Preparation

Wednesday, August 25, 2010
11:55 AM

class exercises
Hunter Rouse videos on viscosity

3.1-2

$V = Q/A$ velocity = discharge / cross sectional area

$m/s = (m^3/s) / (m^2)$

Reynolds Number = inertial forces / viscous forces

What would you expect to happen when this ratio is low?

high?

$Re = D V/\nu$ for pipe flow $\nu = \mu/\rho$

Viscosity is the constant relating velocity gradient to shear stress:

$\tau = \mu \, dV/dx$ Pa = Pa*s (m/s)/m

force per unit area = viscosity * velocity gradient

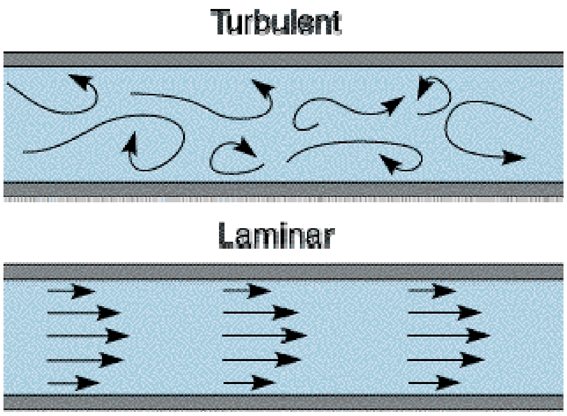
D = diameter for a pipe

R = hydraulic radius = area / wetted perimeter

μ = absolute of dynamic viscosity (Pa*s)

ν = kinematic viscosity (m^2/s)

ρ = density (kg/m^3)



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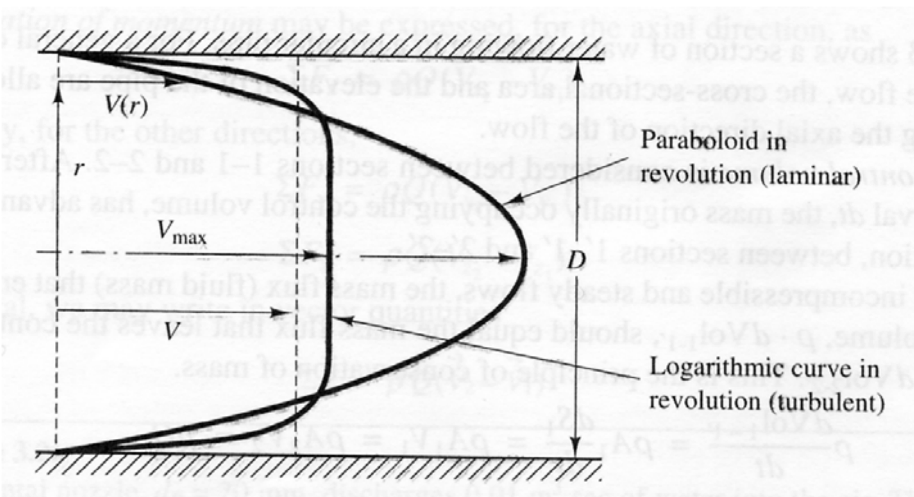
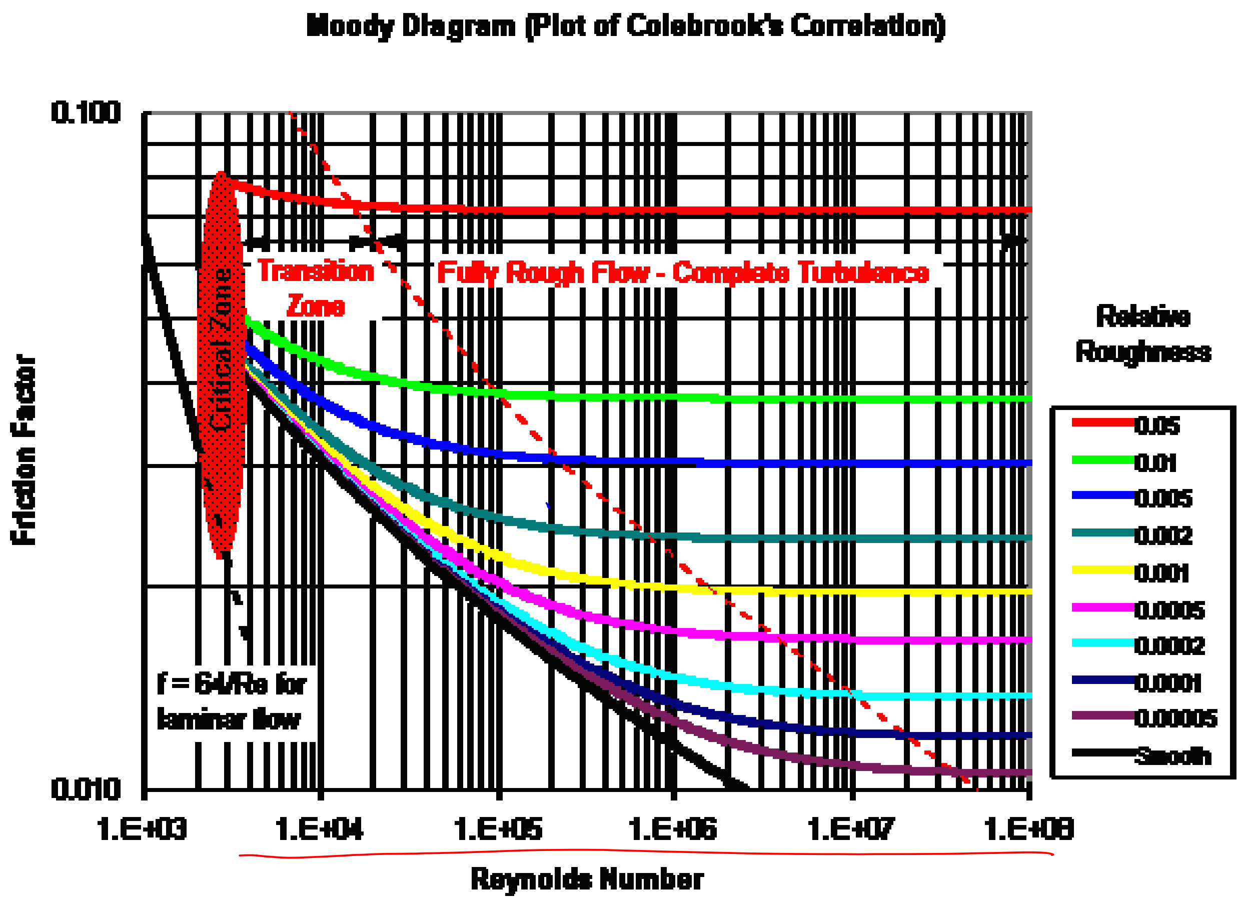


Figure 3.2 Velocity profiles of laminar and turbulent flows in circular pipes.



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note: right click and tell it to open the files to show the videos

laminar

Measuring Kinematic ...

viscosity

energy loss in pipes is caused by internal friction (viscosity) and friction on pipe walls

3.1,2

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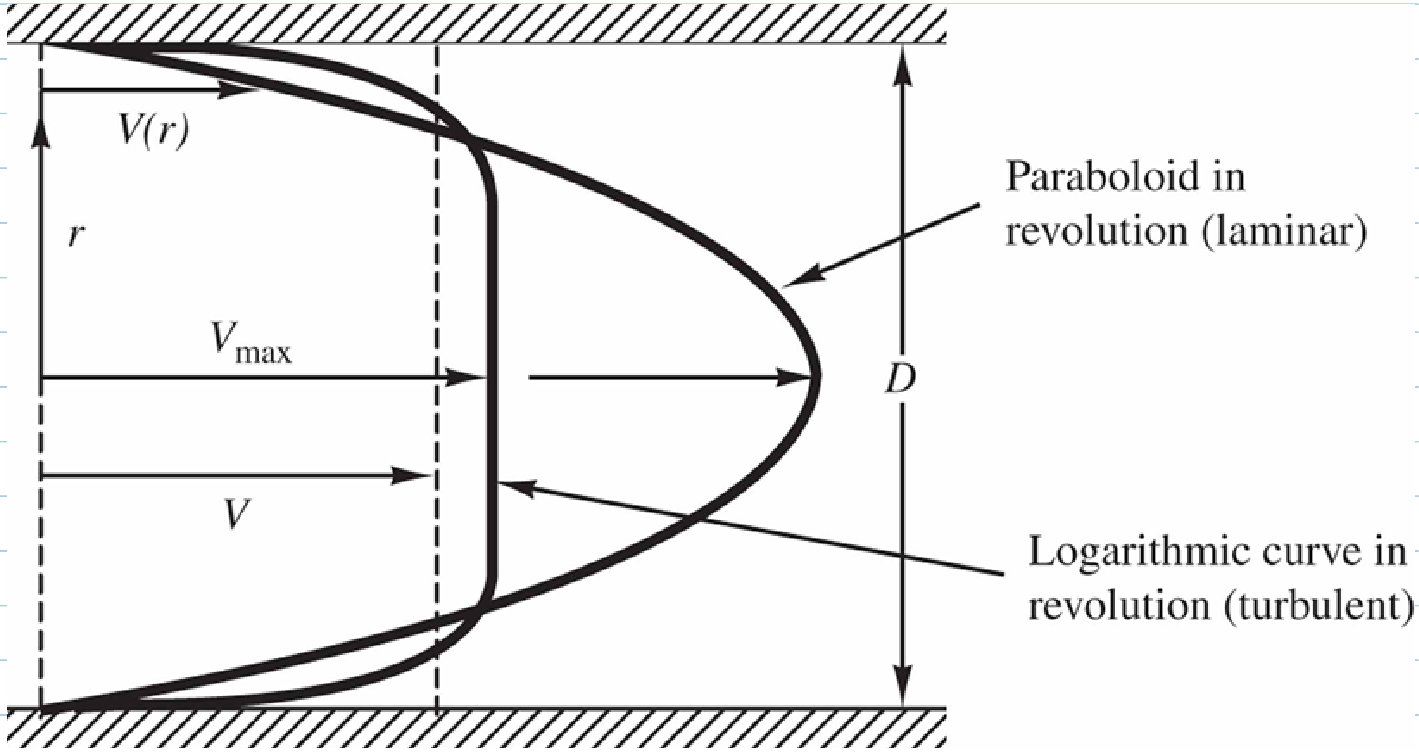
In pipe flow we get two flow regimes, laminar and turbulent; turbulent flow occurs at higher velocity



Reynolds number = Re = V D/ ν = ratio of inertial to viscous forces
Where V = water velocity, D = hydraulic diameter, ν =kinematic viscosity
ν = μ/ρ

Reynolds number is ratio of inertial to viscous forces:

Re = V D/ ν = V D ρ/ μ = V D ρ/ μ = inertia/viscosity

Above Reynolds # of 2,000-4,000 flow is turbulent

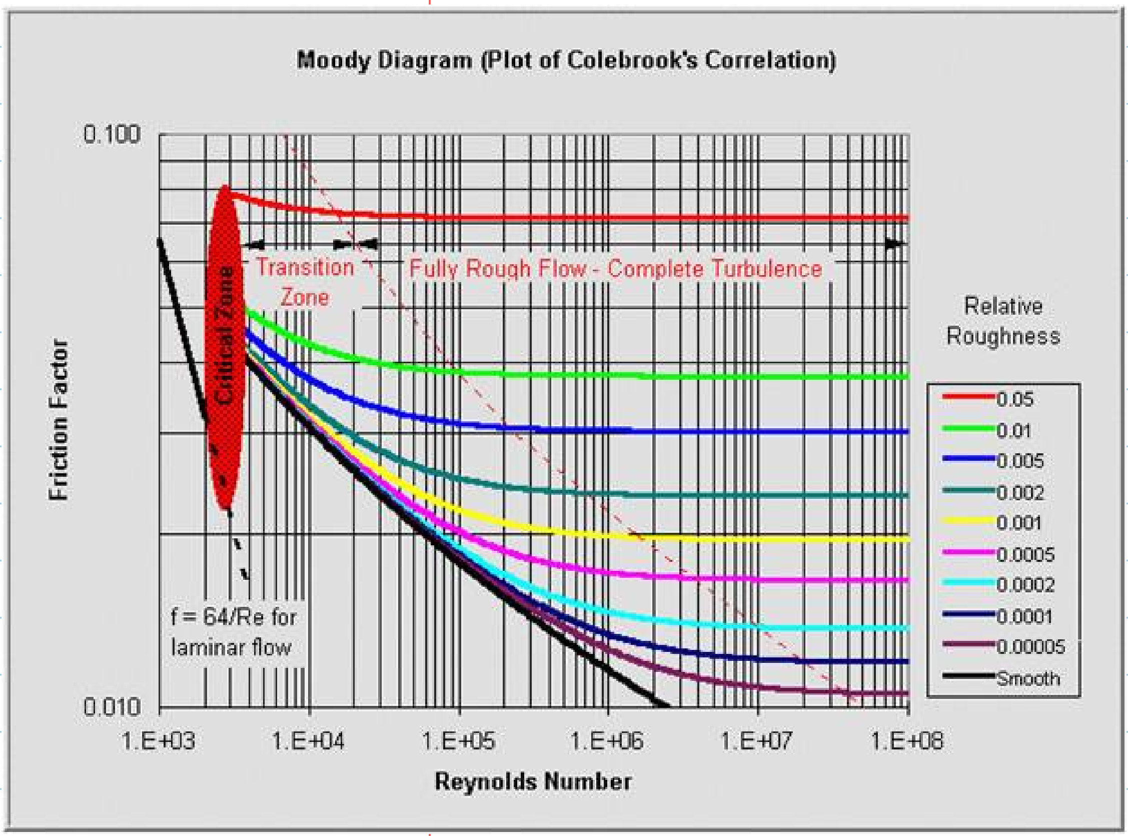
Reynolds Number

Friday, August 22, 2008
12:55 PM

Class Exercise: Reynolds Number

Reynolds number = Re = V D/ ν = ratio of inertial to viscous forces
Where V = water velocity, D = hydraulic diameter, ν =kinematic viscosity
ν = μ/ρ

a) What are the units of the Reynolds number? What does each term mean in words?
b) What is the definition of relative roughness?
c) What relative roughness lines have the most amount of flow per unit head loss? Why?
d) What does the "transition zone" transition between?



V = velocity (m/s)
D = diameter (m)

μ/ρ

ν = kinematic viscosity $\frac{Pa\text{-}s}{kg/m^3}$

$= \frac{N \; s \; m^3}{m^2 \; kg} = \frac{N m}{kg} = \frac{kg \; m}{s^2} \cdot \frac{m}{kg}$

$= \frac{m}{s^2}$

Answer:
V = Velocity (m/s)
D = Diameter (m)

- = kinematic viscosity = μ/ρ
- = density (kg/m^3)
- = absolute viscosity (Pa*s) or (kg/(m*s))

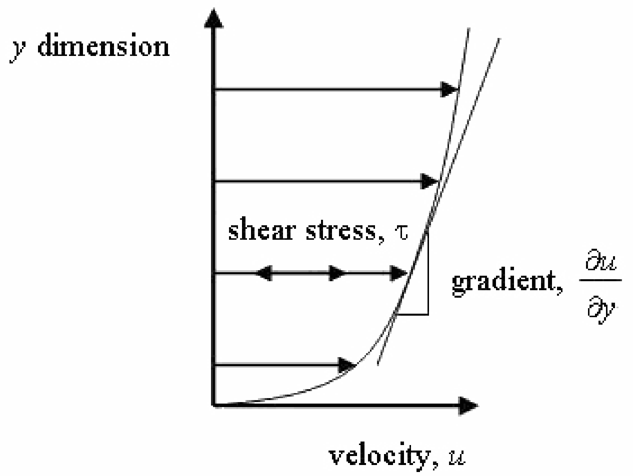
- = kinematic viscosity = μ/ρ in units of (m^2/s)

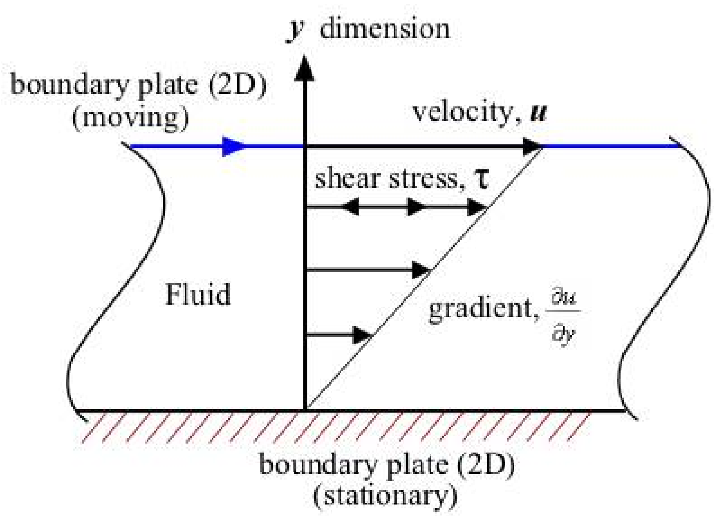
Re = V D/n = units of (dimensionless) = ratio of inertial to viscous forces

Dynamic or absolute viscosity is the coefficient relating the amount of shear stress caused by a velocity gradient:

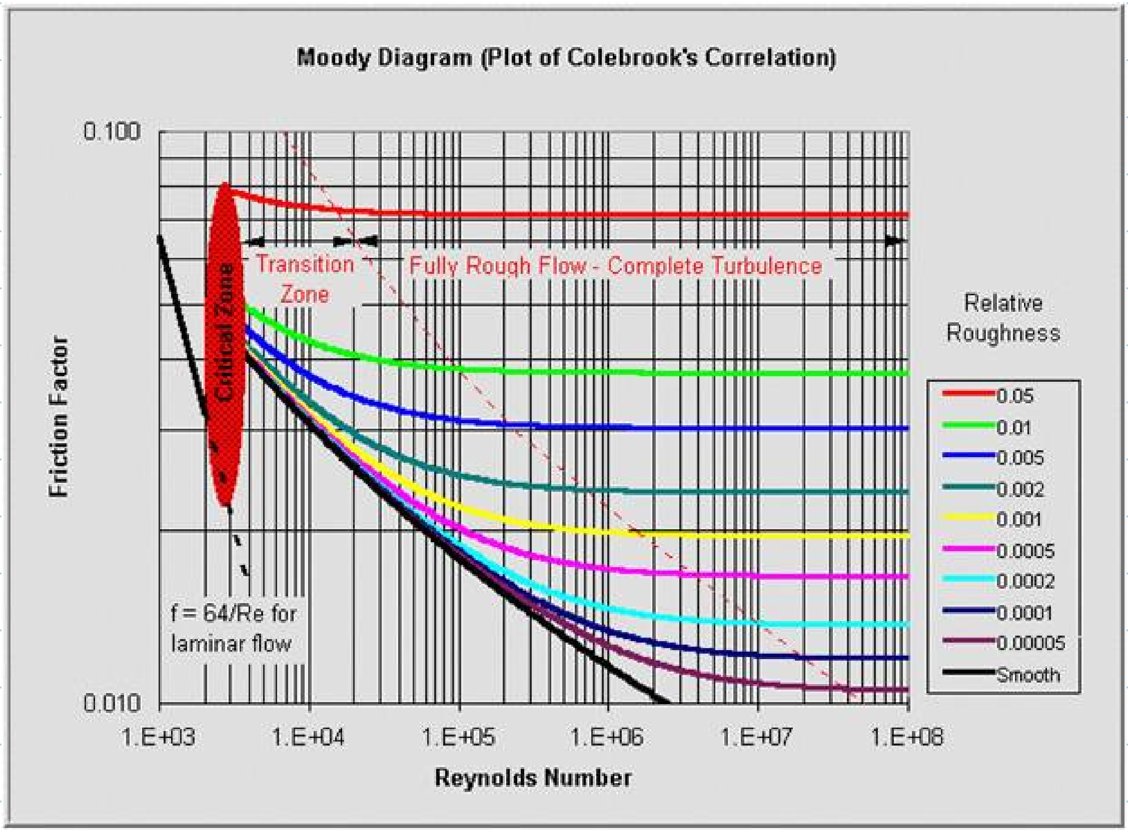
$$\tau = u\frac{\partial V}{\partial y}$$

For example, what shear stress is placed on the walls of a pipe when water flows through the pipe?





Relative roughness is the roughness/ pipe diameter



When the inertial forces dominate (high Reynolds numbers) we get turbulent flow. When viscous forces dominate there is laminar flow. The transition area is in between. When turbulent flow is fully developed the friction factor is no longer dependent upon Reynolds number.

Head loss is related to the friction factor, smooth pipes with low relative roughness have lower friction factors & (if everything else is constant) higher flow rates.

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3.3

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In hydraulics we use:

a) Conservation of mass, the continuity equation

Or flow in = flow out at steady state

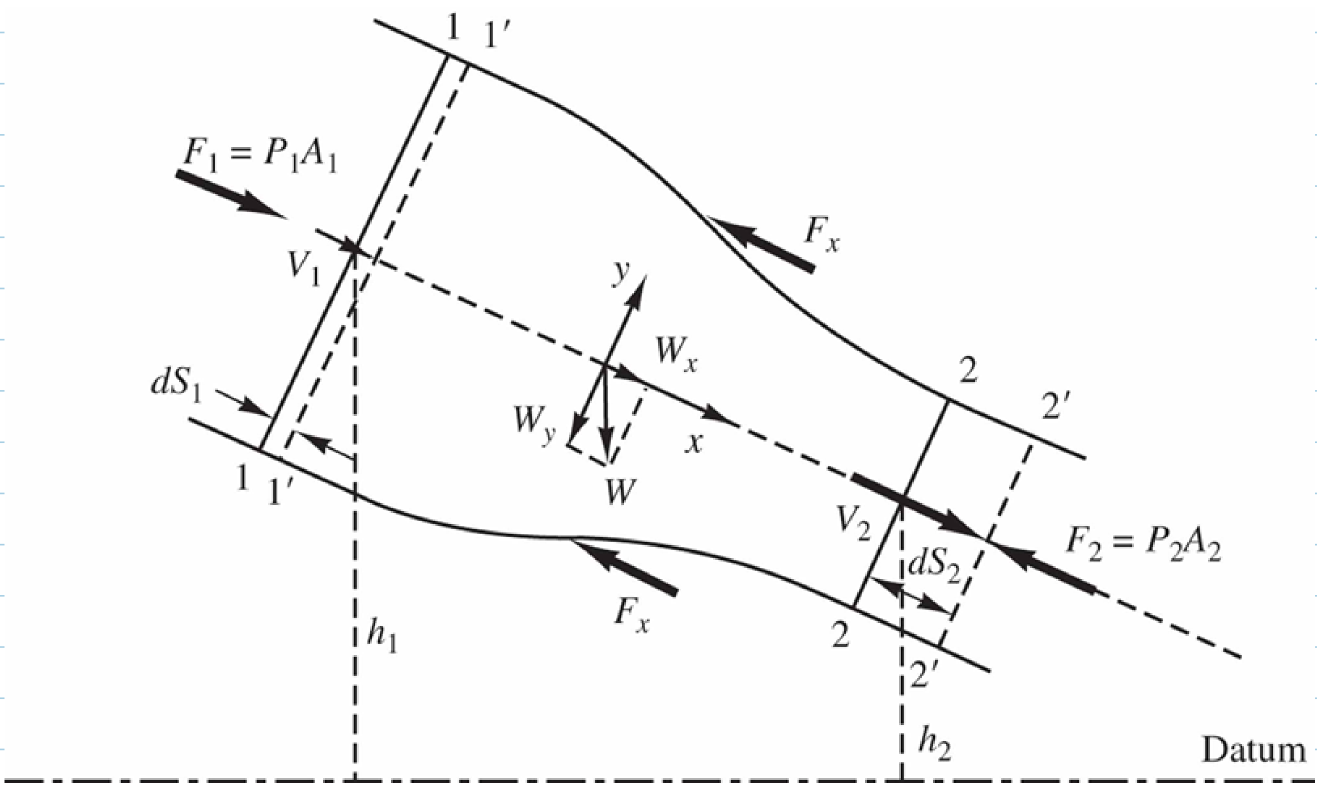
Q = volumetric flow rate (m^3/s) = $A_1V_1 = A_2V_2$

b) Conservation of energy, mostly in hydraulic engineering this takes the form of the Bernoulli equation:

$z_1 + p_1/(\rho g) + v_1^2/(2 g) - h_{loss} = z_2 + p_2/(\rho g) + v_2^2/(2 g)$

in the form of energy per unit weight (J/N or head)

c) conservation of momentum (mass*velocity)



consider the forces in a pipe:

Wx = weight of water in x direction
Fx = external force on pipe supports/holders

for axial (flow) direction:

sum of forces = $-F_x + W_x + P_1A_1 - P_2A_2 = \rho (Q)(V_2 - V_1)$

Note: best derived on board

$$\frac{p_1}{\rho g} + z_1 + \frac{V_1^2}{2g} + H_G = \frac{p_2}{\rho g} + z_2 + \frac{V_2^2}{2g} + H_L \qquad (3)$$

where:

H_G = head gain, usually from a pump (m) = e/g

H_L = head loss in the system (m)

$\frac{p}{\rho g}$ = pressure head, for the SI system p is in Pascals or Newtons/m^2, ρ is the density of water (1000 kg/m^3), g is the acceleration of gravity (9.8 m/s^2); for the English system pressure is generally converted to pounds force per square foot, $\rho g \equiv \gamma$ = specific weight = 62.4 pounds force per cubic foot

$\frac{V^2}{2g}$ = velocity head (m)

The energy equation can also be expressed as energy per unit mass (J/kg) if we multiply by g:

$$\frac{p_1}{\rho} + \frac{V_1^2}{2} + gz_1 + w_{pump} = \frac{p_2}{\rho} + \frac{V_2^2}{2} + gz_2 + w_{turbine} + e_{loss} \qquad (4)$$

or energy per unit volume (J/m^3 = Pa) if we multiply the original equation by ρg:

$$p_1 + \frac{\rho V_1^2}{2} + \rho g z_1 + \rho w_{pump} = p_2 + \frac{\rho V_2^2}{2} + \rho g z_2 + \rho e_{loss} \qquad (5)$$

Note that pressure is energy per unit volume. In hydraulics we typically use energy per unit weight because it is more convenient.

EGL, HGL

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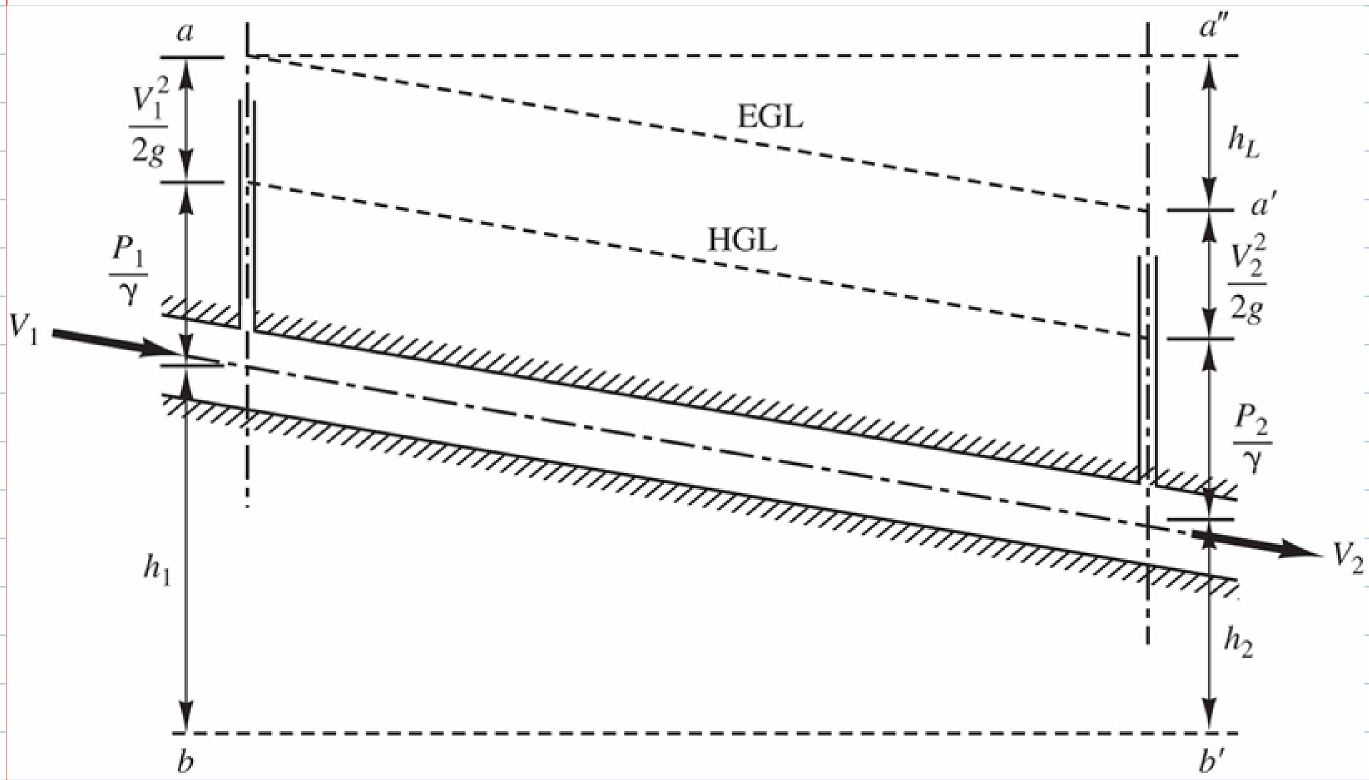


Question: the standpipes do not capture any of the velocity head; how far does the water rise in the pipes?

Energy Grade Line = total energy per unit weight of the water in the system at any point drawn relative to the centerline of the pipe

Hydraulic Grade Line = elevation + pressure heads drawn from the centerline of the pipe, as such the height of the HGL from the pipe represents the pressure head

Energy Equation

Bernoulli's equation written using pressure and elevation heads is

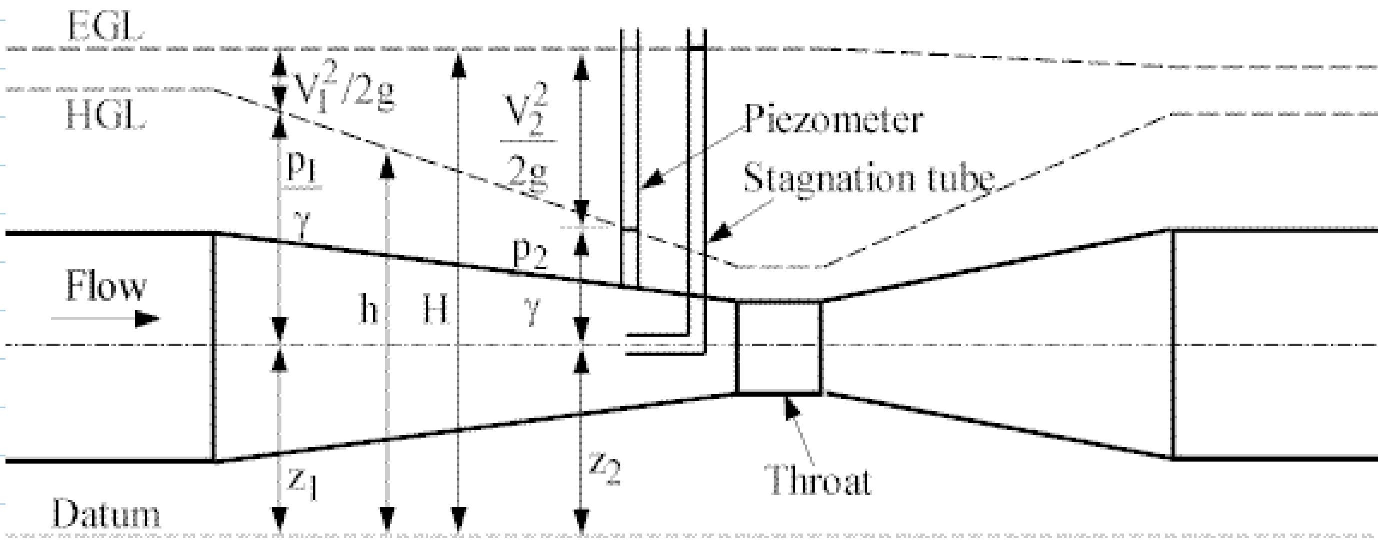
$$\frac{V_1^2}{2g} + \frac{p_1}{\gamma} + z_1 = \frac{V_2^2}{2g} + \frac{p_2}{\gamma} + z_2 = \text{constant}$$

Bernoulli's equation is the energy equation we use in Hydraulic Engineering minus the head loss term.

Head terms

Head	Terms	Grade line and position
elevation head	z	centerline of pipe
pressure head	$\frac{p}{\gamma}$	between centerline of pipe and HGL
velocity head	$\frac{V^2}{2g}$	between EGL and HGL
piezometric head	$h = \frac{p}{\gamma} + z$	HGL
total head	$H = \frac{V^2}{2g} + \frac{p}{\gamma} + z$	EGL

Since all of these heads have dimensions of length, they can be shown on a drawing or sketch (Fig. 4.1) that is drawn to correspond to physical dimensions. For flow in a pipe, z is usually taken to be the elevation of the centerline of the pipe. A *hydraulic grade line* (HGL) can be drawn to show the variation of the piezometric head. The distance from the centerline of the pipe to the HGL is the pressure head. An HGL above a pipe corresponds to positive pressure while an HGL below the centerline means that the pressure is negative. An *energy grade line* (EGL) shows the variation of the total head. Since the difference between the total head and the piezometric head is the velocity head, the distance between the EGL and the HGL is also the velocity head. (The flow disturbance and the internal shear in the expansion are large enough that Bernoulli's equation does not apply. The result is a decrease in the Bernoulli constant as the flow goes through the expansion. These effects will be discussed further in conjunction with the energy equation and flow in conduits.)



Schematic diagram
Fig. 4.1 - Experimental Apparatus to Illustrate Bernoulli's Equation and Grade Lines

Draw the rise of the water into the piezometer and stagnation tube. If the stagnation tube is 10 cm long in the vertical direction, how fast is the water flowing through the system (assuming the drawing is to scale)? Where is the water flowing most rapidly?, Most slowly? Where is pressure the greatest? Where is pressure the lowest?
If velocity in the pipe changes, where does the energy come from?

How much head loss occurs in the system?

Quiz

Monday, August 27, 2007
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3.3.2 At a firefighter's convention, a certain competition pits two contestants in mock combat. Each is armed with a fire hose and a shield. the object is to push your opponent backward a certain distance with the spray. A choice of shields is offered. One shield is a flat garbage can lid; the other is a hemispherical lid that direct the water back toward your opponent. Which shield would you choose and why?

Design the optimal shield for this fight! Draw a simple diagram of it and explain how it works.

3.5 Friction

Monday, August 27, 2007
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$\frac{V^2}{2g}$ $\frac{P}{\rho g}$ $\frac{J}{N} = \frac{N \cdot m}{N} = m$

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The Darcy Weisbach calculates friction losses as:

$$h_L = \frac{fLV^2}{D2g}$$

where f is the friction factor. The friction factor is calculated from the Moody diagram or one of several curve fit formulas

Note: in tests we will use the Moody Diagram

The quantity h/L = head loss per unit length of pipe is called the friction slope.

Moody Diagram

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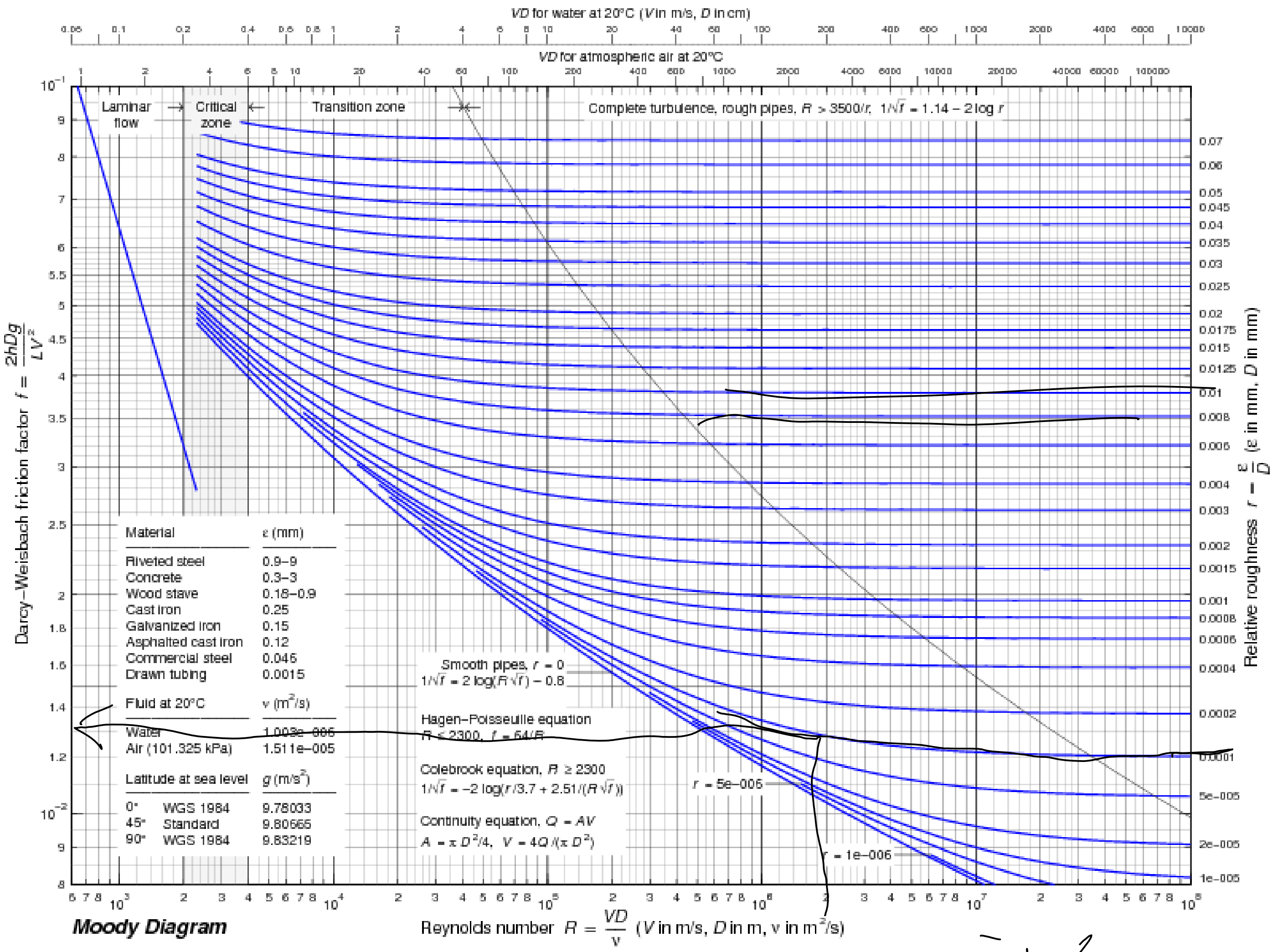

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1.3×10^{-2}

$Re = \frac{VD}{\nu}$ — f

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

Walk through steps of the Moody Diagram

a) Reynolds Number
b) Relative Roughness Line
c) Friction Factor

concept of fully turbulent flow where friction factor is no longer a function of Reynolds Number

3.6 Other Head Loss Equations

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General equation format:

General Equation Format

All the equations for friction losses have the format:

$$V = kCR^{x}S^{y} \tag{13}$$

V	=	average velocity (m/s)
k	=	factor to account for empirical constants, unit conversions, and anything else required
C	=	a flow resistance factor
R	=	hydraulic radius (m)
S	=	friction slope
x,y	=	variable exponents

The lining material of the flow channel or pipe usually determines the flow resistance (or roughness factor), C.

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S, the friction slope = f/L in a pipe = head loss per unit length of pipe = slope of energy grade line

Manning Equation, used mostly for open channel flow:

Manning Equation

The Manning equation is the most used equation for open channel flow such as irrigation canals. The roughness constant is represented by the Manning's n.

$$V = \frac{k}{n} R^{\frac{2}{3}} S^{\frac{1}{2}} \qquad (14)$$

k = is 1.49 for US units of (ft, s) and 1.00 for SI units of (m, s)

n = is obtained from tables and based upon roughness of the liner

S = slope of the grade, since we have steady uniform flow the slope of the grade or channel is also the friction slope.

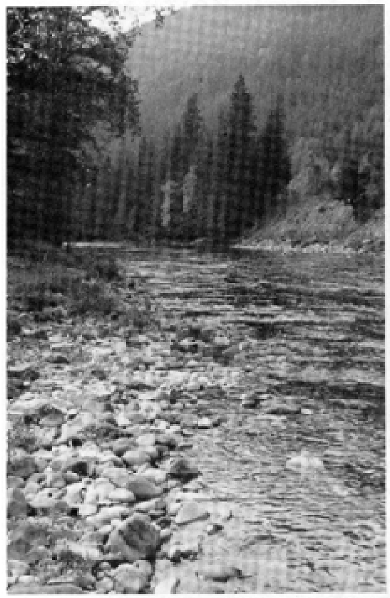
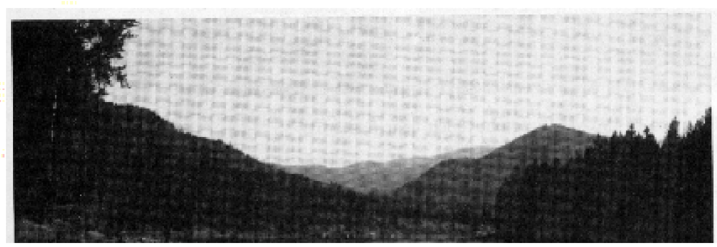


Figure 4-3 Moyie River above left near Eastport, Idaho—$n = 0.038$ for $R = 7.0$ ft

Figure 4-4 Boundary Creek above right near Porthill, Idaho—$n = 0.073$ for $R = 4.0$ ft, $d_{84} = 375$ mm



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Chezy or Kutter's Equation is used for sewer design:

Chezy's (Kutter's) Equation

This is used for sanitary sewer design.

$$V = C\sqrt{RS} \qquad (16)$$

where C can be calculated from an equation given in the text, Kutter's equation

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Hazen-Williams Equation

The Hazen-Williams Equation is most frequently used in the design and analysis of pressure pipe systems. The coefficients are for water only in the "normal" temperature range for water supply. It should not be used, for example, for hot water.

$$V = kCR^{0.63}S^{0.54} \tag{17}$$

k = 1.32 for US Standard units, or 0.85 for SI units

C = Hazen-Williams coefficient from a table

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Darcy-Weisbach (Colebrook-White) Equations

This equation is most commonly used for pressure pipe systems. However it can be used for any liquid flow and/or for open channels. The equation is:

$$V = \sqrt{\frac{8g}{f}RS} \tag{18}$$

f = the friction factor, this is generally looked up from the Moody diagram but it may also be calculated from the Colebrook equation

A more typical format for the Darcy-Weisbach equation is in terms of the head loss. The head loss is just the friction slope times the distance traveled or length of the pipe. Replacing S by h_L /L and hydraulic radius by D/4 gives:

$$V = \sqrt{\frac{8g}{f}RS} = \sqrt{\frac{8g}{f}\frac{D}{4}\left(\frac{h_L}{L}\right)} \tag{19}$$

solving for h_L gives:

$$h_L = \frac{fLV^2}{D2g} \tag{20}$$

$$h_L = \frac{fLV^2}{D2g} \quad (20)$$

Minor losses

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Sudden contractions in pipes cause excess turbulence and thus energy loss, for minor losses of this type we calculate the head loss in terms of multiples of the velocity head ($V^2/2g$)

Minor Head Losses

In addition to friction losses there may be a number of minor or fitting head losses. Changes in directions, expansions, and contractions in the pipe all disturb the flow and lead to increased head losses. The loss coefficient can be looked up in tables and calculated as:

$$h_L = \frac{V^2}{2g}\left[\frac{fL}{D} + K\right] \qquad (4)$$

where

K = the dimensionless head loss coefficient, if more than one loss is present (e.g., 3 pipe bends and one expansion) the K's can all be summed.

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Note: student should know what types of situations and valves lead to more or less head loss

...n which give rise to the local head loss.

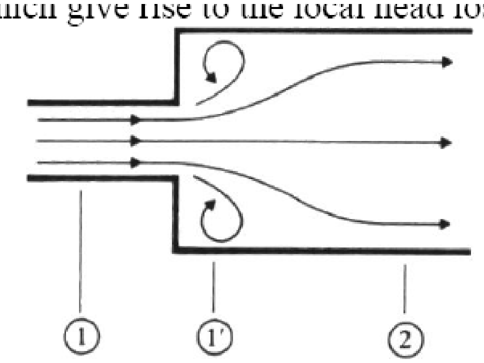


Figure 6: Sudden Expansion

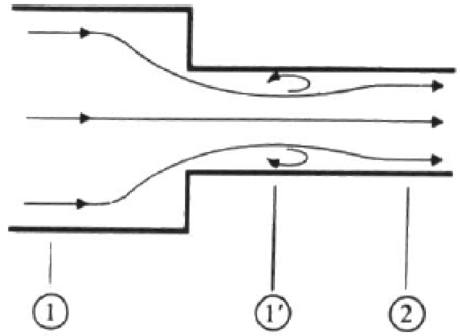
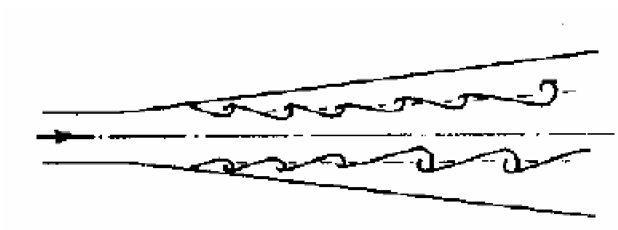
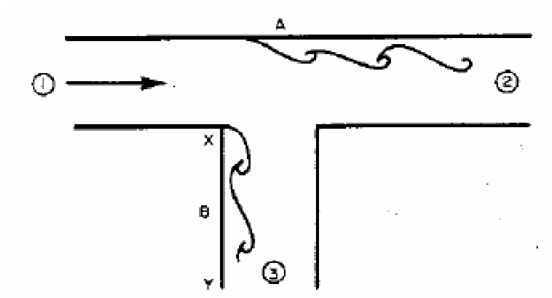


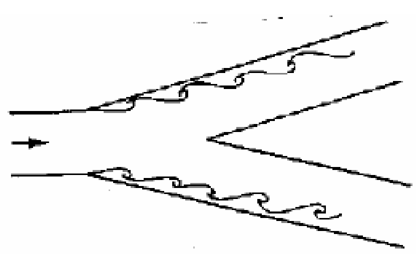
Figure 7: Sudden Contraction



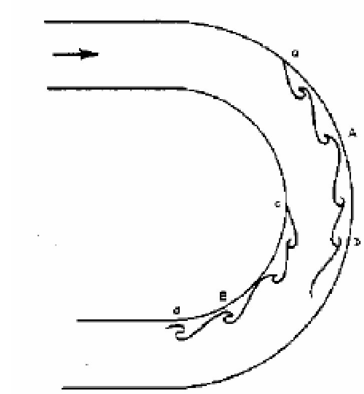
A divergent duct or diffuser



Tee-Junctions

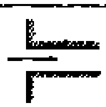
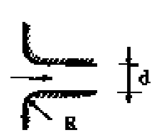


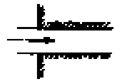
Y-Junctions



Bends

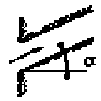
Figure 9: Local losses in pipe flow

	Perpendicular square entrance: k = 0,50
	Perpendicular rounded entrance: R/d 0,05 0,1 0,2 0,3 0,4 k 0,25 0,17 0,08 0,05 0,04
	Perpendicular reentrant entrance:



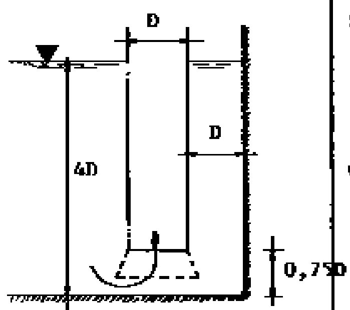
Perpendicular reentrant entrance:

$k = 0{,}8$



Skewed entrance:

$k = 0{,}5 + 0{,}3 \sin \alpha + 0{,}2 \sin^2 \alpha$



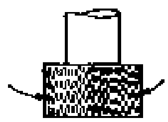
Suction pipe with conical mouthpiece:

$$h_\ell = 0{,}60\ D + 1{,}20 \frac{Q}{\sqrt{D^3}} - \frac{v^2}{2g}$$

without mouthpiece:

$$h_\ell = 0{,}53\ D + 1{,}30 \frac{Q}{\sqrt{D^3}} - \frac{v^2}{2g}$$

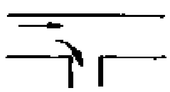
width of sump: 3,5 D



Strainer bucket:

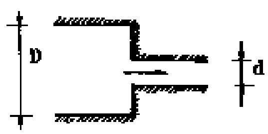
$k = 10$ with foot valve

$k = 5{,}5$ without foot valve



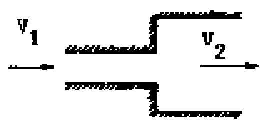
Standard Tee, entrance to minor line:

$k = 1{,}8$



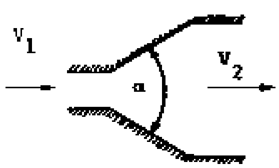
Sudden contraction:

$(d/D)^2$	0,01	0,1	0,2	0,4	0,6	0,8
k	0,5	0,5	0,42	0,33	0,25	0,15



Sudden expansion:

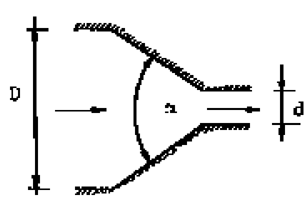
$$h_\ell = \left(1 - \frac{v_2}{v_1}\right)^2 \frac{v_1^2}{2g}$$



Confusor:

$$h_\ell = k\ (v_1^2 - v_2^2)/2g$$

α^o	20	40	60	80
k	0,20	0,28	0,32	0,35



Diffusor:

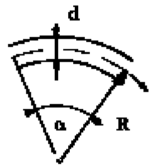
$$h_\ell = k\ (v_1^2 - v_2^2)/2g$$

α^o		8	15	30	45
k	D = 3d	0,05	0,15	0,49	0,60
for	D = 2d	0,11	0,21	0,51	0,60

for D = 2d 0,11 0,21 0,51 0,60

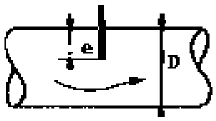
Sharp elbow:

α°	15	30	45	60	90
k	0,024	0,108	0,26	0,49	1,17



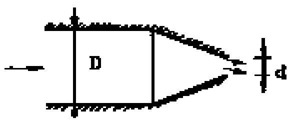
Bends:

α°	15	30	45	60	90
k for R/d = 1	0,01	0,09	0,17	0,27	0,53
R/d > 3	0,01	0,03	0,12	0,20	0,24



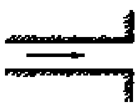
Gate valve:

e/D	0	1/3	1/4	1/2	3/4
k	0	0,07	0,26	2,06	17,0



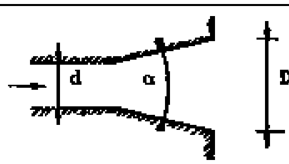
Confusor outlet:

d/D	0,5	0,6	0,8	0,9
k	5,5	4	2,55	1,1



Exit from pipe into stagnant water:

k = 1,0



Diffusor outlet for D/d > 2:

α°	8	15	30	45
k	0,05	0,18	0,5	0,6

Pasted from <http://www.fao.org/docrep/X5744E/x5744egm.gif>

Table 2.6 Minor loss coefficients

Fitting	K_L	Fitting	K_L
Pipe entrance		90^0 smooth bend	
Bellmouth	0.03-0.05	Bend radius/D = 4	0.16-0.18
Rounded	0.12-0.25	Bend radius/D = 2	0.19-0.25
Sharp-edged	0.50	Bend radius/D = 1	0.35-0.40
Projecting	0.78	Mitered bend	
Contraction - sudden		$\theta = 15^0$	0.05

Projecting	0.78	Mitered bend	
Contraction - sudden		$\theta = 15^o$	0.05
D_2/D_1=0.80	0.18	$\theta = 30^o$	0.10
D_2/D_1=0.50	0.37	$\theta = 45^o$	0.20
D_2/D_1=0.20	0.49	$\theta = 60^o$	0.35
Contraction - conical		$\theta = 90^o$	0.80
D_2/D_1=0.80	0.05	Tee	
D_2/D_1=0.50	0.07	Line flow	0.30-0.40
D_2/D_1=0.20	0.08	Branch flow	0.75-1.80
Expansion - sudden		Tapping T Branch	
D_2/D_1=0.80	0.16	d = tapping hole diameter D = main line diameter	$1.97/(d/D)^4$
D_2/D_1=0.50	0.57	Cross	
D_2/D_1=0.20	0.92	Line flow	0.50
Expansion - conical		Branch flow	0.75
D_2/D_1=0.80	0.03	45^o Wye	
D_2/D_1=0.50	0.08	Line flow	0.30
D_2/D_1=0.20	0.13	Branch flow	0.50
Gate valve - open	0.39	Check valve - conventional	4.0
3/4 open	1.10	Check valve - clearway	1.5
1/2 open	4.8	Check valve - ball	4.5
1/4 open	27	Cock - straight through	0.5
Globe valve - open	10	Foot valve - hinged	2.2
Angle valve - open	4.3	Foot valve - poppet	12.5
Butterfly valve - open	1.2		

Walski (1984)

AWDM Online
http://www.haestad.com/library/books/awdm/online/wwhelp/wwhimpl/java/html/wwhelp.htm
Screen clipping taken: 8/30/2007, 10:09 AM

double diameter

Wednesday, August 25, 2010
2:00 PM

Class Exercise – Double Pipe Diameter

What happens to head loss when we double the diameter of a pipe?

Assumptions:

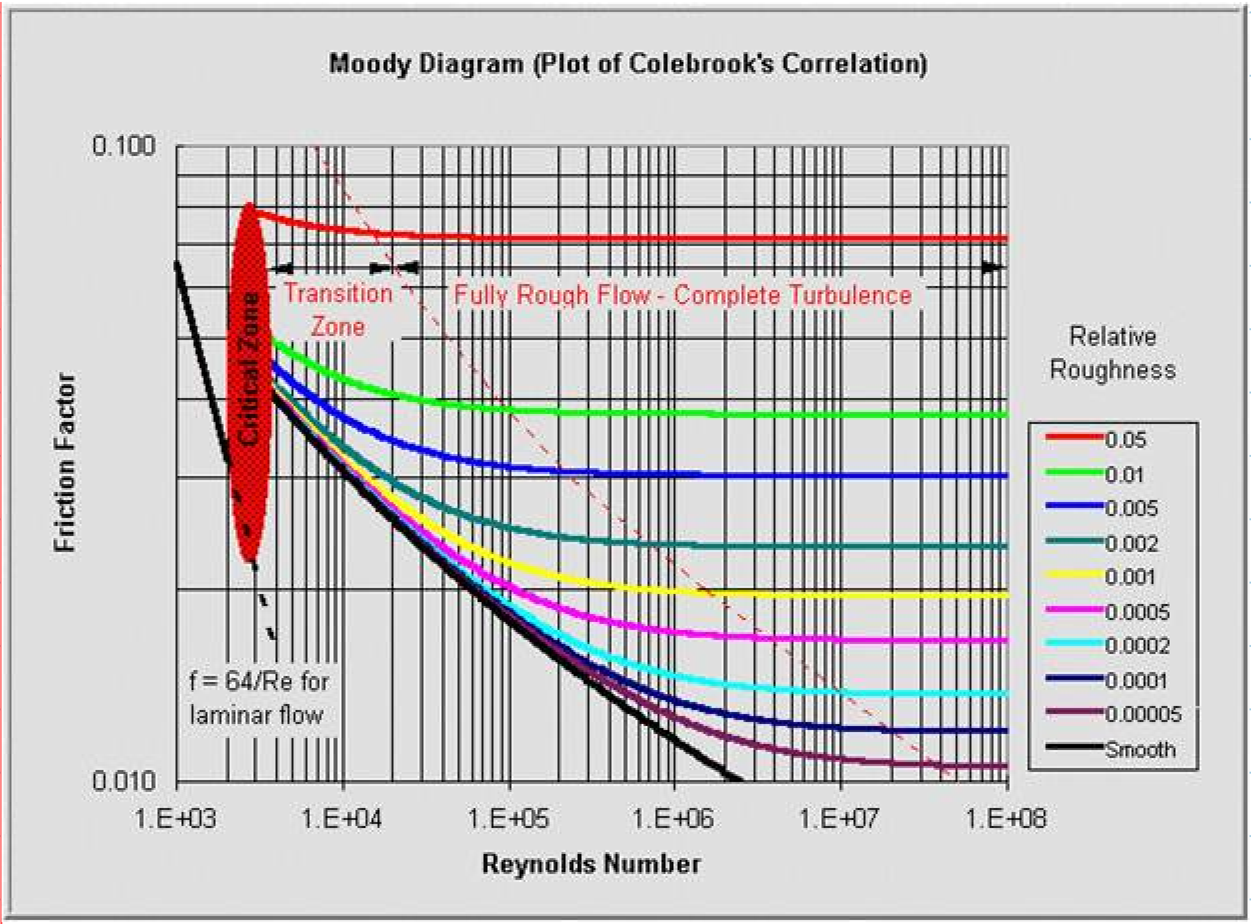
- fully turbulent flow
- same relative roughness
- same discharge (*Q*)
- ignore minor loss terms

Answer:

The head loss in closed conduit flow is proportional to the velocity head:

$$h_l = \frac{V^2}{2g}\left(\frac{fL}{D}\right)$$

Friction factor is constant in fully turbulent flow:



$$h_l = \frac{V^2}{2g}\left(\frac{fL}{D}\right)$$

Solution:

$Q_1 = Q_2$

$V_1 A_1 = V_2 A_2$

$V_2 = V_1 A_1/A_2$

Doubling the pipe diameter increases the area by a factor of four

$$\frac{A_1}{A_2} = \frac{4\pi D_1^2}{4\pi(2D_1)^2} = \frac{1}{4}$$

So the velocity in the larger pipe is ¼ that in the smaller pipe.

Head loss is proportional to the velocity squared and the inverse of the diameter.

$V_1/V_2 = 4$

$$h_l = \frac{V^2}{2g}\left(\frac{fL}{D}\right)$$

Substitution, letting the constants cancel gives:

$$\frac{h_{l1}}{h_{l2}} = \left(\frac{V_1}{V_2}\right)^2 \frac{D_2}{D_1} = 4^2 2 = 32$$

So doubling the pipe diameter reduced the head loss by a factor of 32!

double area

Wednesday, August 25, 2010
2:02 PM

What happens if we double the area of the pipe rather than the diameter?

Now $V_1 = 2\ V_2$ since Q is constant and $Q = VA$
For diameter we get:
$A_2 = 2\ A_1$

$$\frac{\pi D_2^2}{4} = 2\frac{\pi D_1^2}{4}$$

$$D_2^2 = 2D_1^2$$

$$D_2 = \sqrt{2}D_1$$

$$\frac{h_{l1}}{h_{l2}} = \left(\frac{V_1}{V_2}\right)^2 \frac{D_2}{D_1} = 2^2\sqrt{2} = 5.66$$

So doubling the area of the pipe decreases head loss by a factor of 5.66