# Chapter 11 flow in closed conduits 

Chapter 11 Flow in Closed Conduits CN2122 / CN2122E Main Topics if $1 / 4$ if $1 / 4$ if $1 / 4$ if 1 ¹/ if 1 ¹/4 - - - Introduction Reynolds' Experiment Dimensional Analysis of Conduit Flow Friction Factor for Fully Developed Laminar Flow Friction Factor for Fully Developed Turbulent Flow Smooth Pipe Law Rough Pipe Law Different Workers Results Application if ${ }^{\sim}$ if ${ }^{\sim}$ if ${ }^{\sim}$ Energy/ pressure loss problem Velocity/ flow rate problem Pipe Sizing Problem - Explicit Equation for Friction Factor CN2122 / CN2122E Main Topics if 1 ¹/4 if 1 ¹/ if 1 ¹ 4 - - Equivalent Diameter for Non- Circular Conduit Pressure Drop due to Fittings Loss of Head at Abrupt Enlargement Exit Loss Loss of Head at abrupt Contraction Entry Loss if 1 ¹/4 Combinations of Pipes CN2122 / CN2122E 11. 0 Introduction In this chapter, we will go back to consider what we have left out in Chapter 7viscous work done term. Because of this, this chapter is quite important for it is dealing with real practical problems. For chemical engineers, more than $90 \%$ of their problems involve flows in closed conduits. CN2122 / CN2122E 11. 1 Reynolds' Experiment The classic Reynolds experiment on viscous flow was conducted in 1883. Water is made to flow through a glass pipe as shown in Fig. 11. 1. 1, the velocity being controlled by an outlet valve. At the inlet of the pipe, a dye having the same specific weight as water is injected into the flow. When the outlet valve is only slightly open, the dye will move through the glass pipe intact, forming a thread as illustrated in Fig. 11. 1. 2. a. The orderly nature of this flow is apparent from this demonstration. However, as the valve is progressively opened, a condition will be reached whereby the dye assumes a fluctuating motion as it proceeds through the pipe. (As depicted in Fig. 11. 1. 2. b.) A transition is taking place from the previous well ordered flow, which may be considered as laminar flow, to an unstable type of flow. Further opening of the valve then results in a condition whereby
irregular fluctuations are developed in the flow so that the thread of dye is completely dispersed before proceeding very far along the pipe. (As shown in Fig. 11. 1. 2. c.) This irregular flow is called turbulent flow. The experiment brings out the essential difference between laminar and turbulent flow. The former, while having irregular molecular motions, is macroscopically a well ordered flow. However, in the case of turbulent flow, there is the effect of a small but macroscopic fluctuating velocity superimposed on a well ordered flow. Visualization CN2122 / CN2122E Figure 11. 1. 1 Reynold's apparatus 11. 1 Reynolds' Experiment It was found by Reynolds that the criterion for the transition from laminar to turbulent flow in a pipe is the Reynolds number based on the pipe diameter. In the experiment, the Re was continuously increased by increasing the velocity. However, this could have been accomplished by using pipes of different diameters or using fluids with different viscosities or densities. A Re of approximately 2300 was found to denote the imminence of a transition from laminar to turbulent flow. Under special operating condition, it is found that laminar flow can be maintained for Re up to 40000. All experiments thus far indicated by most workers that below 2300, there can be only laminar flow. (However, Bird et al gives a value of 2100 , to be on a safer side, we will take 2100 as the criterion.) Thus after 2100 has been reached, there may be a transition depending on the extent of local disturbances. We called this value (2100) of Re the critical Re. CN2122 / CN2122E 11. 2 Dimensional Analysis of Conduit Flow To consider the flow of fluid in a straight and horizontal circular pipe of constant cross section, we do not have to worry about the surface tension, because there is no free surface; there is no need to consider gravity, because the pipe is placed on an horizontal plane. We only have to consider the diameter of the
pipe (D), the velocity of the flow (v), the density of the fluid ( $\overline{\mathrm{I}})$ ), the pressure drop across the pipe (-gcî" P), the viscosity of the fluid (î1/4), the roughness of the pipe (e) and the length of the pipe (L). Dimensional Matrix can be set up. Dvï - gcî" P î1⁄ e L M 0011100 L11-3-1-111 î, 0-1 0 -2-100 All together, there are seven parameters involved and the rank of the above dimensional matrix is 3, so according to the Buckingham's $̈ €$ theorem, there shall be four dimensionless groups. Ï€1 $=\mathrm{f}($ Ï $€ 2, \mathrm{Ï€3}, \mathrm{Ï€4)} \mathrm{(11}$. 2. 1) where Ï€ $=\operatorname{Da}$ vb $̈$ 亿 $(-g c i ̂ " P)=M c+1 L a+b-3 c-1 t-b-2=D 0$ v-
 D-1 v-1 Ï Ï 0 e = e / D Ï€4 = Da vb Ï c L = Mc La +b-3c + 1t-b = D-1 v0 Ï 0 L = L / D CN2122 / CN2122E 11. 2 Dimensional Analysis of Conduit Flow e, L (11. 2. 2) $D D$ This is a rather complicated relation, fortunately, from experimental fact done by previous workers, it is known that the Eu is directly proportional to L/D, (that is when a pipe is longer, the pressure drop will be larger, when a pipe size is reduced, the pressure drop will also become larger), so this term can be isolated from the rest, and (eq. 11. 2. 2) becomes, $E u=L / D f^{\prime}(R e, e / D)(11.2 .3)$ The function $f^{\prime}(R e, e / D)$, is a dimensionless expression, which is designated as friction factor Ï†. There are many kinds of definition for Ït, such as Fanning friction factor: Eu = 2 Ï†f (L / D) (11. 2. 4) Darcy friction factor: Eu = Ï†D / 2 (L/D) (11. 2. 5) Ti friction factor: $\mathrm{Eu}=\mathrm{Ï} \dagger \mathrm{T}(\mathrm{L} / \mathrm{D})(11.2 .6)$ It can be observed to find that Ï†D $=2$ Ï $\dagger \mathrm{T}=$ 4 Ï $\dagger f$ There might be other forms of Ï $\dagger$, but the two introduced are the most popular. In this course, Fanning friction factor will be used extensively. Therefore, Eu'fRe, CN2122 / CN2122E 11. 2 Dimensional Analysis of Conduit Flow Please be noted that although the Euler's expression (eqn 11.
2. 4-11.2.6) gives the relationship of pressure drop to the friction, but the pressure drop here is considered to be the cause of the flow and it is to compensate the energy loss in the system. In fact energy loss can be considered as pressure drop, heat transfer, viscous work done or internal energy change. Energy loss in the system may accompany temperature change of the fluid, and the temperature change may give rise to a heat transfer and the energy loss will give viscous work done to the surrounding. If all three terms have to be considered then it may become messy, so it will be easier if the energy loss is to lump into a single term. In the following working, energy loss is considered to be in the viscous work done term only and the other term, namely, heat transfer and internal energy change have been considered to be zero. CN2122 / CN2122E 11. 3 Friction Factor for Fully Developed Laminar Flow Since friction factor related to Euler number Eu, and this is to the pressure drop. We recall the relation of the pressure drop with the velocity of fully developed laminar incompressible flow. The Hagen Poiseuille equation, (i. e. eq. 9. 1. 7), \&dP dx ' 8 î1/4 vx, ave gc R 232 î1/4 vx, ave L gc D 2 ' 32 Î¼ vx, ave gc D 2 (9. 1. 7) (11. 3. 1) After integrating, we will have (\& î" P) ' Make the left hand side of the above equation to become
 ï v2 From (eq. 11. 2. 4), it is known that for fully developed laminar flow in closed conduit, the Fanning friction factor related with Re in the following form, Ï†f ' 16 Re (11. 3. 2) CN2122 / CN2122E 11. 4 Friction Factor for Fully Developed Turbulent Flow From eqs. (11. 2. 4) to (11. 2. 6), it is already noticed that friction factor is a function of Reynolds number and relative roughness. By experimental experiences, it is known that when Re is low, Ï $\dagger$ is merely a function of $R e$, when $R e$ is very high, then Ï $\dagger$ is a function of (e /
D). This characteristic has already been proven partially in the laminar flow region, Ï $\dagger$ is indeed a function of Re only. When the flow velocity is high enough to be beyond the laminar flow region, but not too high, it is found that Ï $\dagger$ agrees to Smooth Pipe law, when the flow velocity is very high, then Ï $\dagger$ agrees to Rough Pipe law. 11. 4. 1 Smooth Pipe Law: This law states that the transmission factor (that is the reciprocal of the square root of friction factor (1/ì ${ }^{\text {a }}$ ) depends on the Reynolds number Re only. That is to say that for the laminar sublayer, the locus of all viscous effects, is decreasing in size as the Reynolds number increases, allowing more of the conduit cross section to flow in a turbulent condition, but that flow is still unaffected by the conduit wall. It will have the following form 1 Ï $\dagger$ ' A log10 Re 1/Ï† \% B (11. 4. 1. 1) SPL CN2122 / CN2122E 11. 4 Friction Factor for Fully Developed Turbulent Flow 11. 4. 2 Rough Pipe Law: It states that the transmission factor depends only on the cross sectional area of flow, i. e. it is a function of the ratio of diameter to wall roughness, and is independent of fluid properties. This implies that over here the laminar sublayer has shrunk to the point where it is no longer a continuum, and surface texture now protrudes into the turbulent core (which in effect fills the entire pipe) and affects the nature of the flow. The rough pipe law thus defines the limiting value of the transmission factor as flow rate continues to increase. It has the following form, 1 Ï† RPL ' C log10 D \% E e (11. 4. 2. 1) (The reason for having the smooth pipe law and rough pipe law can be thought to be due to the boundary layer thickness. When Re is small, the boundary layer thickness is thick and the roughness of the pipe is within the layer. When Re is high, then the thickness of Boundary layer is thin, and the roughness of pipe becomes protruding above the Boundary layer.) CN2122 / CN2122E 11. 4 Friction

Factor for Fully Developed Turbulent Flow 11. 4. 3 Different Workers Results: In 1932, Nikuradse was the first to carry out experimental works by painstakingly gluing sands on the pipe wall, according to his results, the coefficients in Smooth pipe law (SPL) \& Rough pipe law (RPL), A, B, C, E are 4. $0,-0.40,4.0 \& 2.28$ respectively. In 1956, Smith and his coworkers redid Nikuradse's experimental and their work seems to work very well, their coefficients A, B, C, E are, 4. 06, $-0.60,4.0 \& 2.273$ respectively, which are very closed to Nikuradse's work. However, it is believe that Ti's coefficients are the best, which are simply the average of the two. So A, B, C, E are 4. 03, -0. 50, 4. 0 \& 2. 2765. Coefficients for SPL \& RPL Nikuradse Smith 4. 04.06 0. $40-0.604 .04 .02 .282 .273$ Ti 4. $03-0.504 .02 .2765$ A B C E CN2122 / CN2122E 11. 4 Friction Factor for Fully Developed Turbulent Flow It is known that as the flow increases, the friction factor Ï† will relate according to SPL and RPL. There must be a transitional region exists between SPL \& RPL, Colebrook in 1939, proposed an equation for this transition zone which actually combine the SPL \& RPL into one equation. 1 Ï† ' \& $4 \log 10$ e 1.255 $1 /$ Ï $\dagger$ \% 3. 715 D Re (11. 4. 3. 1) Which becomes asymptotic to the SPL at low Re, and asymptotic to RPL at high Re. This was the first reasonably successful attempt to define a universal Ï† relationship for turbulent flow. Up to now, we know that when the flow is laminar the Ït relates Re according to (eq. 11. 3. 2), when the Re increases to turbulent then we can use eqs. (11. 4. 1. 1), (11. 4. 2. 1) or (11. 4. 3. 1). But using these equations may involve trial and error, fortunately, in 1944 Moody based on Colebrook's equation developed a correlation which has become an engineering design standard. The Moody diagram is used far and wide in fluid mechanics work and piping system specification, for which the correlation is generally valid and
accurate. However, when numerical computation is required (via computer), then eqs. (11. 3. 2) \& (11. 4. 3. 1) can be used for laminar and turbulent flow respectively. Care must be taken at the transitional region, as the friction factor is not continuous in this region. CN2122 / CN2122E Laminar ïᄀ, ow 0. $020.0180 .0160 .0140 .012 \mathrm{ff}=16 / \operatorname{Re}$ Complete turbulence, rough pipes 0.050 .040 .030 .020 .015 Fanning Friction factor 0. 010.0090 .0080. 0070.0060 .0050 .010 .008 0. 0060.0040 .0020 .001 0. 00080.00060. 0004 0. 0002 0. 004 Smooth pipe 0. 0030.0000001 0. 00010.000050. 0000050.002681030 .00000235810423581052358106235 81072358108 Reynolds number = Dv/ 11. 4 Friction Factor for Fully Developed Turbulent Flow 11. 4. 4 Application: It may be classified to have three types of pipe flow problems that occur in engineering practice, they are listed as follow: 1. The pressure drop problem: Given pipe diameter (D), length (L), surface roughness (e), fluid properties (ï), î1/4), and velocity (v) or flow rate (Q), find the pressure drop (-ī" P). 2. The velocity/flow rate problem: Given pipe diameter, length, roughness, fluid properties, and pressure drop, find the resulting velocity or flow rate. 3. The pipe sizing problem: Given pipe length and roughness, fluid properties, pressure drop, and velocity or flow rate (but not both), select an appropriate pipe diameter. Example 11. 4. 4. 1 Example 11. 4. 4. 2 Example 11. 4. 4. 3 Design example CN2122 / CN2122E Example 11. 4. 4. 1: Water at 20oC is pumped from a reservoir to the top of a mountain through a 15 cm pipe of relative roughness 0.0003 at an average velocity of $3.5 \mathrm{~m} / \mathrm{s}$. The pipe discharges into the atmosphere at a level 1500 m above the water level at the reservoir. The pipeline itself is 1650 m long. If the efficiency of the pump is $70 \%$ and the cost of electric energy for the pumping is $\$ 0.10$ per kW-hr, what is the hourly energy cost
for pumping the water? The density and viscosity of water at 200 C is 997.3 $\mathrm{kg} / \mathrm{m} 3$ and $0.001023 \mathrm{~kg} / \mathrm{s} / \mathrm{m}$ respectively. Given: e $/ \mathrm{D}=0.0003, \mathrm{D}=0.15$ $\mathrm{m}, \mathrm{L}=1650 \mathrm{~m}, \mathrm{I}\rangle=997.3 \mathrm{~kg} / \mathrm{m} 3, \mathrm{I} 1 / 4=0.001023 \mathrm{~kg} / \mathrm{m} / \mathrm{s} P 0=$ Patm, v0 = $0, \mathrm{zO}=0, \mathrm{P} 2=$ Patm, v2 $=3.5 \mathrm{~m} / \mathrm{s}, \mathrm{z} 2=1500 \mathrm{~m}$ For this problem, we make section 0 to be at the surface of the reservoir, section 1 to be at the entrance of the pipe, section 2 to be at the discharge end. Between sections 0 and 1, we may apply Bernoulli equation, from the given data, if we take gage pressure, the total Bernoulli energy will be zero at sections 0 and 1 . Between section 1 and 2, we have to apply Energy equation, since we have adiabatic flow, so there is no heat transfer, the heat transfer term is zero. No temperature change, so there is no internal energy change. The total Bernoulli energy at section 1 is zero. So from the given data, the energy equation can be reduced to the following form, The viscous work done term actually is the energy loss due to the friction. So we may combine the two equations to give, (1) The fanning friction factor can be found by Moody Diagram. First we have to find the Reynolds Number. From Moody diagram, with relative roughness at 0.0003 , then Ïtf is 0.004 . Substituting the value of the viscous work done term back into Eqn(1), we obtain, $=1391020 \mathrm{Nm} /$ $s=1391.02 \mathrm{~kW}$ Hourly Cost $=1391.0 \tilde{A}-0.1=\$ 139.10$ The same problem can also be solved without the Moody diagram. Assuming the pipe to be very rough, then from Rough Pipe law, (eq. 11. 4. 2. 1), The friction factor can be considered to have converged. Or we may start with the Blasius equation, With this initial guess, we can then use Colebrook equation to find the improved value. The friction factor can be considered to have converged. With this friction factor, we may solve the problem as above. Example 11. 4. 4. 2: Gasoline flows in a long, underground pipeline at a
constant temperature of 150 C . Two pumping stations at the same elevation are located 13 km apart. The pressure drop between the stations is 1.4 MPa . The pipeline is made from 0.6 m diameter pipe with a roughness of $1.8 \tilde{A}-$ $10-4 \mathrm{~m}$. The specific gravity of the gasoline is 0.68 . Compute the volumetric flow rate of gasoline through the pipe. Viscosity of gasoline can be taken as $5 \tilde{A}-10-4 \mathrm{~kg} / \mathrm{m} / \mathrm{s}$. Take control volume between the two pumping stations. There is no heat transfer (adiabatic flow), no shaft work (no pump or turbine), no kinetic energy change (since the pipe is of the same cross section throughout), no potential energy change (same elevation), no internal energy change (constant temperature), and steady flow. So the Energy equation can be reduced to have the following form, The second term is in fact the term due to friction, it can be rearranged as follow, Substituting the above equation into its previous one, we have Substituting the known value into the above equation, it obtains, Ï†f Q2 $=3.798235 \mathrm{~A}-10-3$ As for the Reynolds no, it has the following form, $\mathrm{Re}=4 \mathrm{I}\rangle \mathrm{Q} /($ (Ï€ î14 D) In order the solve this problem, trial and error process has to be used. For the fist attempt, assuming the flow to be fully turbulent, then from the relative roughness of the pipe e / $D=3 \tilde{A}-10-4$, the Fanning friction factor is found from the Moody diagram to be 0.0037 , Ï $\dagger 0.00370 .0038$ Q (from (1)) 1. 0132 0. $9998 \operatorname{Re}(f r o m(2))$ 2. $92 A ̃-106$ 2. 89Ã—106 Ï† (from MD) 0.00380. 0038 (2) (1) Therefore the volumetric flow rate is $0.9998 \mathrm{~m} 3 / \mathrm{s}$. However, if the above problem is solved by the correlating equations, instead of using the Moody diagram, then the trial and error steps may be avoided. The method of working is to rearrange the expression of (11.2.4) as follows, (11. 4. 4. 2. 1) Let the product be the modified Reynolds number and is abbreviated as Rem. Also rearranging the Colebrook's equation to the
following form, (11.4.4.2.2) Then for the above problem, we may solve for the modified Reynolds number Rem, since it is independent of the flow rate. Once the friction factor is solved, then the volumetric flow rate may be found in the similar way. Example 11. 4. 4. 3: A pipe is to permit the flow of 175 $\mathrm{gal} / \mathrm{min}$ of 60 oF water when it is subjected to a pressure drop of 1.2 psi per 100 feet of pipe. Assuming the pipe is horizontal and the roughness is given to be 0.00015 ft , what is the diameter of the pipe? (Given that the density and viscosity of water are $62.4 \mathrm{lbm} / \mathrm{ft}$ and $0.000761 \mathrm{lbm} / \mathrm{ft}-\mathrm{s})$ Given: $\mathrm{Q}=$ $175 \mathrm{gpm}=0.3899 \mathrm{ft} 3 / \mathrm{s}, \mathrm{i} 仑=62.4 \mathrm{lbm} / \mathrm{ft} 3, \hat{1} / 4=7.61 \tilde{A}-10-4 \mathrm{lbm} / \mathrm{ft}-\mathrm{s},(-$ $\hat{\imath} \prime \prime P) / L=1.2 \mathrm{psi} / 100 \mathrm{ft}=1.728 \mathrm{lbf} / \mathrm{ft} 3, \mathrm{e}=0.00015 \mathrm{ft}$. Find: The diameter D. Solution: To solve this problem, we can examine from two points, where section 1 is at the entrance of the pipe, section 2 is at the exit of the pipe. The energy equation may be reduced to its simplified form by the assumptions of no heat transfer (adiabatic flow), no shaft work (no pump or turbine), no kinetic energy change (since the pipe is of the same cross section throughout), no potential energy change (same elevation), no internal energy change (constant temperature), and steady flow. We then have As Rearranging the above equation in terms of the diameter, we have (1) For the Reynolds number, we can set up another equation, (2) Substituting the known values into (1) \& (2), we have, D5 = 0. 5532 Ï $\dagger \mathrm{f} \mathrm{Re}=$ 40706. 5 / D First assuming a diameter, say 1 ft, D 1. $00.315 \operatorname{Re}(f r o m(4)$ ) 4. 1Ã-104 1. 30Ã-105 e/D 0. 000150.000476 Ï† (from M. D.) 0.00560. 0049 D (from (3)) 0.3150 .3066 (3) (4) 0. 3066 1. 33Ã-105 0.0004890. 0049 0. 3066 Therefore the diameter is 0.3066 ft . This problem can also solve by the modified forms of the correlation, but the trial and error procedures still cannot be avoided. This type of the problem is the most
difficult problem of all. Example 11. 4. 4. 3: A pipe is to permit the flow of $175 \mathrm{gal} / \mathrm{min}$ of 60 oF phenol when it is subjected to a pressure drop of 1.2 psi per 100 feet of pipe. Assuming the pipe is horizontal and the roughness is given to be 0.00015 ft , what is the diameter of the pipe? (Given that the density and viscosity of phenol are $1.0722 \mathrm{~g} / \mathrm{cm} 3$ and 3.49 cp ) Given: $\mathrm{Q}=$ $175 \mathrm{gpm}=0.3899 \mathrm{ft} 3 / \mathrm{s}, \mathrm{I} \widehat{\imath}=1.0722 \tilde{A}-62.4 \mathrm{lbm} / \mathrm{ft} 3,1 \not 1 ⁄ 4=3.49 \tilde{A}-6$. 72043 Ã-10-4 lbm/ft-s, (-î" P) / L = 1. $2 \mathrm{psi} / 100 \mathrm{ft}=1.728 \mathrm{lbf} / \mathrm{ft} 3, \mathrm{e}=0$. 00015 ft . Find: The diameter D. Solution: To solve this problem, we can examine from two points, where section 1 is at the entrance of the pipe, section 2 is at the exit of the pipe. The energy equation may be reduced to its simplified form by the assumptions of no heat transfer (adiabatic flow), no shaft work (no pump or turbine), no kinetic energy change (since the pipe is of the same cross section throughout), no potential energy change (same elevation), no internal energy change (constant temperature), and steady flow. We then have As Rearranging the above equation in terms of the diameter, we have (1) For the Reynolds number, we can set up another equation, (2) Substituting the known values into (1) \& (2), we have, D5 $=0$. 593155 Ï†f Re = 14161. 24 / D First assuming a diameter, say 1 ft, D 1.00. $3350.32150 .3211 \operatorname{Re}(f r o m(4)) 1.416 \tilde{A}-1044.23 A ̃-1044.405 A ̃-1044$. 410Ã-104 e/D 0.000150 .0004480 .000467 0. 000467 Ï† (from M. D.) 0. $007130.005790 .005760 .00576 \mathrm{D}(\mathrm{from}(3)) 0.3350 .32150 .32110$. 3211 (3) (4) Therefore the diameter is 0.3211 ft . This problem can also solve by the modified forms of the correlation, but the trial and error procedures still cannot be avoided. This type of the problem is the most difficult problem of all. 11. 4 Friction Factor for Fully Developed Turbulent Flow 11. 4. 5 Explicit Equation for Friction Factor: Colebrook equation has received wide
acceptance, probably because it was used by Moody (1944) in the preparation of his friction factor charts. However, Colebrook's equation is implicit in Fanning's friction factor, Ï†f, and must therefore be solved by iteration, a formidable task in 1944 when Moody presented his charts which, no doubt, accounts for their popularity. Solution of Colebrook's equation by numerical methods to any desired degree of precision is accomplished easily, quickly and cheaply with today's digital computers. Even then, an explicit equation for friction factor is still preferred at any time. In 1979, N. H. Chen proposed the following explicit equation, which is reckoned to be the best. It has the following form, 1 Ï $\dagger \mathrm{f}$ ' \& 4 log10 e/D 5. 0452 \& log10 3. 7065 $\operatorname{Re}(e / D) 1.1098$ \% 2. 8257 7. $149 \operatorname{Re} 0.8981$ With the Chen's equation, we may obtain the friction factor explicitly. Examples Tables 11.4. 1 and 11. 4. 2 CN2122 / CN2122E Example 11. 4. 4. 1, we know already $R e=5.12 A \tilde{A}-10$ 5 , and e / D = 0.0003, then friction factor ïtf is found to be 4. 0727Ã-10-3, which is same as what we read from Moody diagram. Example 11. 4. 4. 2, same as using Moody diagram, we have to solve by trial and error, Ït Q (from (1)) $\operatorname{Re}($ from (2)) Ï† (from Chen) 60.0037 1. 0132 2. 92 $\mathrm{A}-103.8031 \tilde{A}-10-$ 3 0. 003803 0. 9998 2. 89Ã-10 6 3. 8038Ã-10-3 Example 11. 4. 4. 3, same as using Moody diagram, we have to solve by trial and error, D Re (from (4)) e / D Ï† (Chen) D (from (3)) 1. $04.1 A ̃-1040.000150 .00560 .31550 .315$ 1. 30 Ã-10 0. 0004760.00490 .30660 .3066 1. 33Ã-10 50.0004890. 0049 0. 3066 Table 11. 4. 1 Effective Surface Roughness Surface Concrete Cast iron Galvanized iron Commercial steel Drawn tubing î $\mu$ (ft) 0.001-0.01 $0.000850 .00050 .000150 .000005 \mathrm{I} \mu(\mathrm{mm}) 0.3-3.00 .250 .150 .0460$. 0015 Table 11. 4. 2 Representative Steel Pipe Size Nominal Size (in) 0. 250. D. (in) 0. 540 Schedule No. 40804080408040804080408040804080

40 Wall Thickness (in) 0.0880 .1190 .1090 .1470 .1130 .1540 .1330. 1790.1450 .2000 .1540 .2180 .2160 .300 0. 237 0. 337 0. 280 I. D. (in) 0.3640 .3020 .6220 .5460 .8240 .742 1. 0490.957 1. 610 1. 500 2. 067 1. 939 3. 068 2. 9004.0263 .826 6. 0350.50 .8400 .751 .05011 .3151. 501.9002 2. 37533.50044 .500800 .432 5. 761 Regardless of schedule number, pipes of a particular size all have about the same outside diameter. As the schedule number increases, the wall thickness increases, and the actual bore is reduced. For other sizing, please refer to Perry's Handbook 66. 625 11. 5 Equivalent Diameter for Non- Circular Conduit For laminar flow in different cases (eg. in flat walls, pipes, annular conduit and inclined plane), we have already introduced. Since Moody diagram can only work for circular pipe, so we can not solve for the turbulent flow in many non- circular conduits unless, the diameter D used in the Moody diagram is replaced by the equivalent diameter Deq defined by the following relation, (11.5.1) Deq $=4 \mathrm{rH}$ In this equation, rH is the hydraulic radius, which is defined by the following equation, rH ' A lp Where A is the cross sectional area of the conduit, and Ip is the wetted perimeter of the conduit. For the flow of a gas, Ip will always be the length of wall that is actually in contact with the fluid.; for liquids, however, it will be somewhat less than the periphery if the liquid has a free surface and incompletely fills the total cross section, it will then be the wetted length, the free surface length will be excluded. The use of equivalent diameter is to provide a means for non-circular conduit to use Moody diagram to evaluate the friction factor term. That is to find the Reynolds Number and the relative roughness. When flow rate is involved, one should use the actual cross section area. CN2122 / CN2122E 11. 6 Pressure Drop due to Fittings The pressure drop (or energy loss) caused by
friction in a pipe calculated from eqs. (11.2.4) or (11.2.5) is only a part of the total energy dissipation which must be overcome in pipe lines and other fluid flow conduits. Other losses may occur due to the presence of valves, elbow and other fittings that involve a change in the direction of flow or in the size of the flow passage. The energy dissipation caused by bends, elbows, joints, valves and other disturbing elements are frequently referred to as ' minor losses'. However, they can often be more significant in a piping system than the losses due to wall friction. The total energy loss is consisted of major and minor loss, where major loss is due to the friction of the pipe wall, and minor loss is due to the pipe fitting. Major loss: gc $\hat{I}^{\prime}$ Wî¼, L I Q I 't /0 ' 2 Ï†f 00 major D v2 Minor loss: gc Ï Q Î' Wî¹/4, Î't 'K /0 00 minor v2 2 Alternatively, with equivalent length approach gc Ï Q Î'Wî¼, Î't /0' 2 Ï 0 f 00 minor Leq D v2 CN2122 / CN2122E 11. 6 Pressure Drop due to Fittings Table 11. 6. 1 Figure 11. 6. 1 CN2122 / CN2122E Table 11. 6. 1 Friction Ioss coefficient for various pipe fitting Fitting Globe valve, wide open Angle valve, wide open Gate valve, wide open Gate valve, 3 / 4 open Gate valve, 1 / 2 open Gate valve, 1 / 4 open Standard 90o elbow Short radius 90o elbow Long radius 90 elbow Standard 450 elbow Tee, Through side outlet Tee, straight through 180o bend K 7.53 .80 .150 .854 .4200 .70 .90 .40 .351 .50 .4 1. 6 Leq / D 35017074020090032412015672075 11. 7 Loss of Head at Abrupt Enlargement One ' minor loss' which can be subjected to analysis is that at an abrupt enlargement of the cross section, such as that illustrated in Fig. 11. 7. 1. Derivation of (eq. 11. 7. 6) 11. 7. 1 Exit Loss: If A2 approaches to â^ž, then (eq. 11. 7. 6) shows that the loss at an abrupt enlargement tends to (v12 / 2 ). This happens at the outlet of a submerged pipe discharging into a large reservoir. In such circumstances the loss is
usually termed the exit loss for the pipe. The loss coefficient for exit loss is thus equal to one. 11. 7. 2 Loss of Head at abrupt Contraction: Although an abrupt contraction is geometrically the reverse of an abrupt enlargement, it is not possible to apply the momentum equation to a control volume between sections $1 \& 2$. This is because, just upstream of the junction, the curvature of the stream lines and the acceleration of the fluid cause the pressure at the annular face to vary in an unknown way. However, immediately downstream of the junction a vena contracta is formed, after which the stream widens again to fill the pipe. Eddies are formed between the vena contracta and the wall of the pipe, and it is these which cause practically all the dissipation of energy. CN2122 / CN2122E 11. 7 Loss of Head at Abrupt Enlargement: (4. 1. 1) (11. 7. 1) (11. 7. 2) or (11. 7. 3) (11. 7. 4) (11. 7. 5) (11. 7. 6) Similarly, 11. 7 Loss of Head at Abrupt Enlargement Between the vena contracta and the downstream section 2, where the velocity has again become sensibly uniformed - the flow pattern is similar to that after an abrupt enlargement, and so the loss of head is assumed to be given by the similar form of (eq. 11. 7. 6). ghL' v2 22 1\& A2 Ac 2 (11. 7. 2. 1) Where Ac represents the cross sectional area of the vena contracta, although the area A1 is not involved in (eq. 11. 7. 2. 1) explicitly, the value Ac depends on the ratio of A2 / A1 . 11. 7. 3 Entry Loss: As A1 approaches â^ž, the value of $K$ tends to 0.5 (by experiment), and this limiting case corresponds to the flow from a large reservoir into a sharp edged pipe, as in Fig. 11. 7. 3. 1. If the pipe is protruded into the reservoir, then it will cause a greater loss of head, as in Fig. 11. 7. 3. 2. For a non protruding sharp edged pipe the loss $0.5(\mathrm{v} 12 / 2)$ is known as the entry loss. If the inlet to the pipe is well rounded, as in Fig. 11. 7. 3. 3, the fluid can follow the boundary
without separating from it, and the entry loss can be taken as zero. CN2122 / CN2122E 11. 8 Combinations of Pipes Pipes can be connected in series (i. e. end to end) or in parallel (i. e. sharing the same ends), no matter which kinds of combinations we are having, they all follow Kirchhoff's two laws. Kirchhoff's first law: Through a node, those entering must equal to those leaving. Kirchhoff's second law: For a closed loop, the pressure drop of this loop is zero. (Since that becomes taking the pressure drop at the same point.) Applying the two Kirchhoff's laws, not only we can solve the simple pipes in series or in parallel problem, but we can also solve a very complicated network as well. For branches connected in series, the flow rate through them will be the same but the pressure drop across them will be the sum of the pressure drop across each branch. For branches connect in parallel, the pressure drop across them will be same as the pressure drop across each individual branch, the flow rate through them will be the sum of the flow through each individual branch. CN2122 / CN2122E Points to remember if $11 / 4$ The energy loss in the system can be considered to be contributed by the heat transfer, viscous work done, internal energy change, (or even a pressure change). However, it will be troublesome if we have to consider the individual contribution separately. It is more convenient to lump all the losses into one single term and putting the rest to zero. I make use of the viscous work done term, but you have the freedom to consider in whichever term you prefer. ïf $1 / 4$ The term, head is just expressing the energy in the dimension of length. We can have potential head, pressure head or kinetic head. So head loss is another term for energy loss. if $\mathrm{f}^{1} / 4$ Chen's equation can be used in substitution for the Moody diagram. It has the same characteristics as the Moody diagram. iif $1 / 4$ For non-circular conduit, we use
its equivalent diameter to find the Reynolds number as well as the relative roughness. (The reason for coming up with the equivalent diameter is to ensure that we can make use of the Moody diagram.) CN2122 / CN2122E Points to remember iif $1 / 4$ Two ways to consider minor loss, they are the equivalent length and the loss coefficient if $1 / 4$ When we have a pipeline network, for branches connected in series, the flow rate through them will be the same but the pressure drop across them will be the sum of the pressure drop across each branch. For branches connect in parallel, the pressure drop across them will be same as the pressure drop across each individual branch, the flow rate through them will be the sum of the flow through each individual branch. CN2122 / CN2122E Tutorial Link to Tutorial 7 CN2122 / CN2122E Tutorial 8 (Chapter 11) 1. An oil with kinematic viscosity of 0.08 Ã-$10-3 \mathrm{ft} 2 / \mathrm{s}$ and a density of $57 \mathrm{lbm} / \mathrm{ft} 3$ flows through a horizontal tube 0.24 in. in diameter at the rate of $10 \mathrm{gal} / \mathrm{hr}$. Determine the pressure drop in 50 feet of tube. The pressure drop in a section of pipe is determined from tests with water. A pressure drop of 13 psi is obtained at a flow rate of $28.3 \mathrm{lbm} /$ sec. If the flow is fully turbulent, what will be the pressure drop when liquid oxygen (density is $70 \mathrm{lbm} / \mathrm{ft} 3$ ) flow through the pipe at the rate of $35 \mathrm{lbm} /$ sec ? Water at the rate of $118 \mathrm{ft} 3 / \mathrm{min}$ flows through a smooth horizontal pipe 250 feet long. The pressure drop is 4.55 psi. Determine the tube diameter. Determine the flow rate through a 0.2 meter gate valve with upstream pressure of 236 kPa when the valve is, a) fully open; b) half open. A galvanized rectangular duct 8 in square is 25 ft long and carries 600 ft 3 / min of standard air. Determine the pressure drop in inches of water. Water is to be withdrawn from a large main, in which the pressure is 35 psig, and carried through 175 ft of pipe to discharge to the atmosphere at a point 22 ft https://assignbuster.com/chapter-11-flow-in-closed-conduits/
above the main. What is the minimum diameter of pipe require to assure a flow of $275 \mathrm{gal} / \mathrm{min}$ ? Water is drawn from a reservoir and pumped an equivalent length of 2 mile through a horizontal, circular concrete duct of 10 in ID (roughness is 0.01 foot). At the end of this duct, the flow is divided into a 4 and a 3 in schedule- 40 steel pipe. The 4 in line has an equivalent length of 200 ft and rises to a point 50 ft above the surface of the water in the reservoir, where the flow discharges to the atmosphere. This flow must be maintained at a rate of $1000 \mathrm{gal} / \mathrm{min}$. The 3 in line discharges to the atmosphere at a point 700 ft from the junction, the discharge is at the level of the surface of the water in the reservoir. Calculate the horsepower input to the pump, which has an efficiency of $70 \%$. A pneumatic system constructed of capillary tubing is arranged as shown in Fig. T. 8. 8. The lengths and diameters of the lines are given in the accompanying table except for the inside diameter of line 4. Assuming laminar flow in all parts of the system and negligible kinetic and potential energy changes, find the ID of line 4 which would give zero velocity in line 5 . Line Length (ft) ID (ft) 110 0.0052120 .00838 .33330 .010420 ? 5150.005 Water at 70oF flows into a rectangular tank from an overhead outlet at the rate of $5 \mathrm{ft} 3 / \mathrm{min}$. The tank is 3 ft wide, 2 ft deep, and 4 ft long. At the bottom is an open drain 14 2. 3. 4. 5. 6. 7. 8. 9. Tutorial 8 (Chapter 11) connected to an equivalent length of 75 ft of 1-in ID plastic tubing. The drain discharges into a sewer at atmospheric pressure at a point 30 ft lower in elevation than the bottom of the tank. Will the tank overflow if allowed to fill at the specific rate. (Plastic tubing can be assumed to be very smooth.) 10. Water at 60oF flows in laminar motion through 600 ft of horizontal, half in, schedule-40 steel pipe and then discharges through a stationary nozzle into the atmosphere. On
leaving the nozzle the water rises 22 ft straight up in the air before falling back to the ground. If the pressure at the upstream end of the pipe is 10 psig, what is the flow rate in gal/min from the nozzle? (Viscosity of water is assumed to be 1.12 cp ) The system sketched in Fig. T. 8.11 is in service in a manufacturing operation. A solution of 4 cp viscosity is to be transferred from tank $A$ to tank $B$. The density of solution is 65 pound-mass per cubic foot. All piping is 1 in nominal diameter schedule-40 standard steel. Elbows are standard. Pipe connection to the tanks are of ordinary type. (a) For a required flow rate of 15 gpm , will a pump be needed? (b) If so, what should be its power requirement at 80\% overall efficiency? 11. 15

