calculations of the Experiment& Results

Introduction

In this chapter, after the experiment was done, the readings are tabulated, then the mass flow rate, discharge, velocity, head loss, pressure differences between two points are calculated and tabulated, also the errors values were found, the causes were discussed.

4.1 Mass Flow Rate Calculation

The mass flow rate is to be calculated, using this equation:

M = Water mass/ Time.

Mass Flow Rate = $\dfrac{\Delta m}{\Delta t}$.

M: mass flow rate, *[kg/s]*.

4.2 Discharge Calculations

This volumetric flow rate is to be calculated using this equation:

$Q = M / \rho_{water}$., where;

Q: discharge f low rate, $[m^3/s]$.

M: mass flow rate, *[kg/s]*.

4.3 Velocity Calculation

As the three pipes are connected in series, the water velocity ,can be calculated as follows:

$Q = A_1 V_1 = A_2 V_2 = A_3 V_3$

$V_3 = A_1 V_1 / A_3 = A_2 V_2 / A_3$, where;

V : velocity of the fluid, $[m/s]$.

A : cross sectional area, $[m^2]$.

4.4 Head Losses Calculation

Head losses, in various diameter pipe as in figure 4.1 can be calculated as follows;

$h_f = k_L + h_{L1} + h_{L2}$ where;

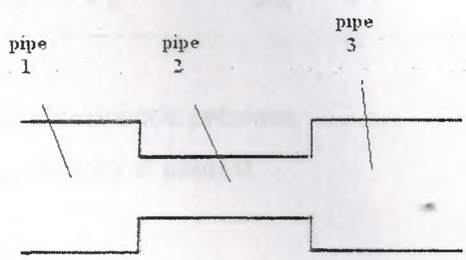

Figure. (4.1) Different Diameter Pipe.

The sudden contraction losses, between pipe 1 and 2, (h_{L1}) as seen in Fig 4.1. Where the sudden contraction losses can be calculated as follows;

$(h_{L1}) = .478\ (V_2^2 / 2g)$

V_2: velocity, *[m/s]*

The sudden enlargement, between pipe 2 and 3, *(h_{L2})*, sudden enlargement losses which can be calculated as given below;

$$h_{l2} = (1 - \frac{A_1}{A_2})^2 \frac{V_2^2}{2g} \quad \text{, where;}$$

A_1, A_2 : Cross Sectional Areas for pipes, *[m^2]*.

V_2: velocity, *[m/s]*.

4.5 Pressure Difference Calculation

The pressure difference to be calculated between point 0 (open tank) and point 1 at the first pipe (*10 cm* dia.), using the following equation, considering the losses, as follows;

$$\frac{p_0}{\rho g} + \frac{V_0^2}{2g} + z_0 = \frac{p_1}{\rho g} + \frac{V_1^2}{2g} + z_1 + h_f \quad \text{, where;}$$

P_0 : atmospheric pressure.

V_o: velocity at point 0.

$h_f = k_L + h_{L1}$

The pressure difference inside the pipe, between the 1st portion and the 2nd portion is to be calculated between point 1 and point 2 as seen in Fig 4.1, using the following equation.

$$\frac{P_1}{\rho g}+\frac{V_1^2}{2g}=\frac{P_2}{\rho g}+\frac{V_2^2}{2g}+h_f \text{, where,}$$

$$h_f = h_{L1} + h_{L2}$$

$$h_{L1} = .478\ (V^2_2/\ 2g)$$

$$h_{l2} = (1-\frac{A_1}{A_2})^2\,\frac{V_2^2}{2g}$$

Pressure Difference Calculation Using the Manometer

The pressure calculation between points (1) to (3) as seen in fig (4.1); this equation as expressed as;

$$p_1 - p_3 = x\ (\ \rho_{Water} + \rho_{Mercury})$$

Error calculation

The error can be carried out as follows;

$$Error = \frac{(P_1 - P_3)_{manometer} - (P_1 - P_3)_{Bernoulli's\ equation}}{(P_1 - P_3)_{manometer}} \times 100\%$$

4.6 Experimental Measurements

Here are the presentation for the experiment results, as follows:

Table 4.1 Step 1

Experimental No.	Time (s)	Mass (kg)	h (mm)	X (mm)
1	1.50	0.38	350	1.0
2	1.65	0.49	350	1.0
3	2.00	0.79	350	1.0

Table 4.2 Step 2

Experimental No.	Time (s)	Mass (kg)	h (mm)	X (mm)
1	1.12	1.31	260	1.2
2	1.69	1.47	260	1.2
3	2.00	1.56	260	1.2

Table 4.3 Step 3

Experimental No.	Time (s)	Mass (kg)	h (mm)	X (mm)
1	1.72	2.54	200	1.00
2	1.60	2.14	200	1.00
3	2.00	2.75	200	1.00

Table 4.4 Step 4

Experimental No	Time (s)	Mass (kg)	h (mm)	X (mm)
1	1.74	1.46	150	1.5
2	2.07	1.55	150	1.5
3	2.20	1.76	150	1.5

Table 4.5 Step 5

Experimental No	Time (s)	Mass (kg)	h (mm)	X (mm)
1	2.62	2.43	100	1.2
2	2.66	2.68	100	1.2
3	2.74	2.79	100	1.2

Table 4.6 Mass Flow Rate (Step 1)

Experimental No	Time (s)	Mass (kg)	Mass Flow rate (kg /s)
1	1.50	0.38	0.253
2	1.65	0.49	0.296
3	2.00	0.79	0.395
Average	1.72	0.55	0.315

Table 4.7 Mass Flow Rate (Step 2)

Experimental No	Time (s)	Mass (kg)	Mass Flow Rate (kg /s)
1	1.12	1.31	1.169
2	1.69	1.47	0.869
3	2.00	1.56	0.780
Average	1.60	1.44	0.939

Table 4.8 Mass Flow Rate (Step 3)

Experimental No	Time (s)	Mass (kg)	Mass Flow Rate (kg /s)
1	1.72	2.54	1.476
2	1.60	2.14	1.337
3	2.00	2.75	1.375
Average	1.77	2.47	1.396

Table 4.9 Mass Flow Rate (Step 4)

Experimental No	Time (s)	Mass (kg)	Mass Flow (kg /s)
1	1.74	1.46	0.839
2	2.07	1.55	0.748
3	2.20	1.76	0.800
Average	2.00	1.59	0.795

Table 4.10 Mass Flow Rate of Step 5

Experimental No	Time (s)	Mass (kg)	Mass Flow Rate (kg /s)
1	2.62	2.43	0.927
2	2.66	2.68	1.007
3	2.74	2.79	1.018
Average	2.67	2.63	0.984

Discharge Measurements

The Discharge table.

Average No	Time (s)	Mass (Kg)	Mass Flow rate (kg/s)	Discharge m^3 / s
1	1.72	0.55	0.32	0.000322
2	1.60	1.45	0.90	0.000902
3	1.77	2.48	1.39	0.001397
4	2.00	1.60	0.79	0.000794
5	2.73	2.63	0.96	0.000963

Losses Measurements

NO	$v_1 = v_3$ (m/s)	v_2 (m/s)	$h_{l(0,1)}$	$h_{l(1,2)}$	$h_{l(2,3)}$	$h_{l(1,3)}$
1	0.041061	0.164245	0.01075082	4.1076E-05	0.0123745	0.00313466
2	0.114941	0.459764	0.08424271	0.00032187	0.09696465	0.02456303
3	0.177913	0.711652	0.20183558	0.00077116	0.23231586	0.05885012
4	0.101106	0.404422	0.06518328	0.00024905	0.07502622	0.01900579
5	0.122728	0.490912	0.09604388	0.00036696	0.11054798	0.02800395

Pressure Calculation

Pressure table.

NO	Z (m)	Mass Flow Rate (kg/s)	Q (m^3/s)	p_1 (N/m^2)	p_2 (N/m^2)	p_3 (N/m^2)
1	0.60	0.32	0.000322	95007.69	9.50E+01	94976.94
2	0.51	0.90	0.000902	95163.87	9.52E+01	95133.12
3	0.45	1.39	0.001397	94589.67	9.46E+01	94558.92
4	0.40	0.79	0.000794	96431.44	1.91E+01	96400.69
5	0.35	0.96	0.000963	96616.78	9.66E+01	96586.03

Pressure Difference Calculations

Pressure Difference table

P_1-P_3 By using Bernoulli Equation (N/m^2)	P_1-P_3 By using Manometer (N/m^2)	The Error %
30.710	123.07	75.00%
240.35	147.69	38.52%
576.83	123.07	78.66%
186.39	184.65	00.95%
274.68	147.69	46.23%

4.7 The Error Analysis

The causes of the error were explained as follows:

- The pump does not give steady flow.
- The time between filling the tank and opening the valve, was varying each trail.
- The tank is two small in size comparing to the pipes.
- The manometer tube is not well fixed.
- The vibration while reading the mercury elevation.
- The dimension is not accurate.
- The time taken by the stop watch is not accurate at all.
- The valve each time was not opened at the same capacity.

4.8 Conclusion

In this chapter the way of calculating the mass flow rate, the discharge, the velocity, the head losses and the pressure difference using Bernolli's equation, were carried out.

The head losses were specified and discussed, the tank losses, the 90 elbow, the sudden contraction, sudden enlargement, and the valve losses were ignored. The experiment results were tabulated, including the various water elevation, the mass flow rate, the discharge, the velocity, the head losses and the pressure differences also.

Lastly, the differences between the Bernolli's results (calculated) and the manometer were calculated, and the errors were found and discussed.

PROJECT CONCLUSION

The major aim for this project was to calculate and discuss the pressure losses in flow pipes, as follows;

The first chapter was an introduction for fluid mechanics, including: the fluids, and some of fluids properties, such as density, specific weight, specific volume and viscosity. After that the basic equation in fluid mechanics were introduced, the continuity equation which talks about the mass conservation for close system, and the energy equation or Bernolli equation was expressed in terms of pressure, elevation, etc. Then Reynolds number was discussed, considering different flow types.

The different types of flow were discussed, including laminar, turbulent and transition, also the friction coefficient for these types was given in equation with respect to Reynolds number.

Also in that chapter we discussed the way we measure the viscosity, the density, the velocity, the flow rate and the pressure using the pitot tube and U-tube manometer.

In chapter two the aim was to study the head losses in a different diameter pipes, the major losses, the minor losses, losses due to sudden enlargement and sudden contraction were specified and given in Figures and equations. Then the k values for different type of pipes, elbows, fittings and valves were given in tables beside the roughness ratio.

Then in chapter three the experiment set up was given in diagram, the aim was to calculate the pressure losses in pipes using a venturi tube, the procedure for this experiment was given in steps, the equipments were specified.

In chapter four, it was a description for the experiment, each step was given in numerical equation, the tables give information for the mass flow rate, the discharge, the velocity, the losses in pipes, the pressure and finally the error were carried out.

Finally, the error causes were explained, and as mechanical engineers the suggestions to reduce the errors were as follows; to change the size of the inlet and out let tanks to fit the pipes diameter, also to use a suitable pump (capacity) in order to reach steady state flow for enough measuring time. Use more flexible U-tube in order to give the right mercury elevation, beside fixing the tube vertically. The vibration and noise were too high, so the venturi meter should be placed using rubber base for example. One of the suggestions was to place the ventrui tube horizontally for better flow and more accurate mercury readings. Moreover a control valve is preferred to place after the major valve in order to adjust the flow.

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