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ME 400
INTERNAL FLUID FLOW;
FLOW IN PIPES

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ABSTRACT

In this project fluid flow in pipes are described in four chapters, each chapter is introduced common properties and their application.

The first chapter is described fluid properties and definations scope of fluid mechanics, difference between liquid and gases, viscosity and at the end of the chapter Bernoulli's equation.

Second chapter is described laminar and turbulent flow phenomena, importance of viscosity in the laminar and turbulent flow, the role of entrance effects in the flow. However the types of flow such as internal, extarnal flow are discussed

In the third chapter one and two dimensional flows and specifications of these flows are considered. Also Reynolds number laminar, turbulent flows, Reynolds number situation between these flows, critical Reynolds number critic levels of laminar and turbulent flows are considered.

In the last chapter the types of pipe line system which effect the energy losses and efficiency are discussed. Energy losses such as minor and friction losses in turbulent flow that effect efficiency directly are included. Also using of Moddy diagram which is used to determine friction factor are considered.

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CHAPTER 1

INTRODUCTION

1.1FLUID PROPERTIES AND DEFINITIONS

Fluid mechanics is the science of the liquid and is based on the same fundamental principles that are employed in the mechanics.

Fluid mechanics may be divided into 3 branches;

.Fluid Statics
.Fluid Kinematics
.Fluid Dynamics

Fluid Statics: Is the study of the mechanics of fluids at rest.

Fluid Kinematics: Deals with velocity and stream lines without considering forces or energy.

Fluid Dynamics: Is concered with the relation between velocities and acceleration forces.

1.2 HISTORICAL NOTES

Until the turn of this century the study of fluids was undertaken essentially by two groups-hydraulicians and mathematicians. Hydraulicians worked along empirical lines, while mathematicians concentrated on analytical lines. The vast and often ingenious experimentation of the former group yielded much information of indispensable value to the former group yielded much information of indispensable value to the practicing engineer of the day. However, lacking the generalizing benefits of workable theory, these results were of restricted and limited value in novel situations. Mathematicians meanwhile by not availing themselves of experimental information, were forced to make assumptions so simplified as to render their results very often completely at odds with reality.

It became clear to such eminent investigators as Reynolds, Froude, Prandlt and von Karman that the study of fluid must be a blend of theory and experimentation. Such was the beginning of the science of fluid mechanics as it is known today. Our modern research and test facilities employ mathematicians, physicists, engineers and skilled technicians, who, working in teams, bring both viewpoints in varying degrees to their work.

1.3 SCOPE OF FLUID MECHANICS

Having defined a fluid and noted the characteristics that distinguish it from a solid, we might ask the question: 'Why study fluid mechanics?'

Knowledge and understanding of the basic principles and concepts of fluid mechanics are essential to analyze any system in which a fluid is the working medium. The design of virtually all means of transportation requires application of principles of fluid mechanics. Included are aircraft for both subsonic and supersonic flight, ground effect machines, hovercraft, vertical takeoff and landing aircraft requiring minimum runway length, surface ships, submarines, and automobiles. In recent years automobile manufacturers have given more consideration to aerodynamic design. This has been true for sometime for the designers of both racing cars and boats. The design of propulsion systems for space flight as well as for toy rockets is based on the principles of fluid mechanics. The collapse of the Tacoma Narrows Bridge in 1940 is evidence of the possible consequences of neglecting the basic principles of fluid mechanics. It is commonplace today to perform model studies to determine the aerodynamic forces, and flow fields around, buildings and structures. These include studies of skyscrapers, baseball stadiums, smokestacks, and shopping plazas.

The design of all types of fluid machinery including pumps, fans, blowers, compressors, and turbines clearly requires knowledge of the basic principles of fluid mechanics. Lubrication is an application of considerable importance in fluid mechanics. Heating and ventilating systems for private homes, large office buildings, and underground tunnels, and the design of pipeline systems are further examples of technical problem areas requiring knowledge of fluid mechanics. The circularity system of the body is essentially a fluid system. It is not surprising that the design of blood substitutes, artificial hearts, heart-lung machines, breathing aids, and other such devices must rely on the basic principles of fluid mechanics.

Even some of our recreational endeavors are directly related to fluid mechanics. The slicing and hooking of golf balls can be explained by the principles of fluid mechanics
The list of applications of the principles of fluid mechanics could be extended considerably. Our main point here is that fluid mechanics is not a subject studied for purely academic interest; rather, it is a subject with widespread importance both in our everyday experiences and in modern technology.

Clearly, we cannot hope to consider in detail even a small percentage of these and other specific problems of fluid mechanics. Instead, the purpose of this text is to present the basic laws and associated physical concepts that provide the basis or starting point in the analysis of any problem in fluid mechanics.

1.4 DIMENSIONS AND UNITS

Consistent units of force mass, length, time and temperature greatly simplify problem solutions in mechanics;also derivations can be carried out without reference to any particular consistent system if units are used in a consistent manner. A system of mechanics units is said to be consistent when a unit force causes a unit mass to undergo a unit acceleration. The international System (SI) hass been adopted in most countiries and is expected to be adopted in the United States soon. This system has the Newton (N) as the unit of force,the kilogram (kg) as the unit of mass,the meter (m) as the unit of length and the second(s) as the unit of time. With the kilogram meter and second as defined units the Newton is derived to exactly satisfy Newton's second law of mation.

$1\ N = 1\ kg.1\ m/s^2$

1.5 DIFFERENCE BETWEEN LIQUIDS AND GASES

When a liquid is held in a container it tends to take the shape of the container, covering the bottom and sides. The top surface in contact with the atmosphere above it maintains a uniform level. As the container is tipped the liquid tends to pour out; the rate of pouring is dependent on a property called viscosity, which will be defined later.

When a gas is held in a closed container it tends to expand and completely fill the container. If the container is opened the gas tends to continue to expand and escape from the container.

In addition to these familiar differences between gases and liquids another difference is important in the study of fluid mechanics:

- Liquids are only slightly compressible
- Gases are readily compressible

Compressibility refers to the change in volume of a substance when the pressure on it changes. These distinctions are sufficient for most purposes.

1.6 VISCOSITY

1.6.1 Dynamic Viscosity

A fluid has many properties. One important property is viscosity, which is a measure of the resistance the fluid has to shear. Because this property arises from the defination of a fluid we will examine it in that regard. Consider again a fluid-filled space formed by two horizontal parallel plates Figure 1.1. The upper plate has an area A in contact with the fluid and is pulled to the right with a force F_1 at a velocity V_1. If the velocity at each point within the fluid could be measured a velocity distribution like that illustrated in Figure 1.1 might result. The fluid velocity at the moving plate is V_1 because the fluid adheres to that surface. At the bottom, the velocity is zero with respect to the boundary, owing to the nonslip condition. The slope of the velocity distribution is dV_1/dy.

If this experiment is repeated with F_2 as the force a different slope or strain rate results; dV_2/dy. In general, to each applied force there corresponds only one shear stress and only one strain rate. If data from the series of these experiments were plotted as τ versus dv/dy, Figure 1.2 would result for a fluid like water. The points lie on a straight line that passes through the origin. The slope of the resulting line in Figure 1.2 is the viscosity of the fluid because it is a measure of the fluid's resistance to shear. In other words, viscosity indicates how a fluid will react (dV/dy) under the action of external stress (τ)

The plot of Figure 1.2 is a straight line that passes through the origin. This result is characteristic of a Newtonian fluid, but there are other types of fluids called non-Newtonian fluids. A graph of τ versus dv/dy, called a theological diagram , is shown in Figure 1.3 for several types of fluids. Newton's law of viscosity and are represented by the equation.

$$\tau = \mu \, dv/dy$$

τ : the applied shear stress

μ : the absolute or dynamic viscosity of the fluid

dv/dy : the strain rate in dimensions of 1/T

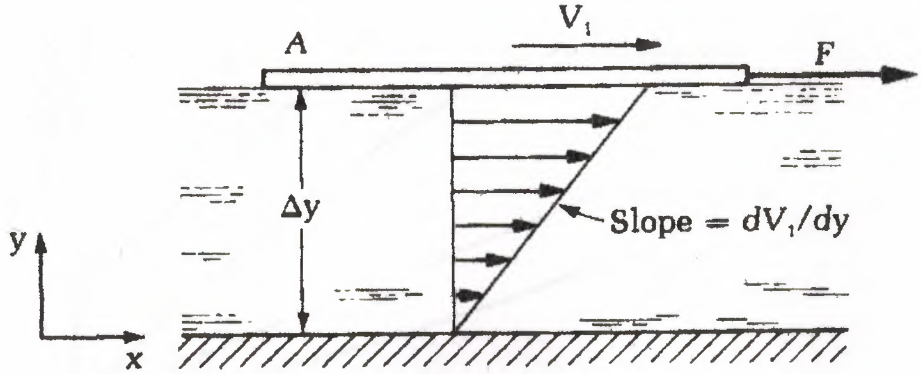


Figure 1.1 Shear stresses applied to a fluid

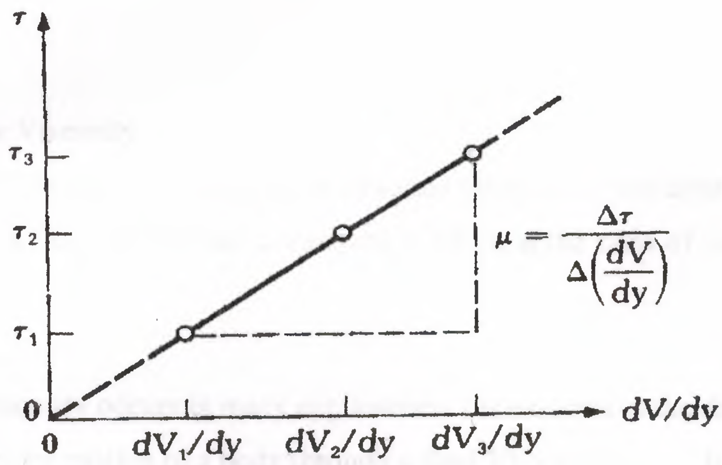


Figure 1.2 A plot of τ versus dV/dy for Newtonian fluids

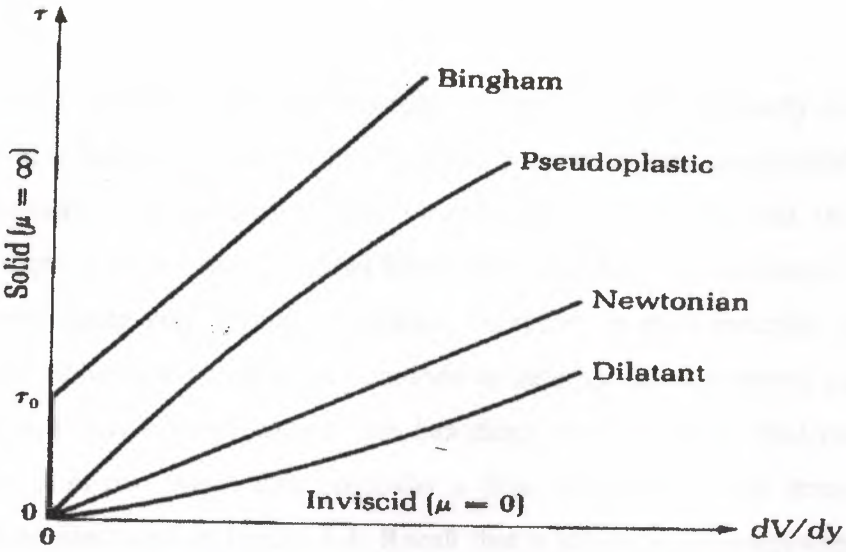


Figure 1.3 A Rheological diagram for Newtonian and non Newtonian time independent fluids

1.6.2 Kinematic Viscosity

The viscosity μ is frequently referred to as absolute viscosity or the dynamic viscosity to avoid confusing it with the kinematic viscosity ν which is the ratio of viscosity to mass density:

$$\nu = \mu / \rho$$

The kinematic viscosity occurs in many applications, for example in the dimensionless Reynolds number for motion of a body through a fluid Vl/ν in which V is the body velocity l is a representative linear measure of the body size. The SI unit of kinematic viscosity 1 m^2/s

In SI units to convert from ν to μ it is necessary to multiply ν by ρ the mass density in kilograms per cubic meter.

1.7 BERNOULLI EQUATION

The Bernoulli Equation gives a relationship between pressure, velocity and position or elevation in a fluid flow field. Normally, these properties vary considerably in the flow field. Normally these properties vary considerably in the flow and the relationship between them if written in differential form quite complex. The equations can be solved exactly only under very special conditions. Therefore in most practical problems it is often more convenient to make assumptions to simplify the descriptive equations. The Bernoulli equation is simplification that has many applications in fluid mechanics. We will derive it in two ways. First, consider a flow tube bounded by streamlines in the flow field as illustrated in Figure 1.4. Recall that a streamline is everywhere tangent to the velocity vector and represents the path followed by a fluid particle in the stream; no flow crosses a streamline. Because the flow is steady and frictionless, viscous effects are neglected. Pressure and gravity are the only external forces acting. For this analysis, we will select a control volume, apply the momentum equation and finally integrate the result along the stream tube. In this direction for the control volume, we have

$$\Sigma F_s = \int_{cs} \int V_s \rho V_n \, dA$$

Evaluating each terms separetely we obtain

$$\Sigma F_s = p\delta A - (p + dp)\,\delta A - \rho g \, ds \, \delta A \cos\theta$$

Where θ is the angle between the s direction and gravity. Also,

$$\int_{cs} \int V_s \, \rho V_n dA = (V + dV - V)\rho V \delta A$$

By substitution we get

$$-d\rho\delta A - \rho g \, ds \, \delta A \cos\theta = \rho V \, dV \, \delta A$$

The term δA divides out; ds cos θ is dz.Therefore after simplification we get

$$Dp/\rho + V \, dV + g \, dz = 0$$

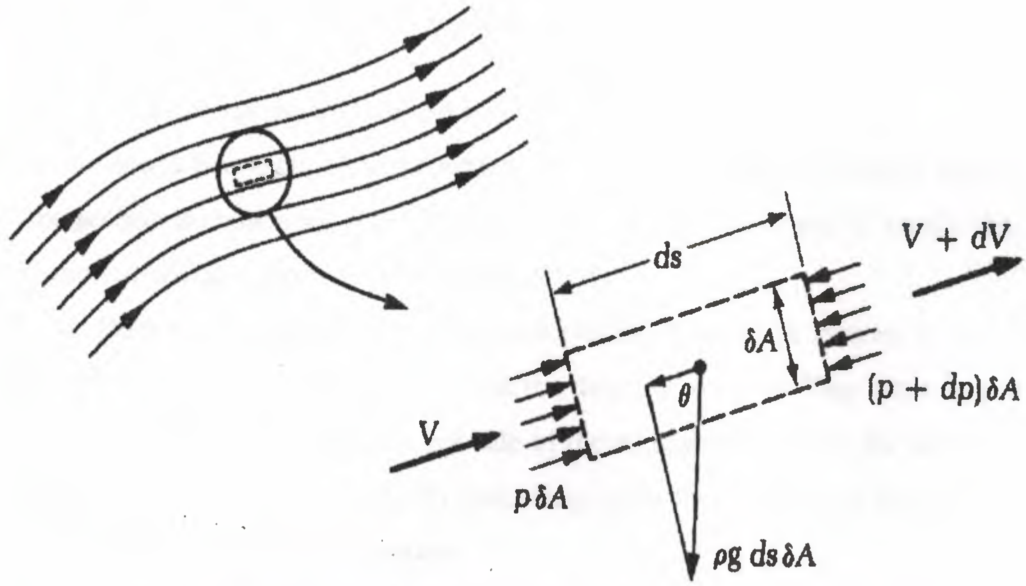


Figure 1.4 A differential control volume for the derivation of Bernoulli's eq.

Integrating between points 1 and 2 along the stream tube gives

$$\int_1^2 \frac{dp}{\rho} + \frac{1}{2}\left(V_2^2 - V_1^2\right) + g\left(z_2 - z_1\right) = 0$$

For the special case of an incompressible fluid density is constant (not a function of pressure) and the equation then becomes;

$$\frac{p_2 - p_1}{\rho} + \frac{V_2^2 - V_1^2}{2} + g\left(z_2 - z_1\right) = 0$$

or

$$\frac{p}{\rho} + \frac{V_2^2}{2} + gz = a \text{ constant}$$

Bernoulli equation for steady incompressible flow along a streamline with no friction (no viscous effects).

1.7.1 Application of Bernoulli's Equation

1-) Decide which items are known and what is to be found.

2-) Decide which two sections in the system will be used writing Bernoulli's equation. One section is chosen for which much data is known. The second is usually the Section at which something is to be calculated.

3-) Write Bernoulli's equation for the two selected sections in the system. It is important that the equation is written in the direction of flow. That is the flow must proceed from the section on the left side of the equation to that on the right side.

4-) Simplify the equation if possible by cancelling terms that are zero or those that are equal on both sides of the equation.

5-) Solve the equation algebraically for the desired term.

6-) Substitute known quantities and calculate the result, being careful that consistent units are used throughout the calculations.

SUMMARY

Fluid mechanics is the science of the liquid and is based in three basic branches. They are fluid statics, fluid kinematics, fluid dynamics. Difference between liquids and gases are examined as followed. Another important factor is viscosity, which is a measure of the resistance the fluid has to shear. At the end of the chapter Bernoulli's equation is determined and also described applications.

CHAPTER 2

FLOW IN CLOSED CONDUITS

INTRODUCTION

The purpose of this chapter is to describe laminar and turbulent flow phenomena, importance of viscosity in the laminar and turbulent flow, the role of entrance effects in the flow. However the types of flow such as internal, external flow are discussed.

2.1 LAMINAR AND TURBULENT FLOW

In early experiments with flow in pipes, it was discovered that two different flow regimes exist- *laminar* and *turbulent*. When laminar flow exists in a system. the fluid flows in smooth layers called *laminae*. A fluid particle in one layer stays in that layer. The layers of fluid slide by one another without apparent eddies or swirls. Turbulent flow, on the other hand, exists at much higher flow rates in the system. In this cage, eddies and vortices mix the fluid by moving particles tortuously ab out the cross section.

The existence of two types of flow is easily visualized by examining results of experiments performed by Osborne Reynolds. His apparatus is shown schematically in Figure 2.l(a). A transparent tube is attached to a constant-head tank with water as the liquid medium. The opposite end of the tube has a valve to control the flow rate. Dyed water is injected into the water at the tube inlet, and the resulting flow pattern is observed. For low rates of flow; something similar to Figure 2.1(b) results. The dye pattern is regular and forms a single line like a thread. There is no lateral mixing in any part of the tube, and the flow follows parallel streamlines. This type of flow is called laminar or viscous flow.

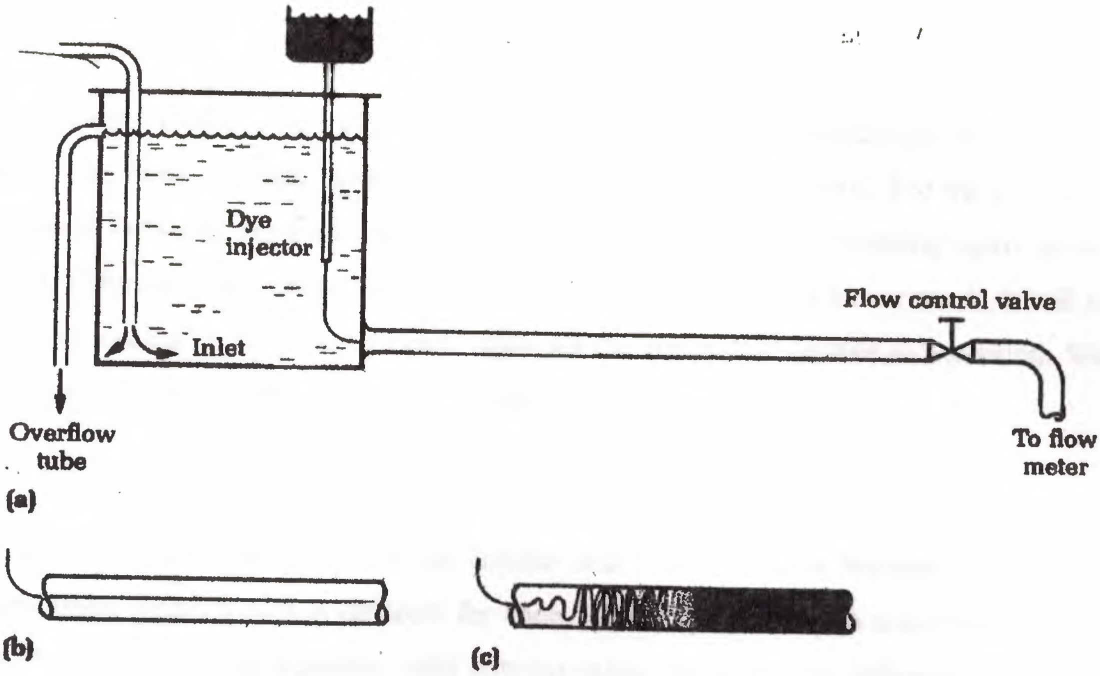


Figure 2.1 An Experiment for Visualising Laminar and Turbulent flow

As the flow rate of water is increased beyond a certain point, the dye is observed not to follow a straight threadlike line but to disperse. The dyed water mixes thoroughly with the pipe water as shown in Figure 2.1(c) as a result of erratic fluid behavior in the pipe. This type of flow is called turbulent flow. The Reynolds number at the point of transition between laminar and turbulent flow is called the critical Reynolds number.

This experiment can be repeated with several pipes of different diameter. A dimensional analysis, when performed and combined with the data, shows that the criterion for distinguishing between these flows is the Reynolds number:

$$Re = \frac{\rho V D}{\mu} = \frac{VD}{\nu}$$

where:

V : average velocity of the flow

D : inside diameter of the tube

For straight circular pipes, the flow is always laminar for a Reynolds number less than 2100. The flow is usually turbulent for Reynolds numbers over 4000. For the transition regime in between, the flow can be either laminar or turbulent, depending upon details of the apparatus that cannot always be predicted or controlled. For our work, it will at times be necessary to have an exact value for the Reynolcls number at transition. We will arbitrarily choose this value to be 2 100.

A distinction must be made between laminar and turbulent flows because the velocity distribution within a duct is different for each. Figure 2.2(a) shows a coordinate system for flow in a tube, for example, with corresponding velocities. As indicated, there can be three different *İnstanta*neous velocity components in a conduit-one for each of the three principal directions. Furthermore, each of these velocities can be dependent upon at most three space variables and one time variable. If the flow in the tube is laminar, we have only one nonzero instantaneous velocity: *Vz* Moreover, Vz is a function of only the radial coordinate r, and the velocity distribution is parabolic as shown in Figure 2.2(b). An equation for this distribution is derivable from the equation of motion performed later in this chapter.

If the flow is turbulent, all three instantaneous velocities *Vr,* V_θ, and Vz are nonzero. Moreover, each of these velocities is a function of all three space variables and of time. An equation for velocity*(Vr,* V_θ, or Vz *)* is not derivable from the equation of motion. Therefore, to envision the axial velocity, for instance, we must rely on experimental data. Figure 2.2(c) shows the axial instantaneous velocity Vz for turbulent flow in a tube.

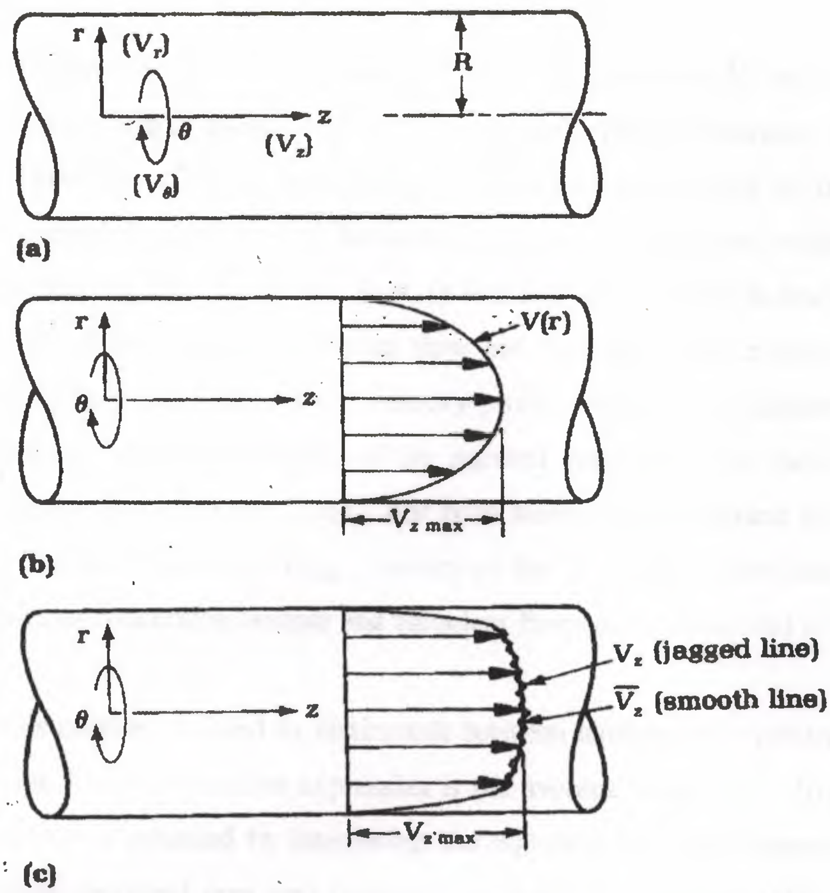


Figure 2.2

(a) Cylinder coordinates and velocity directions in a tube

(b) Axial velocity distribution for laminar flow in a tube

(c) Axial velocity distrubition for turbulent flow in a tube

The instantaneous velocity Vz fluctuates randomly about the mean axial velocity *Vz*. We would need a very sensitiye measuring instrument to obtain Vz bul a relatively insensitive instrument to obtain *Vz*. If the velocity profile in the turbulent flow of Figure 2.2(c) were measured at another instant in time, a different instantaneous profile *(Vz)* would result. It would, however fluctuate about the same mean axial velocity *Vz'*. Thus, the mean axial velocity would be obtained by removing the time dependence (by integration if the function were known) from the instantaneous velocity *Vz*. The time dependence can be further illustrated by loaking at data in the axial or z directian at apoint (say the tube centerline) as a function of time (see Figure 2.3).

As was indicated in the above discussion, the axial velocity Vz in turbulent flow fluctuates about some mean velocity. In general, the fluctuations are small in magnitude, but they cause slower-moving particles in one region of the pipe cross section to exchange position with fastermaving particles in anather region. This is in contrast to what happens in laminar flow, in which a fluid particle in one layer stays in that layer. The fluctuations in turbulent flow are responsible for a mixing effect that manifests itself in a more evened-out velocity profile than that for laminar flow. Also, these fluctuations cause the mixing of the injected water with the tube water in the Reynolds experiment of Figure 2.1(c). For both laminar and turbulent flow, maximum velocity in the axial direction, V_{zmax} , occurs at the centerline of the duct or conduit. These comments concerning laminar and turbulent flows are summarized in Table 2.1.

The Reynolds number is used to distinguish between laminar and turbulent flows. The velocity in the Reynolds number expressian is the average velocity V. In principle, the average velocity is obtained by integrating the equation for instantaneous velocity Vz over the cross~sectional area and dividing the result by the area. This procedure is correct for laminar, transition, or turbulent flow. If there is no equation available, then experimental means are necessary to find the average ivelocity. In the simplest case, we measure volume flow rate (for an incompressible fluid) and divide by cross-sectional area:

$$V = \frac{Q}{A}$$

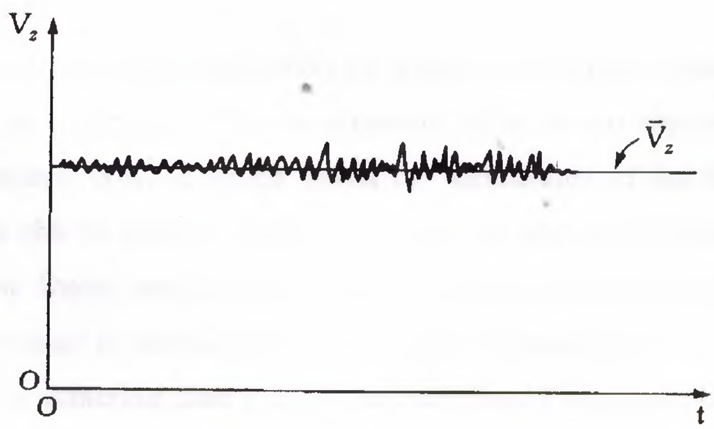
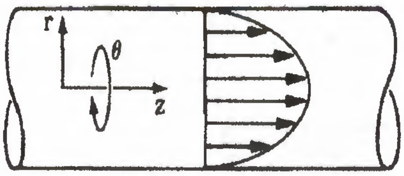
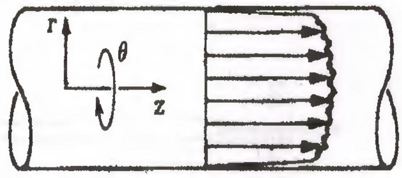


Figure 2.3 Variation of centerline axial velocity with respect to time

Table 2.1 Comparison of Laminar and Turbulent Flow





Laminar Flow	Parameter	Turbulent Flow
V_z only; $V_r = V_\theta = 0$	Velocity	V_r, V_θ, V_z all nonzero
$V_z = V_z(r)$ only	Functional dependence	$V_r = V_r(r, \theta, z, t)$ $V_\theta = V_\theta(r, \theta, z, t)$ $V_z = V_z(r, \theta, z, t)$
Parabolic (see above); solution from equation of motion	Velocity distribution	Determined from experimental data
$\dfrac{V_z}{V_{zmax}} = 1 - \left(\dfrac{r}{R}\right)^2$	Equation	$\dfrac{\bar{V}_z}{V_{zmax}} \approx \left(1 - \dfrac{r}{R}\right)^{1/7}$
$\dfrac{V}{V_{zmax}} = \dfrac{1}{2}$		$\dfrac{\bar{V}}{V_{zmax}} \approx \dfrac{4}{5}$
for Re $\leq$ 2100		for $5 \times 10^5 \leq$ Re $\leq 10^7$

2.2 EFFECT OF VISCOSITY

Table 2.1 shows the velocity distribution for laminar and turbulent flow. In both cases, the velocity at the wall is zero. This phenomenon, called the nonslip condition, is due to viscosity. In laminar flow, in which inertia or momentum of the fluid is small, the viscous effect is able to penetrate farther info the cross section from the wall than it can in turbulent flow. Stated another way, in turbulent flow, in which the viscous effects are small, the momentum or inertia of the flow is able to penetrate farther outward toward the wall from the centerline than it can in laminar flow. This penetration of momentum or inertia is called the momentum transport phenomenon. Consider the case of a fluid between two parallel plates with the upper plate moving as shown in Figure 2.4. The up per plate has fluid adhering to it owing to friction. The plate exerts a shear stress on the particles in layer *A*. This layer in turn exerts a shear stress onlayer B and so on. It is the x component of velocfty in each layer that causes this shear stress to be propagated in the negative z direction. That is, the A layer pulls the B layer along and so forth.

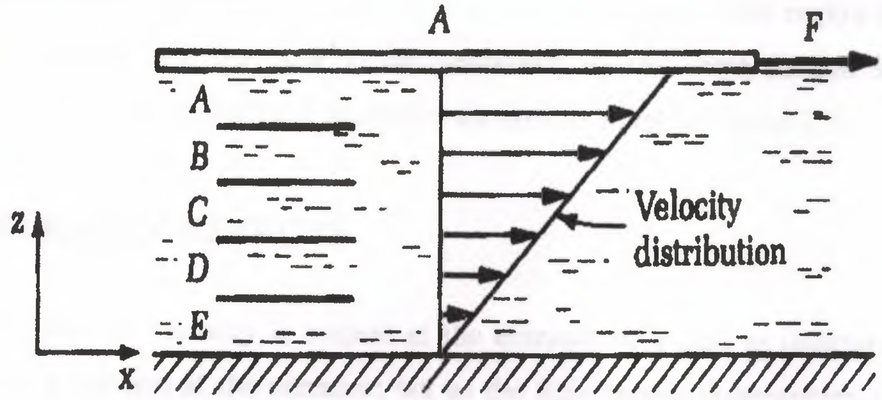


Figure 2.4 Layers of Fluid Flow between parallel plates

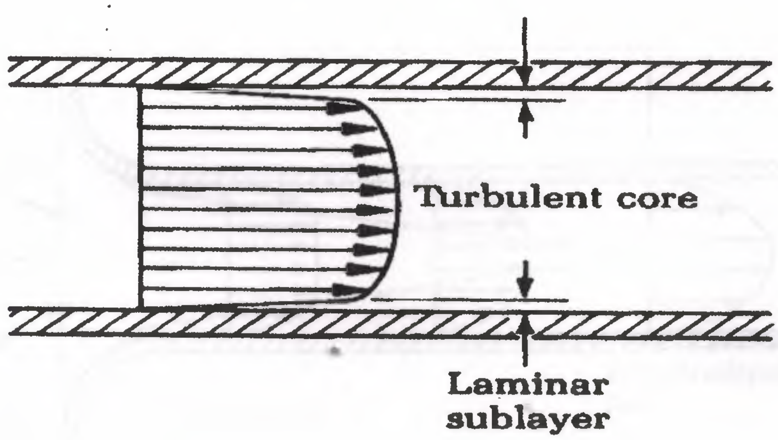


Figure 2.5 Laminar sublayer in Turbulent Pipe Flow.

As this shear stress approaches the stationary wall, movement is retarded by the effect of zero velocity at the bottom propagating upward. That is, the E layer retards the D layer and so on. The resultant effect on velocity is the distribution sketched in Figure 2.4

As we saw earlier, in turbulent flow, the velocity at a stationary wall is zero. Near the wall, then, there must be a region of now that is laminar. This region is called the laminar sublayer, and the now in the remainder of the cross section is called the turbulent core. Both regions are illustrated for now in a pipe in Figure 2.5.

2.3 ENTRANCE EFFECTS

Another effect of viscosity is evident at the entrance to a pipe as illustrated in Figure 2.6. Flow is uniform at the entrance; but as the fluid travels downstream, the effect of zero wall velocity propagates throughout the cross section. The now is divided into a viscous layer and a core region. Particles in the core do not sense that a wall is present. Eventually, the core disappears, and the velocity distribution becomes fully developed.

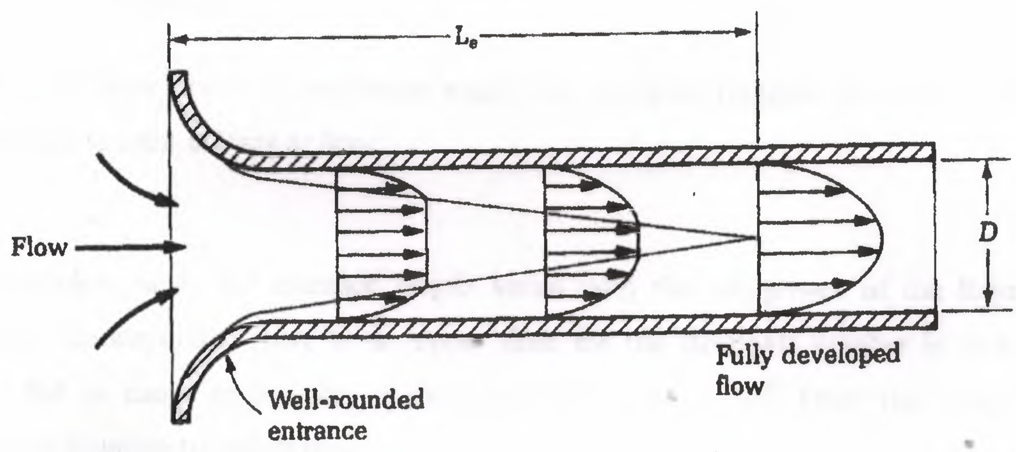


Figure 2.6 Laminar Flow near a pipe inlet

The distance *Le* Figure 2.6 is called the entrance length, and its magnitude is dependent upon the forces of inertia and viscosity. It has been determined from numerous experimental and analytical investigations that the entrance length can be estimated with;

$$Le = 0.06D(Re) \text{ (Laminar flow)}$$

$$Le = 4.4D(Re)^{1/6} \text{ (Turbulent flow)}$$

Where;

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

For laminar flow, we see that the entrance length varies directly with the Reynolds number. The largest Reynolds number encountered in laminar flow is 2100.

$$Le = 0.06D(2100) = 126D$$

Thus, 126 diameters is the maximum length that would be required for fully developed conditions to exist in laminar flow.

For turbulent now, the entrance length varies with the 1/6 power of the Reynolds number. Conceptually, there is no upper limit for the Reynolds number in turbulent flow, but in many engineering applications, $10^4 < Re < 10^6$. Over this range, we calculate equation turbulent flow.

$$20 \langle \frac{Le}{D} \langle 44$$

So in turbulent flow, the entrance length varies to values that are considerably less than the 126 diameters required at a Reynolds number of 2100. The reason that a shorter length is required in turbulent flow is the mixing action. For abrupt or sharp-edged entrances, additional turbulence is created at the inlet. The effect is to decreas the inlet length required for fully developed flow to exist.

2.4 INTERNAL AND EXTERNAL FLOWS

Another method of categorizing flows is by exarnining the geometry of the flow field. Internal flow involves flow in a bounded region, as the name implies. External flow involves fluid in an unbounded region in which the focus of attention is on the flow pattern around a body immersed in the fluid.

The motion of a real fluid is influenced significantly by the presence of the boundary. Fluid particles at the wall remain at rest in contact with the wall. In the flow field a strong velocity gradient exists in the vicinity of the wall, a region referred to as the boundary layer. A retarding shear force is applied to the fluid at the wall, the boundary layer being a region of significant shear stresses.

This chapter deals with flows constrained by walls in which the boundary effect is likely to extend through the entire flow. The boundary influence is easily visualized at the entrance to a pipe from a reservoir, seen in Fig. 2.7 At section *A-A,* near a o well-rounded entrance, the velocity profile is almost uniform over the cross section. The action of the wall shearing stress is to slow down the fluid near the wall. As a consequence of continuity, the velocity must increase in the central region. Beyond a transitional length L' the velocity profile is fixed since the boundary influence has extended to the pipe center line. The transition length is a function of the Reynolds number; for laminar flow Langhaar [2] developed the theoretical formula ;

$$\frac{L'}{D} = 0{,}058R$$

which agrees well with observation. In turbulent flow the boundary layer grows more rapidly and the transition length is considerably shorter than given by the equation.

In external flows, with an object in an unbounded fluid, the frictional effects are confined to the boundary layer next to the body.

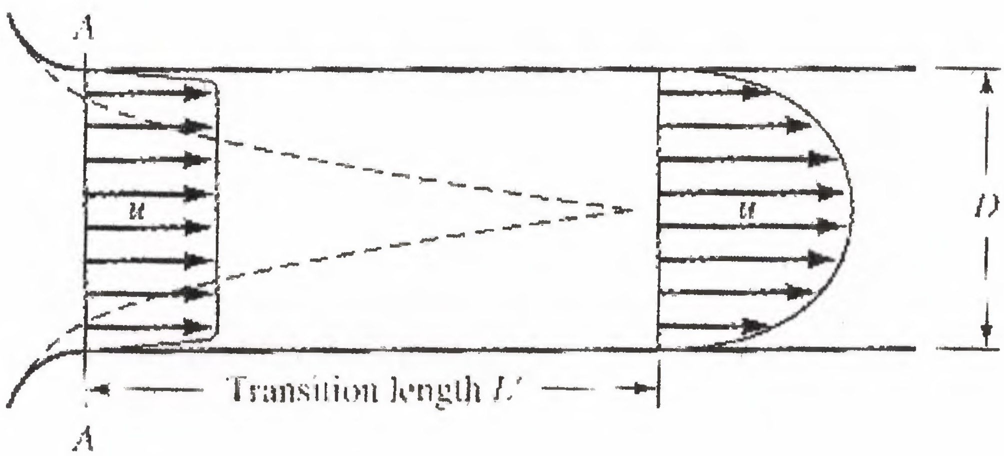


Figure 2.7 Entrance Zone of pipe line

SUMMARY

In this chapter laminar and turbulent flow are described. When the fluid flows in smooth layers it is laminar flow, if much higher flow rates existed in the system it is turbulent flow. According to the fluid are examined effect of viscosity and entrance effects. Another categorizing flows are by examinig the geometry of the flow field, which are internal and external flows. Internal flow involved flow in an unbounded region in the focus of attention is on the flow pattern a round a body immersed in the fluids.

CHAPTER 3

FOUNDATIONS OF FLOW ANALYSIS

INTRODUCTION

In this chapter one and two dimensional flows and specifications of these flows are considered. Also Reynolds Number laminar, turbulent flows , Reynolds number situation between these flows , critical Reynolds Number critic levels of laminar and turbulent flows are considered.

3.1 ONE AND TWO-DIMENSIONAL FLOWS

In every analysis a hypothetical substance or process is set forth which lends itself to mathematical treatment while still yielding results of pratical value. We have already discussed the continuum concept. Now, simplified flows are set forth, which, when used with discretion, will permit the use of higly developed theory on problems of engineering interest.

One-Dimensional flow is a simplification where all properties and flow characteristics are assumed to be expressible as functions of one space coordinate and time. The position is usually the location along some path or conduit. For instance, a one – dimensional flow in the pipe shown in Figure 3.1 would require that the velocity, pressure,etc.be constant over any given cross section at any given time and vary only with (s) at this time.

In reality, flow in pipes and conduits is never truly one dimensional, since the velocity will vary over the cross section. Shown in Figure 3.2 are the respective velocity profiles of a truly one-dimensional flow and that of an actual case. Nevertheless, if the departure is not too great or if avarage effects at a cross section are of interest, one-dimensional flow may be assumed to exist. For instance, in pipes and ducts this assumption is often acceptable where

. Variation of cross section of the container is not too excessive.

. Curvature of the streamlines is not excessive.

. Velocity profile is known not to change appreciably along the duct.

Two-dimensional flow is distinguished by the condition that all properties and flow characteristics are functions of two cartesian coordinates,say, x , y , and time, and hence do not change along the z direction at a given instant.All planes normal to the z direction will, at a given instant,have the same streamline pattern. The flow past an airfoil of infinite aspect ratio[16] or the flow over a dam of infinite length and uniform cross section are mathematical examples of two-dimensional flows. Actually, in a real problem a two-dimensional flow is assumed over most of the airfoil or dam,and "end corrections" are made to modify the results properly.

Figure 3.1 One Dimensional Flow

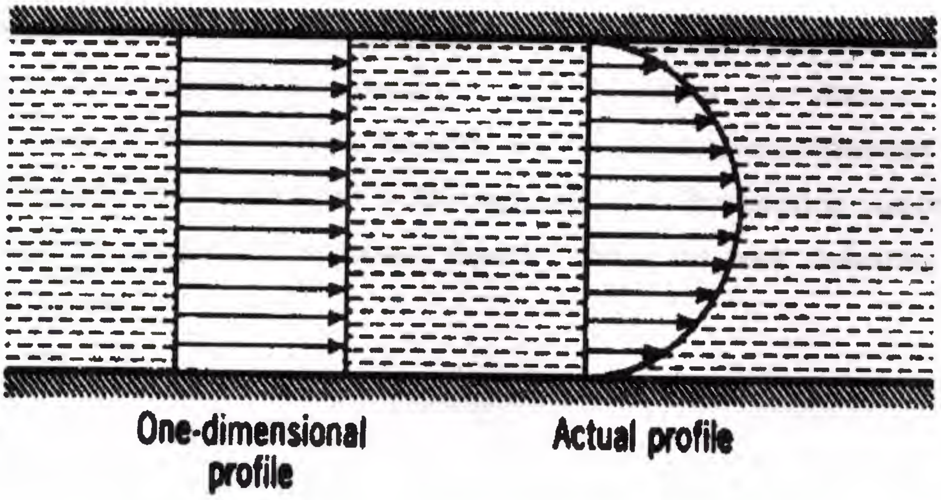


Figure 3.2 Comparison of One Dimensional Flow and Actual Flow

3.2 REYNOLDS NUMBER

The behavior of fluid, particularly with regard to energy losses, is quite dependent on whether the flow is laminar or turbulent. For this reason I want to have means of predicting the type of flow withouth actually observing it.

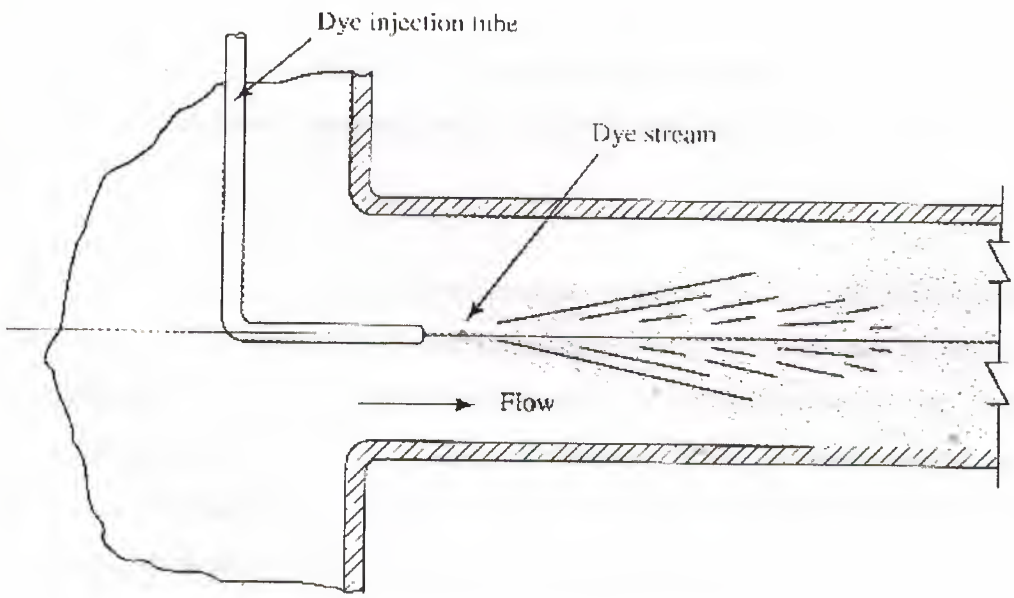


Figure 3.3 Dye Stream Mixing with Turbulent Flow

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

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

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

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

Because all units can be cancelled, Re is dimensionless. However, it is essential that all terms in the equation be in consistent units in order to obtain the correct numerical value for Re.

Reynolds number is one of several dimensionless numbers useful in the study of fluid mechanics and heat transfer.The process dimensional analysis can be used to determine dimensionless numbers. Reynolds number is the ratio of the inertia force on an element of fluid to the viscous force.The inertia force is developed from Newton's second law of motion, F= ma. As discussed in Chapter 1 the viscous force is related to the product of the shear stress times area.

Flows having large Reynolds numbers, typically because of high velocity and/or low viscosity, tend to be turbulent. Those fluids having high viscosity and/or moving at low velocities will have low Reynolds numbers and will tend to be laminar. The following section gives some quantitative data with which to predict whether a given flow system will be laminar or turbulent.

The formula for Reynolds number takes a different form for noncircular cross sections,open channels,and for the flow fluid around immersed bodies.

3.2.1 Critical Reynolds Numbers

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

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

If $Re < 2000$, the flow is LAMİNAR.

If $Re < 4000$, the flow is TURBULENT.

Example Problem: Determine whether the flow is laminar or turbulent if glycerine at 25°C flows in a pipe with a 150-mm inside diameter.The avarage velocity of flow is 3.6 m/s.

Solution We must firs evaluate the Reynolds number using Equation

$$Re = \upsilon D\rho/\mu$$

Where;

$\upsilon = 3.6$ m/s

$D = 0.15$ m

$\rho = 1258$ kg/m^3

$\mu = 9.60 \times 10^{-1}$ Pa .s

Than we have

$$Re = \frac{(3.6)(0.15)(1258)}{9.60x10^{-1}} = 708$$

Because Re = 708 which less than 2000, the flow is LAMİNAR.

3.3 REYNOLDS NUMBER FOR CLOSED NONCIRCULAR CROSS SECTION

When the fluid completely fills the available cross-sectional area and is under pressure , the average velocity of flow is determined by using the volume flow rate and the net flow area in the familiar continuity equation. That is note that the area is the same as that used to compute the hydraulic radius.

$$\upsilon = Q/A$$

The Reynolds number for flow in noncircular sections is computed in a very similar manner to that used for circular pipes and tubes. The only alteration to Reynolds number equation is replacement of the diameter D with 4R, four times the hydraulic radius. The results is;

$$\text{Re} = \frac{\upsilon(4R)\rho}{\mu} = \frac{\upsilon(4R)}{\nu}$$

The validity of this substitution can be demonstrated by calculating the hydraulic radius for a circular pipe;

$$R = \frac{A}{WP} = \frac{\pi D^2/4}{\pi D} = \frac{D}{4}$$

Then ; $D = 4R$

Therefore 4R is equivalent to D for the circular pipe. Thus, by analogy the use of 4R as the characteristic dimension for noncircular cross sections is appropriate. This approach will give reasonable results as long as the cross section has an aspect ratio not much different from that of the circular cross section. In this context aspect ratio is the ratio of the width of the section to its height. So for a circular section the aspect ratio is 1.0

SUMMARY

In the third chapter is considered one and two dimensional flows and Reynolds number. Reynolds number is one of several dimensionless numbers useful in the study of fluid mechanics and heat transfer. Reynolds number is the ratio of the inertia force on an element of fluid to the viscous force. If the Reynolds number is less than 2000 the flow is laminar. Also, ıf the Reynols number is greater than 4000 the flow is turbulent. The range of Reynols number is between 2000 and 4000, is called critical region.

CHAPTER 4

PIPE SYSTEMS AND LOSSES

INTRODUCTION

In this section the types of pipe line system which effect the energy losses and efficiency are discussed. Energy losses such as minor and friction losses in turbulent flow that effect efficiency directly are included. Also using of Moddy diagram which is used to determine friction factor are considered.

4.1 PIPE LINE SYSTEMS

4.1.1 Pipes In Series

When two pipes of different sizes or roughnesses are so connected that fluid flows through one pipe and then through the other, they are said to be connected in series. In such systems fluid flows like a single continuous stream tube without branching. In a series of pipes as in Figure 4.1 the total head loss is the sum of the head losses in each serially connected pipes.

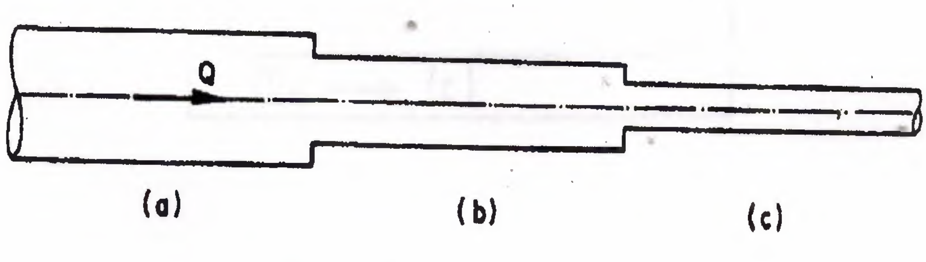


Figure 4.1 Pipes in series

$$(H_L = H_{La} + H_{Lb} + H_{Lc})$$

4.1.2 Pipes In Parallel

A combination of two or more pipes connected so that the flow is divided amoung the pipes and then is joined again, is a parallel pipe system. A typical parallel system of pipes is shown Figure 4.2. The flow in the main line splits into three branches at section 1. and then rejoins at section 2. The head loss in each branch between sections 1 and 2 must be equal that is;

$$(H_{L1\text{-}2}=H_{La}=H_{Lb}=H_{Lc})$$

Also,the volumetric flow rate in the main line is equal to the sum of the Volumetric flowrates through each branch.Hence

$$(Q=Qa+Qb+Qc)$$

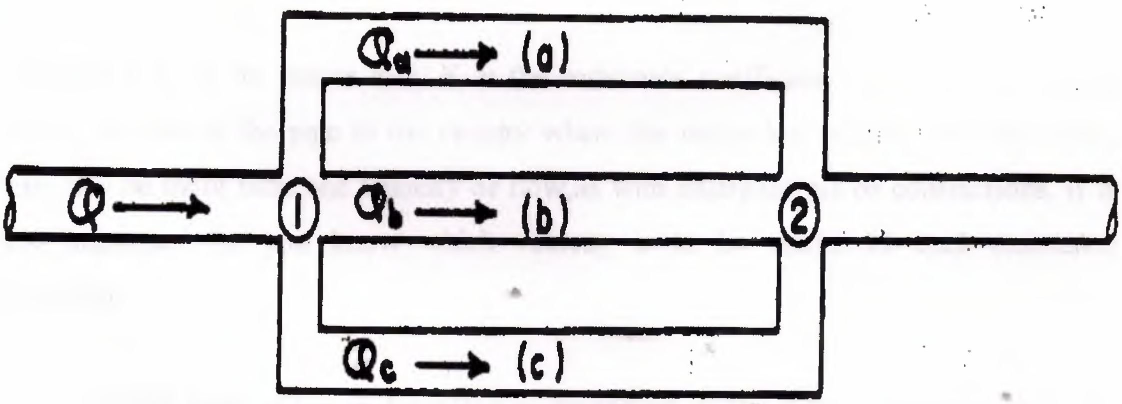


Figure 4.2 Pipes in parallel

4.2 MINOR LOSSES

In most pipe flow system the primary energy loss is due to pipe friction. Other types of losses are usually small by comparison and they are therefore referred to as minor losses. Minor losses occur when there is a change in the cross section of the flow path or in the direction of flow or where the flow path is obstructed, as with a valve. Energy is lost under these conditions due to rather complex physical phenomena. Theoretical prediction of the magnitude of these losses is also complex and therefore, experimental data are normally used.

Energy losses are proportional to the velocity head of the fluid as it flows around an elbow, through an enlargement or constraction of the flow section or through a valve. Experimental values for energy losses are usually reported in terms of a resistance coefficient, K as follows:

$$h_L = K(\upsilon^2/2g)$$

In Equation h_L is the minor loss, K is the resistance coefficient and υ is the average velocity of flow in the pipe in the vicinity where the minor loss occurs. In some cases, there may be more than one velocity of flow,as with enlargements or contractions. It is most important for you know which velocity is to be used with each resistance coefficient.

If the velocity head $\upsilon^2/2g$ in Equation is expressed in the units of meters, then the energy loss h_L will also be in meters or N.m/N of fluid flowing. The resistance coefficient is unitless, as it represents a constant of proportionality between the energy loss and the velocity head. The magnitude of the resistance coefficient depends on the geometry of the device that causes the loss and sometimes on the velocity of flow.

4.2.1 Sudden Enlargement

As a fluid flows from a smaller pipe into a larger pipe through a sudden enlargement its velocity abruptly decreases, causing turbulence that generates an energy loss. See in Figure 4.3 The amount of turbulence and therefore the amounth of energy loss is dependent on the ratio of the size of the two pipes.

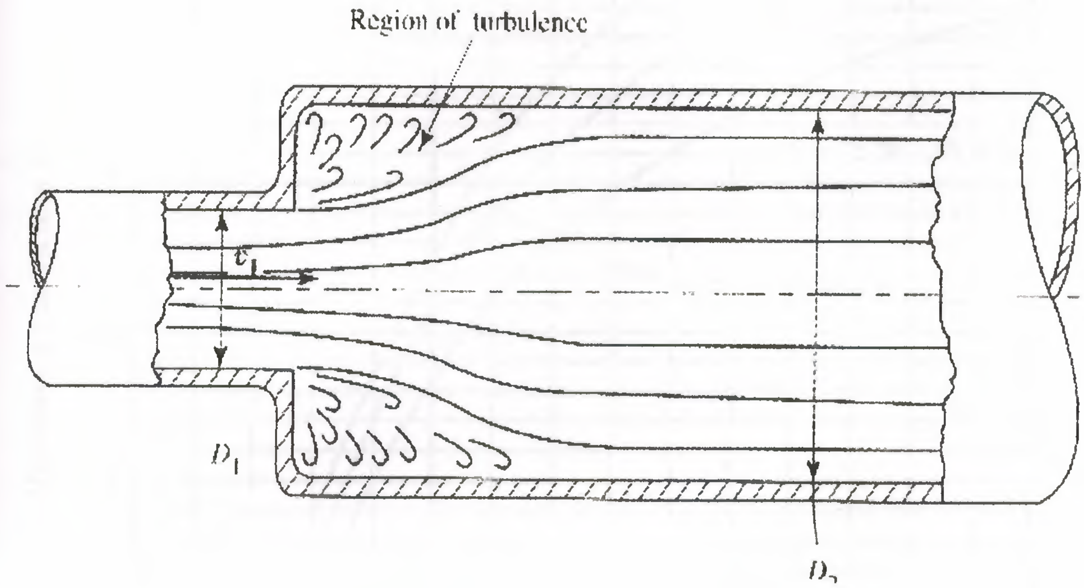


Figure 4.3 Sudden Enlargement

The minor loss is calculated from the equation;

$$h_L = K(\upsilon 1^2/2g)$$

Where υ_l is the average velocity of flow in the smaller pipe ahead of the enlargement. Tests have shown that the value of the loss coefficient K is dependent on both the ratio of the sizes of the two pipes and the magnitude of the flow velocity. This is illustrated graphically in Figure 4.4 and in tabular form in table 4.1.

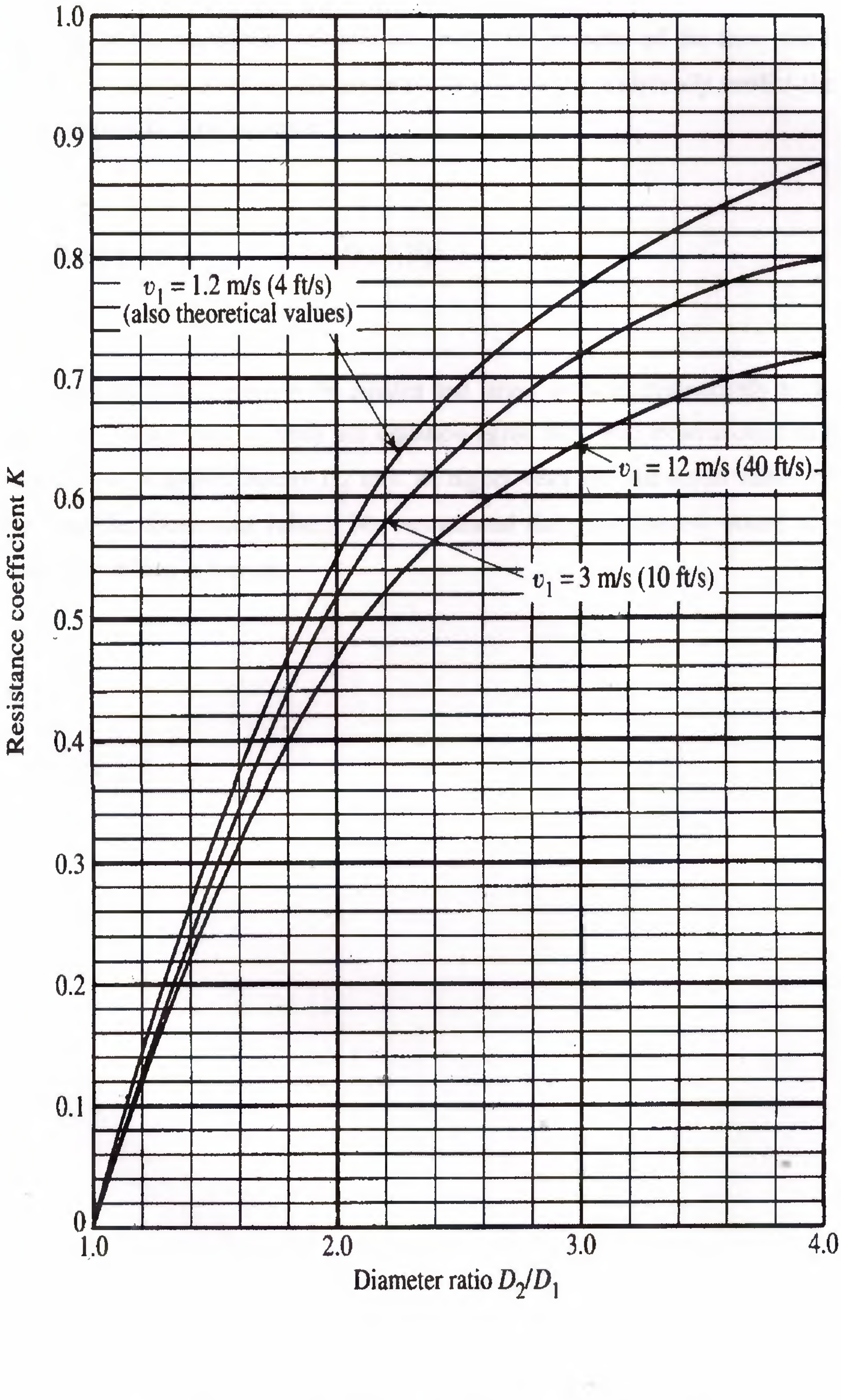


Figure 4.4 Resistance Coefficient-Sudden Enlargement

By making some simplifying assumptions about the character of the flow stream as it expands through the sudden enlargement it is possible to analytically predict the value of K from the following equation;

$$K = [\, 1 - (A_1/A_2)]^2 = [\, 1 - (D_1/D_2)^2]^2$$

The subscripts 1 and 2 refer to the smaller and larger sections, respectively as shown in Figure 4.3. Values from K from this equation agree well with experimental data when the velocity υ_1 is approximately 1.2 m/s. At higher velocities the actual values of K are lower than the theoretical values. We recommend that experimental values be used if the velocity of flow is known.

Table 4.1 Resistance Coefficient-Sudden Enlargement

	Velocity, v_1						
D_2/D_1	0.6 m/s 2 ft/s	1.2 m/s 4 ft/s	3 m/s 10 ft/s	4.5 m/s 15 ft/s	6 m/s 20 ft/s	9 m/s 30 ft/s	12 m/s 40 ft/s
1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1.2	0.11	0.10	0.09	0.09	0.09	0.09	0.08
1.4	0.26	0.25	0.23	0.22	0.22	0.21	0.20
1.6	0.40	0.38	0.35	0.34	0.33	0.32	0.32
1.8	0.51	0.48	0.45	0.43	0.42	0.41	0.40
2.0	0.60	0.56	0.52	0.51	0.50	0.48	0.47
2.5	0.74	0.70	0.65	0.63	0.62	0.60	0.58
3.0	0.83	0.78	0.73	0.70	0.69	0.67	0.65
4.0	0.92	0.87	0.80	0.78	0.76	0.74	0.72
5.0	0.96	0.91	0.84	0.82	0.80	0.77	0.75
10.0	1.00	0.96	0.89	0.86	0.84	0.82	0.80
∞	1.00	0.98	0.91	0.88	0.86	0.83	0.81

4.3 FRICTION LOSS IN TURBULENT FLOW

For turbulent flow of fluids in circular pipes it is most convenient to use Darcy's equation to calculate the energy loss due to friction. We cannot determine the friction factor f by a simple calculation as we did for laminar flow because turbulent flow does not conform to regular predictable motions. It is rather chaotic and is constantly varying. For these reasons we must rely on experimental data to determine the value of f.

$$h_L = f\left(\frac{L}{D}\right)\left(\frac{\upsilon^2}{2g}\right)$$

Where

h_L : Energy loss due to frictionless

L : Length of flow stream

D : Pipe diameter

υ : Average velocity of flow

f : Friction factor

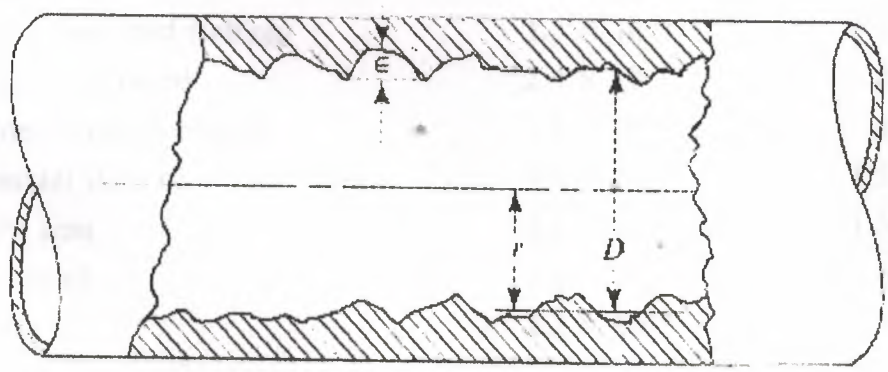


Figure 4.5 Pipe Wall Roughness (Exaggerated)

Tests have shown that the dimensionless number f is dependent on two other dimensionless numbers, the Reynolds number and the relative roughness of the pipe. The relative roughness is the ratio of the pipe diameter D to the average pipe wall roughness ϵ (Greek letter epsilon). Figure 4.5 illustrates pipe wall roughness (exaggerated) as the height of the peaks of the surface irregularities. The condition of the pipe surface is very much dependent on the pipe material and the method of manufacture. For commercially available pipe and tubing, the design value of the wall roughness ϵ has been determined as shown in Table 4.2. These are only average values for new, clean pipe. Some variation should be expected. After a pipe has been in service for a time, the roughness could change due to the formation of deposits on the wall or due to corrosion.

Table 4.2 Pipe Roughness Design Values

Material	Roughness, ϵ (m)	Roughness, ϵ (ft)
Glass, plastic	Smooth	Smooth
Copper, brass, lead (tubing)	1.5×10^{-6}	5×10^{-6}
Cast iron—uncoated	2.4×10^{-4}	8×10^{-4}
Cast iron—asphalt coated	1.2×10^{-4}	4×10^{-4}
Commercial steel or welded steel	4.6×10^{-5}	1.5×10^{-4}
Wrought iron	4.6×10^{-5}	1.5×10^{-4}
Riveted steel	1.8×10^{-3}	6×10^{-3}
Concrete	1.2×10^{-3}	4×10^{-3}

One of the most widely used method s for evaluating the friction factor employs the Moody diagram shown in Figure 4.2. The diagram shows the friction factor f plotted versus the Reynolds number Re, with a series of parametric curves related to the relative roughness $\frac{D}{\epsilon}$. These curves were generated from experimental data by L. F. Moody.

Both f and Re are plotted on logarithmic scales because of the broad range of values encountered. At the left end of the chart, for Reynolds numbers less than 2000, the straight line shows the relationship $f = 64/Re$ for laminar flow. For $2000 < N_R < 4000$, no curves are drawn since this is the critical zone between laminar and turbulent flow and it is not possible to predict the type of flow. Beyond $Re = 4000$, the family of curves for different values of $\frac{D}{\epsilon}$ are plotted. Several important observations can be made from these curves:

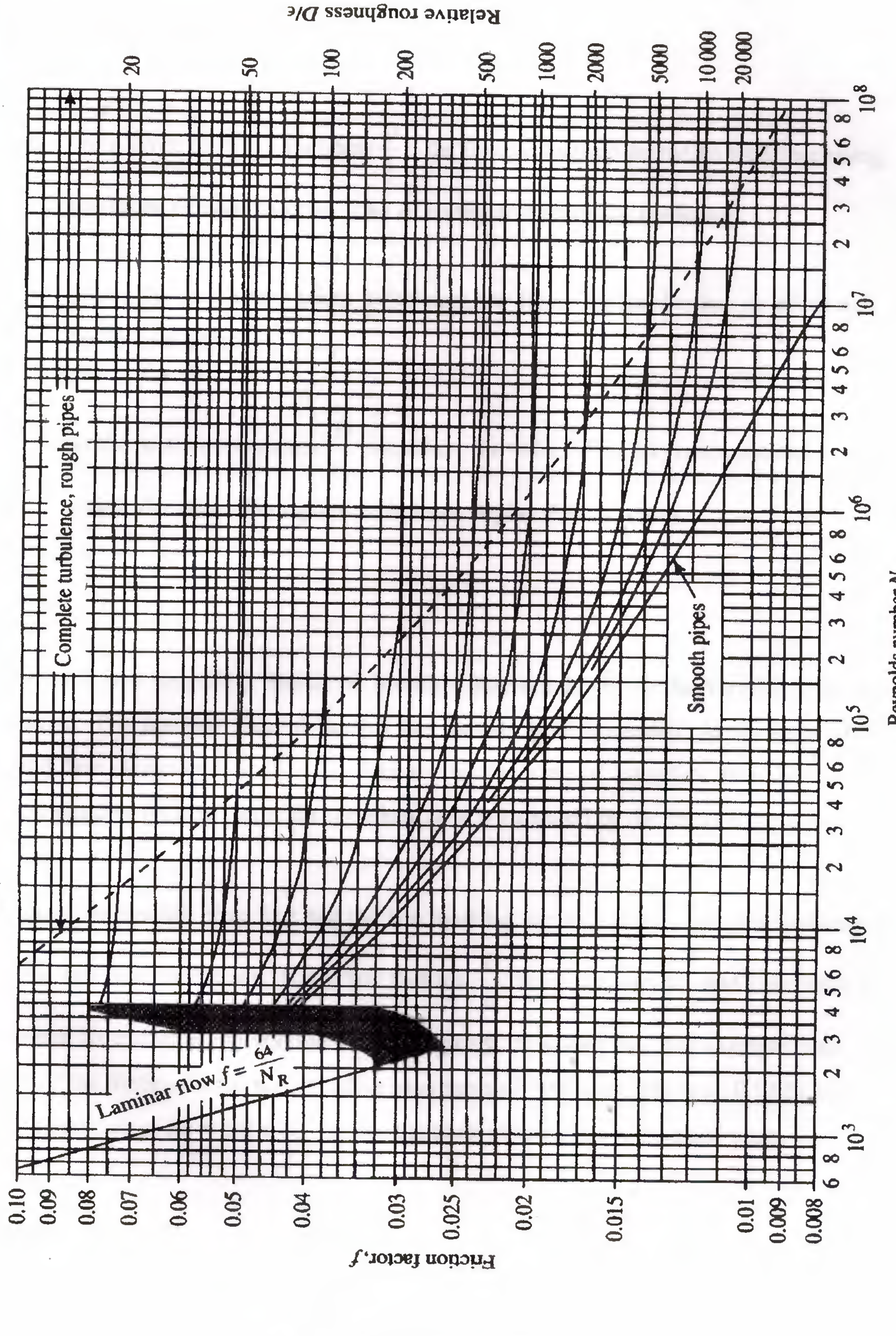


Figure 4.6 Moody's Diagram

1. For a given Reynolds number of flow, as the relative roughness $\frac{D}{\in}$ is increased, the friction factor f decreases.

2. For a given relative roughness $\frac{D}{\in}$, the friction factor f decreases with Increasing Reynolds number until the zone of complete turbulence is reached.

3. Within the zone of complete turbulence, the Reynolds number has no effect on the friction factor.

4. As the relative roughness $\frac{D}{\in}$ increases, the value of the Reynolds number at which the zone of complete turbulence begins also increases.

Figure 4.6 is a simplified sketch of Moody's diagram in which the various zones are identified. The *laminar zone* at the left has already been discussed. At the right of the dashed line downward across the diagram is the *zone of complete turbulence.* The lowest possible friction factor for turbulent flow is indicated by the *smooth pipes* line.

Between the smooth pipes line and the line marking the start of the complete turbulence zone is the *transition zone.* Here, the various $\frac{D}{\in}$ lines are curved, and care must be exercised to evaluate the friction factor properly. You can see, for example, that the value of the friction factor for a relative roughness of 500 decreases from 0.0420 at $Re =$ 4000 to 0.0240 at $Re = 6.0 \times 10^5$, where the zone of complete turbulence starts.

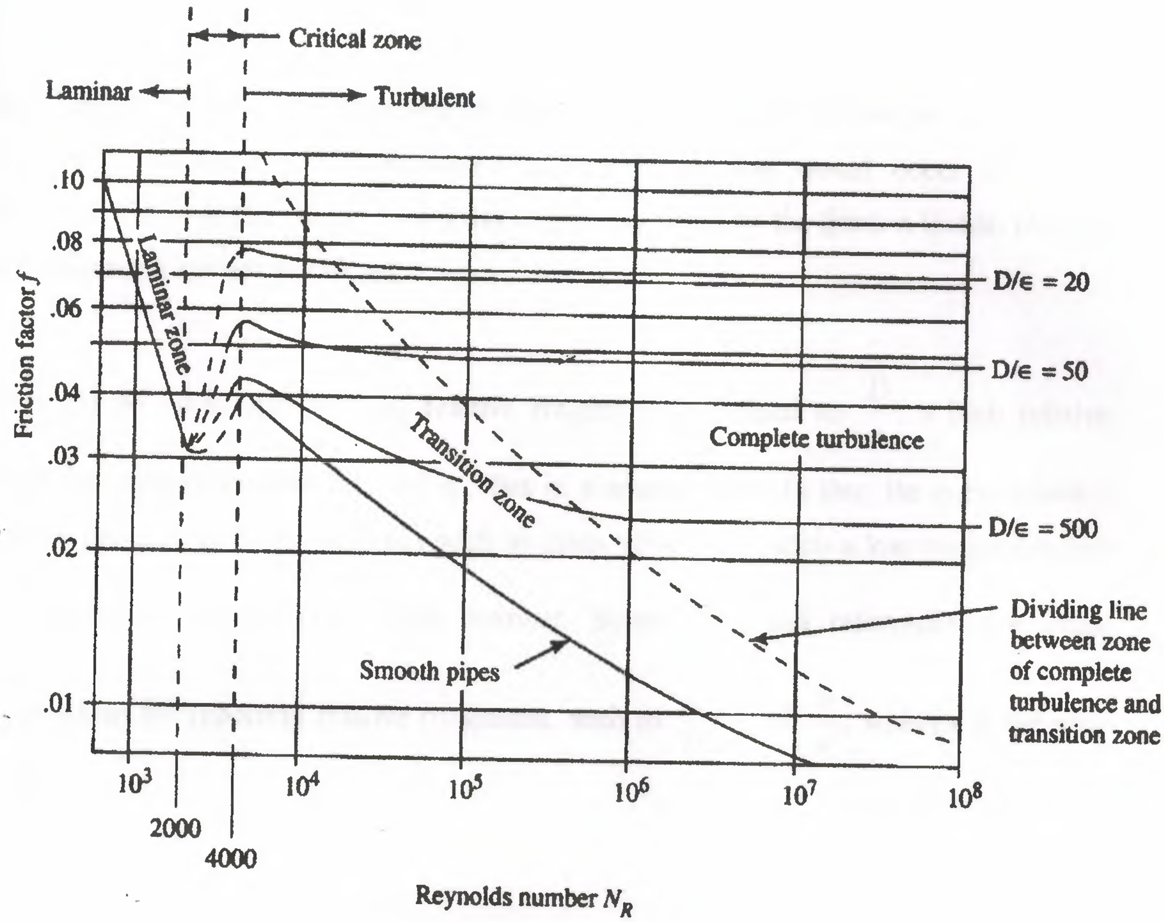


Figure 4.6 Explanation Parts of Moody's Diagram

As stated in Chapter 3, the critical zone between the Reynolds numbers of 2000 and 4000 is to be avoided if possible, because within this range the type of flow cannot be predicted. The dashed curves show how the friction factor could change according to the value of the relative roughness. For low values of $\frac{D}{\epsilon}$ (indicating large pipe wall roughness), the increase in friction factor is great as the flow changes from laminar to turbulent. For example, for flow in a pipe with $\frac{D}{\epsilon}$ = 20, the friction factor would increase from 0.032 for $Re = 2000$ at the end of the laminar range to approximately

0.077 at $Re = 4000$ at the beginning of the turbulent range, an increase of 240 percent. Moreover, the value of the Reynolds number where this would occur cannot be predicted. Because the energy loss is directly proportional to the friction factor, changes of such magnitude are significant.

It should be noted that because relative roughness is defined as $\frac{D}{\in}$, a high relative roughness indicates a low value of $\in$, that is, a smooth pipe. In fact, the curve labelled *smooth pipes* is used for materials such as glass which have such a low roughness that $\frac{D}{\in}$ would be an extremely large number. Some texts and references use other conventions for reporting relative roughness, such as $\frac{\in}{D}, \frac{\in}{r}$, or $\frac{r}{\in}$, where r is the pipe radius.

4.3.1 Use of The Moddy Diagram

Is used to help determine the value of the friction factor Use of the Moody Diagram f for turbulent flow. The value of the Reynolds number and the relative roughness must be known. Therefore, the basic data required are the pipe inside diameter, the pipe material, the flow velocity, and the kind of fluid and its temperature, from which the viscosity can be found. The following example problems illustrate the procedure for finding f.

EXAMPLE 4,1 : Determine the friction factor f if water at 160 F is flowing at 30.0 ft/s in an uncuated cast iron pipe having an inside diameter of 1 in.

SOLUTION : The Reynolds number must first be evaluated to determine whether the flow is laminar or turbulent :

$$\mathrm{Re} = \frac{\upsilon D}{\nu}$$

But D = 1 in = 0.0833 ft, and $\nu = 4.38 x 10^{-6}$ ft^2/s. We now have

$$\mathrm{Re} = \frac{(30.0)(0.0833)}{4.38x10^{-6}} = 5.70x10^5$$

Thus, the flow is turbulent. Now the relative roughness must be evaluated. From Table 4.2 we find $\in = 8x10^{-4}$ ft. Then, the relative roughness is

$$\frac{D}{\in} = \frac{0.0833 ft}{8x10^{-4} ft} = 1.04x10^2 = 104$$

The final steps in the procedure are;

1) Locate the Reynolds Number on the abscissa of the Moody diagram: $\mathrm{Re} = 5.70x10^5$
2) Project vertically until the curve for $\frac{D}{\in} = 104$ is reached. Since 104 is so close to 100, that curve can be used.
3) Project horizontally to the left, and read $f = 0.038$

EXAMPLE 4.2: Determine the friction factor f if ethyl alcohol at 25°C is flowing at 5.3 m/s in a standard 1½ in Schedule 80 steel pipe.

SOLUTION: Evaluating the Reynolds number, use the question

$$Re = \frac{\upsilon D \rho}{\mu}$$

$$\rho = 787 kg/m^3$$
$$\mu = 1.00x10^{-3} Paxs$$
$$D = 0.0381m$$

$$Re = \frac{(5.3)(0.0381)(787)}{1.00x10^{-3}} = 1.59x10^5$$

Thus the flow is turbulent. For a steel pipe, $\in = 4.6x10^{-5} m$, so the relative roughness is

$$\frac{D}{\in} = \frac{0.0381m}{4.6x10^{-5} m} = 828$$

From Figure 4.6 $f = 0.0225$ I must interpolate on both Re and $\frac{D}{\in}$ to determine this value, and I should expect some variation. However, I should be able to read the value of the friction factor f within ± 0.0005 in this portion of the graph

SUMMARY

In this chapter types of pipe line system which effect the energy losses and efficiency are discussed, by using Moddy diagram which is used to determine friction factor are considered.

When two pipes of different sizes or roughnesses are connected that fluid flows through one pipe and then through the other, they are called connected in series. A combination of two or more pipes and than is joined again is a parallel pipe system.

For turbulent flow of fluids incircular pipes it is most conveinent to use Darcy's equation to calculate the energy loss due to friction.

Moddy's diagram in which the various zones are identified. It is used to help determine the value of the friction for turbulent flow. The value of the Reynolds number and the relative roughness must be known. Therefore the basic data required are the pipe inside diameter, the pipe material, the flow velocity and the kind of fluid and its temperature, from which the viscosity can be found.

CONCLUSION

Fluid mechanics is the science of the liquid and is based in three basic branches. They are fluid statics, fluid kinematics, fluid dynamics. First chapter difference between liquids and gases are examined as followed. Another important factor is viscosity, which is a measure of the resistance the fluid has to shear. At the end of the chapter Bernoulli's equation is determined and also described applications.

Second chapter laminar and turbulent flow are described. When the fluid flows in smooth layers it is laminar flow, if much higher flow rates existed in the system it is turbulent flow. According to the fluid are examined effect of viscosity and entrance effects. Another categorizing flows are by exarninig the geometry of the flow field, which are internal and external flows. Internal flow involved flow in an unbounded region in the focus of attention is on the flow pattern a round a body immersed in the fluids. In the third chapter is considered one and two dimensional flows and Reynolds number. Reynolds number is one of several dimensionless numbers useful in the study of fluid mechanics and heat transfer. Reynolds number is the ratio of the inertia force on an element of fluid to the viscous force. If the Reynolds number is less than 2000 the flow is laminar. Also, ıf the Reynols number is greater than 4000 the flow is turbulent. The range of Reynols number is between 2000 and 4000, is called critical region.

Last chapter types of pipe line system which effect the energy losses and efficiency are discussed, by using Moddy diagram which is used to determine friction factor are considered. When two pipes of different sizes or roughnesses are connected that fluid flows through one pipe and then through the other, they are called connected in series. A combination of two or more pipes and than is joined again is a parallel pipe system. For turbulent flow of fluids incircular pipes it is most conveinent to use Darcy's equation to calculate the energy loss due to friction. Moddy's diagram in which the various zones are identified. It is used to help determine the value of the friction for turbulent flow. The value of the Reynolds number and the relative roughness must be known. Therefore the basic data required are the pipe inside diameter, the pipe material, the flow velocity and the kind of fluid and its temperature, from which the viscosity can be found.

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