mybox[1][] colback=white, top=0.25cm, bottom=0.25cm, left=0.25cm, right=0.25cm, colframe=structure, fonttitle=**, enhanced, drop fuzzy shadow, attach boxed title to top left=yshift=-2mm, xshift=5mm, colbacktitle=structure!80!white, 1**

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Module 5 — Friction Losses in Pipes

Water Resources — CIVL318

Types of Flow

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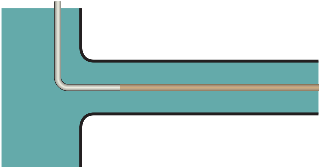

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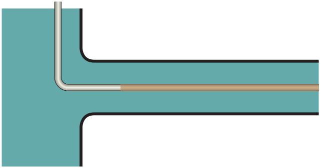
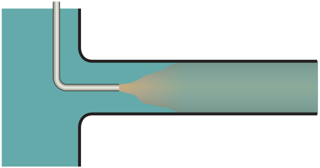


- For a sufficiently high velocity, the dye streak quickly spreads across the pipe, mixing with the water in the pipe. This is turbulent flow.



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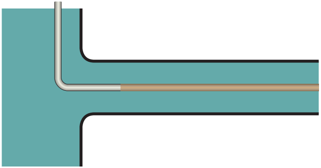

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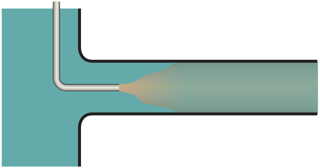

- Between these two conditions is a range of velocities where flow is transitional

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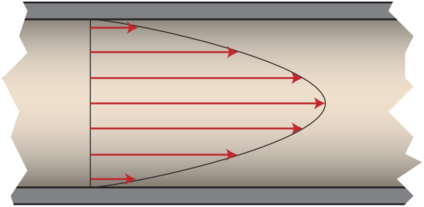

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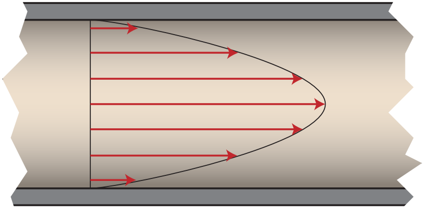

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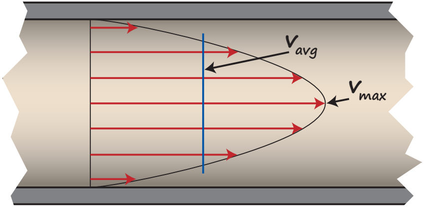

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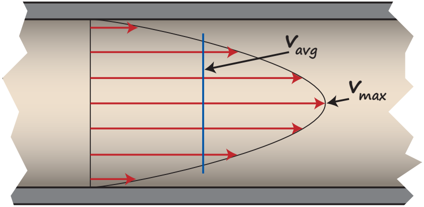

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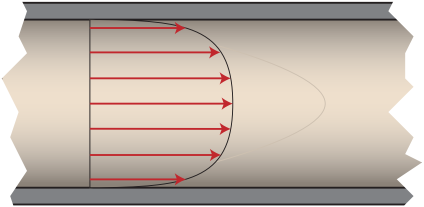

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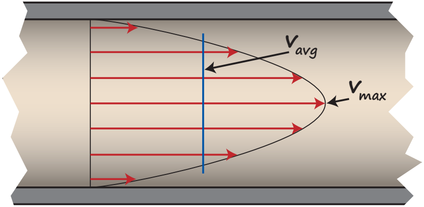

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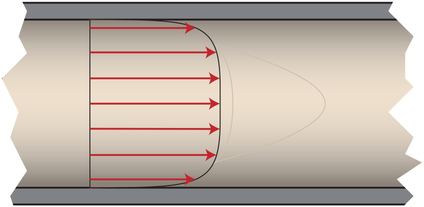
  Especially in case of smooth pipe.



Viscosity

- The viscosity of a fluid is a measure of how easily it pours.
- Heating a viscous fluid, such as cold oil, lowers its viscosity and allows it to flow more easily.
- The flow of high viscosity fluids is more likely to be laminar.
- The flow of low viscosity fluids (such as water) is more likely to be turbulent.

Reynolds Number

- Energy losses within flow in pipes is dependent upon the type of flow.
- Type of flow (in circular pipes) is dependent upon the density, viscosity and velocity of the fluid, and upon the inside diameter of the pipe.
- The Reynolds Number is used to predict flow type:

$$N_R = \frac{vD\rho}{\eta}$$

where:

v	is the average flow velocity (m/s)
D	is the pipe inside diameter (m)
ρ	is the density of the fluid (kg/m^3)
η	is the dynamic viscosity of the fluid (Pa $\cdot$ s)

The Reynolds Number is dimensionless:

$$\begin{aligned}\frac{\mathsf{m}/\mathsf{s}\times\mathsf{m}\times\mathsf{kg}/\mathsf{m}^3}{\mathsf{Pa}\cdot\mathsf{s}} &= \frac{\mathsf{m}/\mathsf{s}\times\mathsf{m}\times\mathsf{kg}/\mathsf{m}^3}{\mathsf{N}/\mathsf{m}^2\cdot\mathsf{s}}\\ &= \frac{\mathsf{m}/\mathsf{s}\times\mathsf{m}\times\mathsf{kg}/\mathsf{m}^3}{\left(\mathsf{kg}\cdot\mathsf{m}/\mathsf{s}^2\right)/\mathsf{m}^2\cdot\mathsf{s}}\\ &= 1\end{aligned}$$

Reynolds Number

- Flows with high velocities and/or low viscosities tend to have turbulent flow.

  Such flows have large Reynolds numbers.

- Flows with low velocities and/or high viscosities tend to exhibit laminar flow.

  Such flows have low Reynolds numbers.

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  Such flows have low Reynolds numbers.

$$\begin{aligned} N_R &< 2000, \text{ flow is laminar} \\ 2000 < N_R &< 4000, \text{ flow is in the `critical region'} \\ N_R &> 4000, \text{ flow can be assumed to be turbulent} \end{aligned}$$

Flow is said to be in the **critical region**, with neither fully laminar or fully turbulent flow, if the Reynolds number for the flow is between 2000 and 4000.

Determine the range of velocities and volume flow rates for which flow is in the critical region for:

1. water at 5℃ flowing in $1/2$-in copper tubing
2. water at 95℃ flowing in $1/2$-in copper tubing
3. fuel oil at 10℃ (sg $= 0.94$, $\eta = 2.4$ Pa $\cdot$ s), flowing in 12-in Schedule 40 steel pipe

Darcy's Equation

Darcy's equation (or Darcy-Weisbach equation) is used to calculate the head loss due to friction in long, straight sections of circular pipe:

$$h_L = f \times \frac{L}{D} \times \frac{v^2}{2g}$$

where:

h_L	is energy loss due to friction (m)
f	is the friction factor (dimensionless)
L	is the length of the pipe (m)
D	is the diameter of the pipe (m)
$\frac{v^2}{2g}$	is the velocity head of the flow based on the average flow velocity in the pipe (m)

Friction Loss in Laminar Flow

- Darcy's Equation may be used for both laminar and turbulent flow
- Calculation of f, the friction factor, depends upon the type of flow
- For laminar flow,

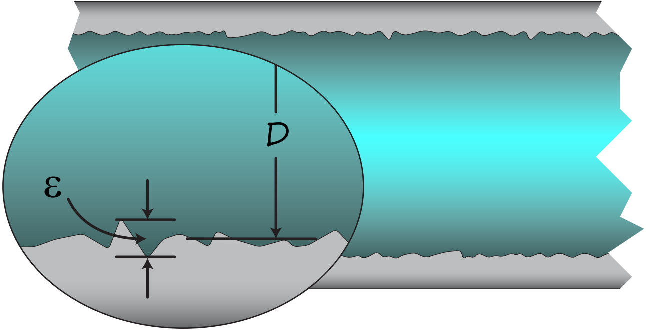
$$\boxed{f = \frac{64}{N_R}}$$

- Losses are independent of the pipe wall surface; losses come from overcoming the frictional (shear) forces between different layers of liquid moving at different velocities.

Determine the headloss due to friction in fuel oil at 10°C flowing through 125 m of 12-in Schedule 40 steel pipe with an average flow velocity of 4.5 m/s (sg $= 0.94$, $\eta = 2.4$ Pa $\cdot$ s).

Friction Loss in Turbulent Flow

- Turbulent flow is chaotic and varying and the value of f has been determined experimentally for many flow situations
- Experiments have shown that f depends upon the Reynolds number for the flow and the **relative roughness**, the ratio $\frac{D}{\epsilon}$ of pipe diameter D to the average wall roughness ϵ.

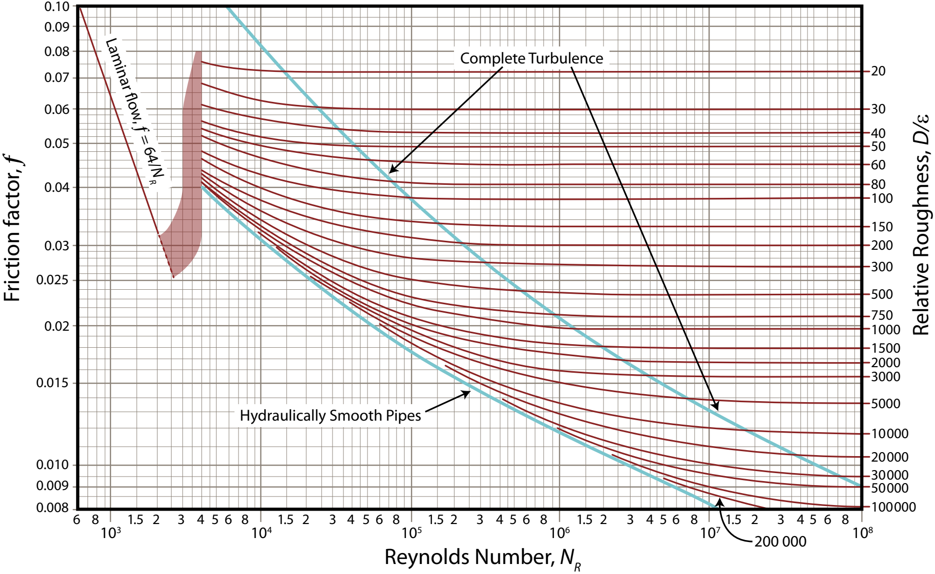


- Values for f can be read from the Moody Diagram

Roughness, ϵ:

Material (new, clean)	ϵ (m)
Glass	Smooth
Plastic	3.0×10^{-7}
Copper, brass, lead (tubing)	1.5×10^{-6}
Commercial steel, welded steel	4.6×10^{-5}
Wrought iron	4.6×10^{-5}
Ductile Iron - coated	1.2×10^{-4}
Ductile Iron - uncoated	2.4×10^{-4}
Concrete	1.2×10^{-4}
Riveted steel	1.8×10^{-3}

The Moody Diagram



Accuracy in Determination of f

"It must be recognized that any high degree of accuracy in determining f is not to be expected. With smooth tubing, it is true, good degrees of accuracy are obtainable; a probable variation in f within about ± 5 per cent and for commercial steel and wrought-iron piping, a variation within about ± 10 per cent. But, in the transition and rough-pipe regions, we lack the primary and obvious essential, a technique for measuring the roughness of a pipe mechanically...

...however, fairly reasonable estimates of friction loss can be made, and, fortunately, engineering problems rarely require more than this...

The charts apply only to new and clean piping, since the rapidity of deterioration with age, dependent upon the quality of water or fluid and that of the pipe material, can only be guessed in most cases; and in addition to the variation in roughness there may be, in old piping, an appreciable reduction in effective diameter..."

Friction Factors for Pipe Flow, Lewis F. Moody, Princeton, N.J. (1944)

Regions of Flow Characteristics

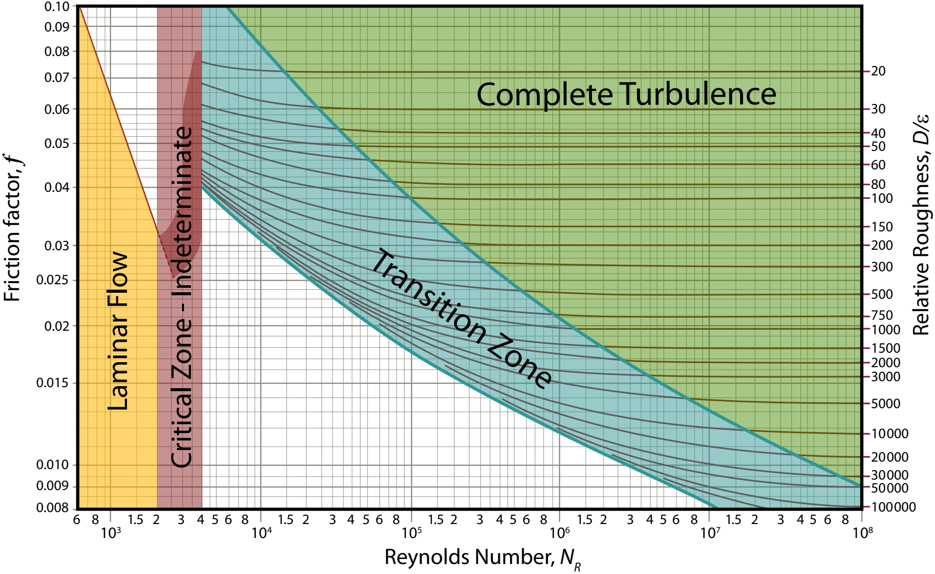
- Up to a Reynolds number of 2000, flow is laminar (where the liquid's viscous forces damp out turbulence).

- For a Reynolds number between 2000 and about 4000, conditions depend upon a number of factors (such as the shape of the pipe entrance, changes in section size, pressure waves, ...). This is the **critical region** indicated on the Moody diagram by the shaded area, where f cannot be calculated. [a]

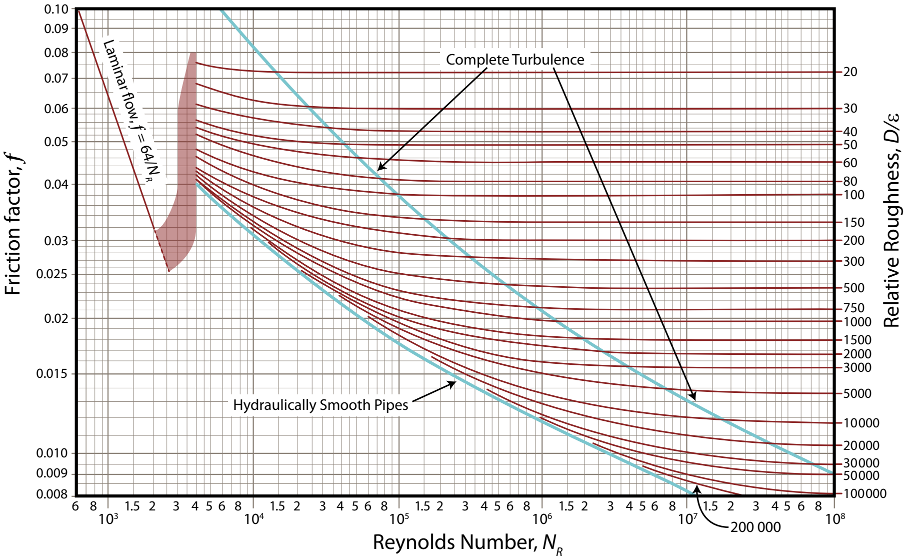
- Above a Reynolds number of 4000, there are two regions:
  - First there is a **transition zone** of incomplete turbulence (the extent of this depends upon the relative roughness of the pipe)
  - The region of **complete turbulence**

[a] Experimental data suggest that for smooth pipe, flow is laminar up to around $N_R = 2700$ and completely turbulent for $N_R > 3000$. We shall use the more recognized ranges where flow can not be determined for $2000 < N_r < 4000$.

Regions of Flow Characteristics



Use the Moody diagram to determine the friction factor for flow with $N_R = 2 \times 10^6$ and a relative roughness of 1428.



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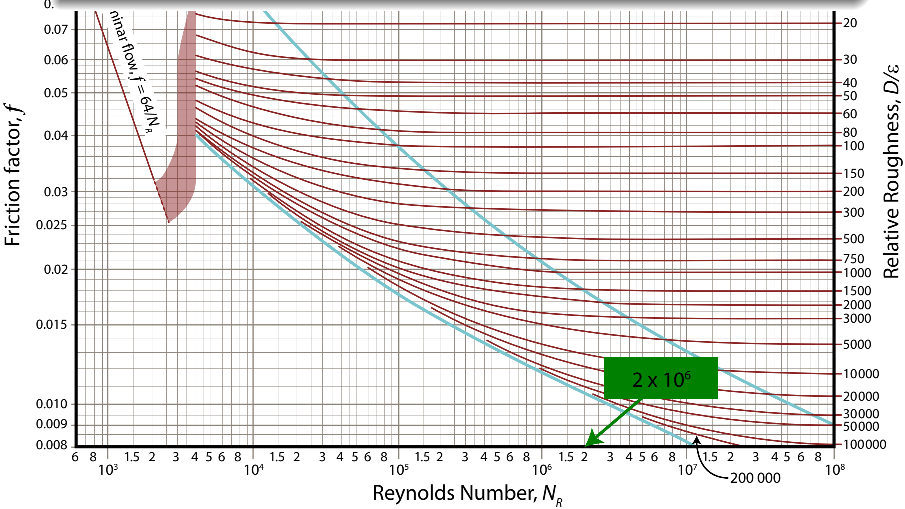

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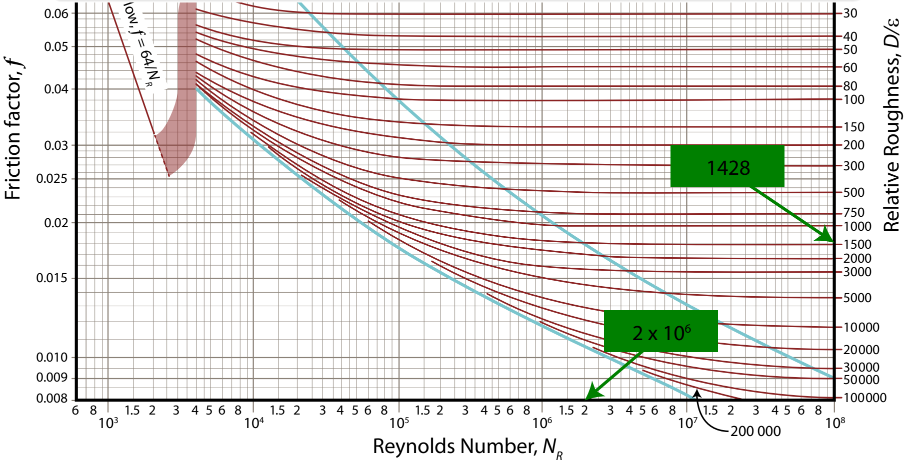

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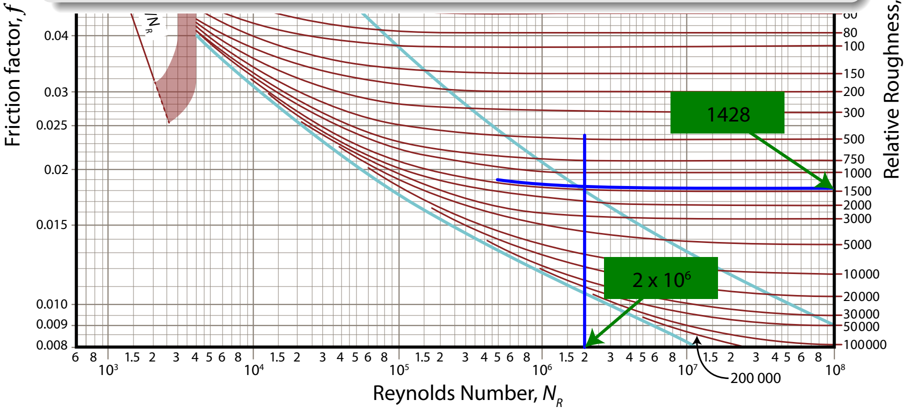

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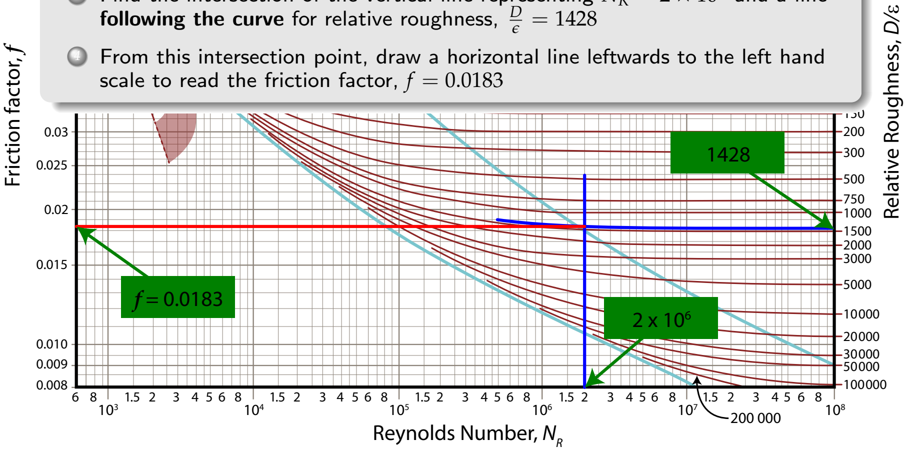

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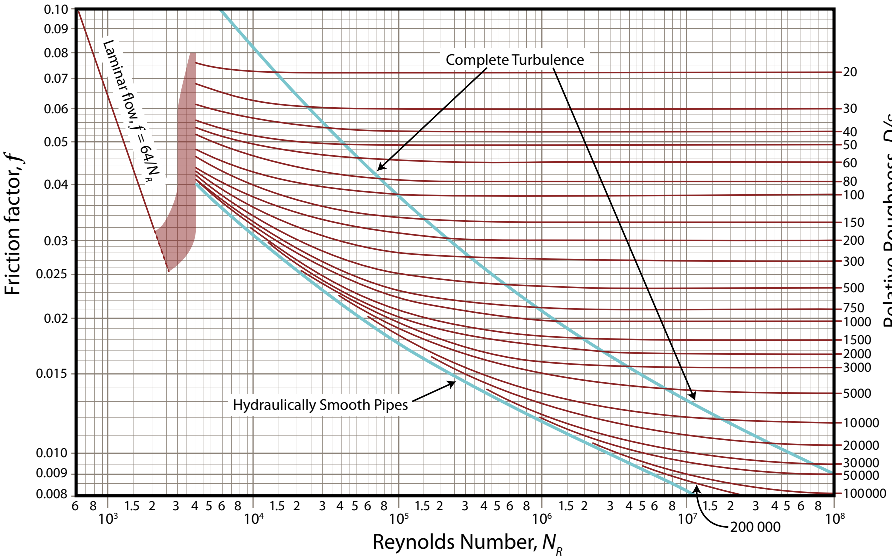

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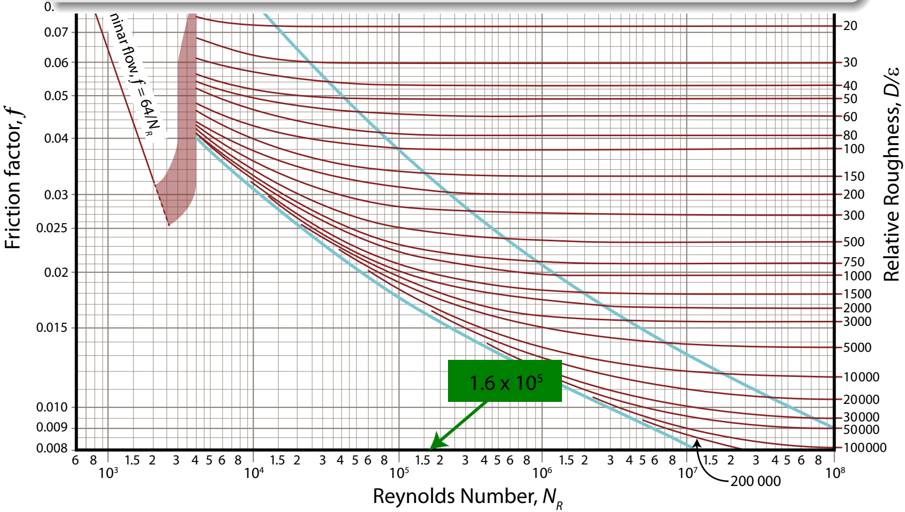

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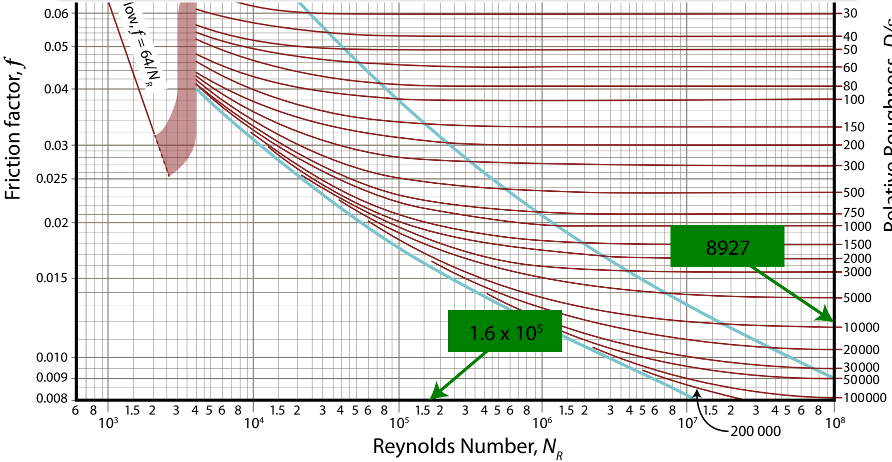

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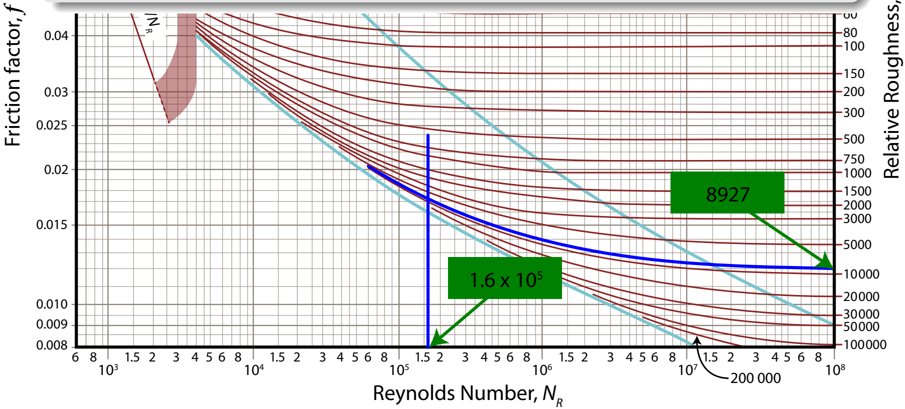

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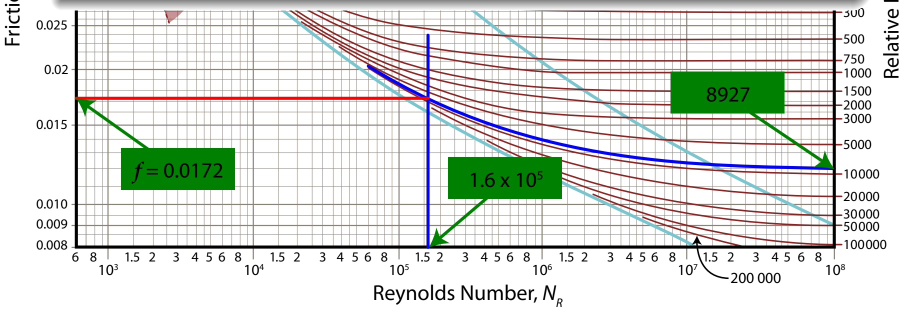
$$f = 0.0172$$



A 75 m section of wooden flume is replaced with 54-in high density polyethylene (HDPE) pipe with inside diameter of 1.37 m. The pipe is smooth and transports 190×10^3 m^3/day. Determine the headloss due to friction in the pipe, assuming an average temperature of 10℃.

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$$v = \frac{Q}{A} = \frac{190 \times 10^3/24/60/60 \text{ m}^3/\text{s}}{\pi(1.37 \text{ m})^2/4} = 1.4918 \text{ m/s}$$

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- Relative roughness: Smooth pipe

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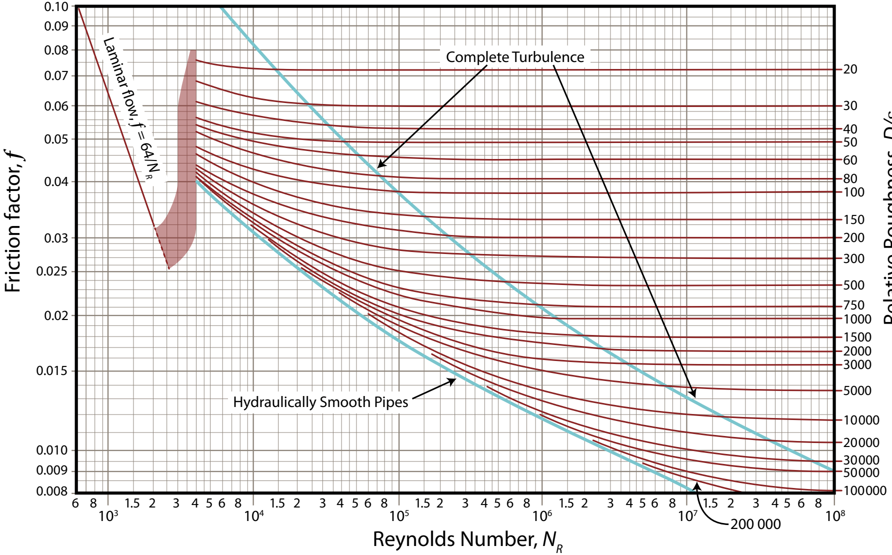
- Relative roughness: Smooth pipe
- Find the friction factor from the Moody diagram...

$N_R = 1.5721 \times 10^6$, smooth pipe



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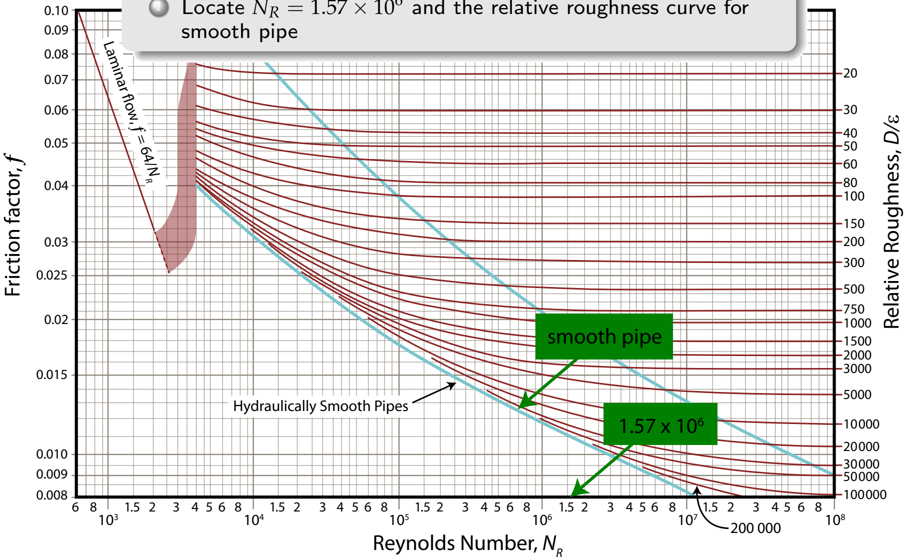
- Locate $N_R = 1.57 \times 10^6$ and the relative roughness curve for smooth pipe



$N_R = 1.5721 \times 10^6$, smooth pipe

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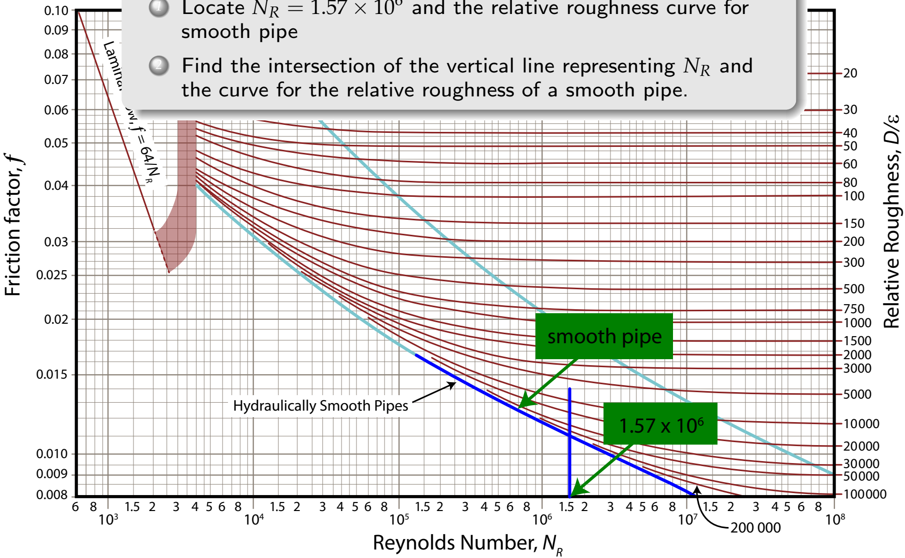

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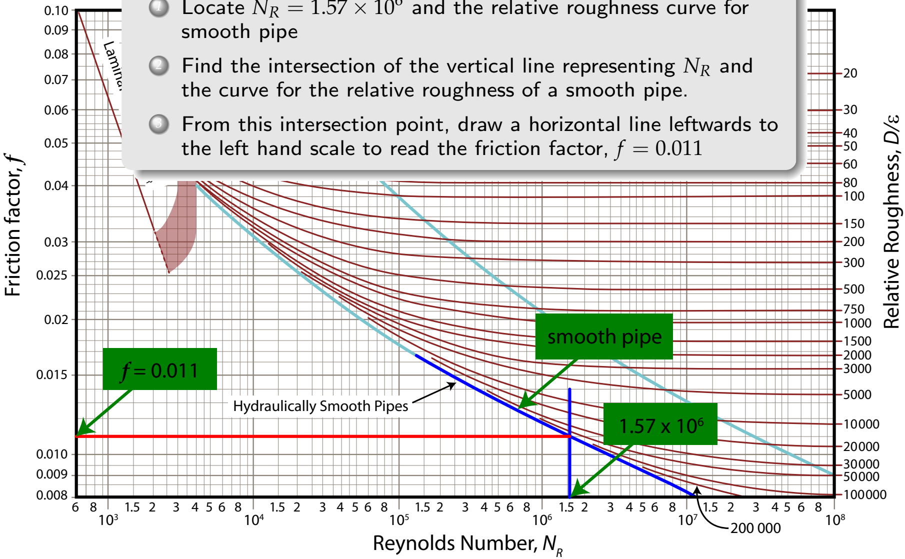
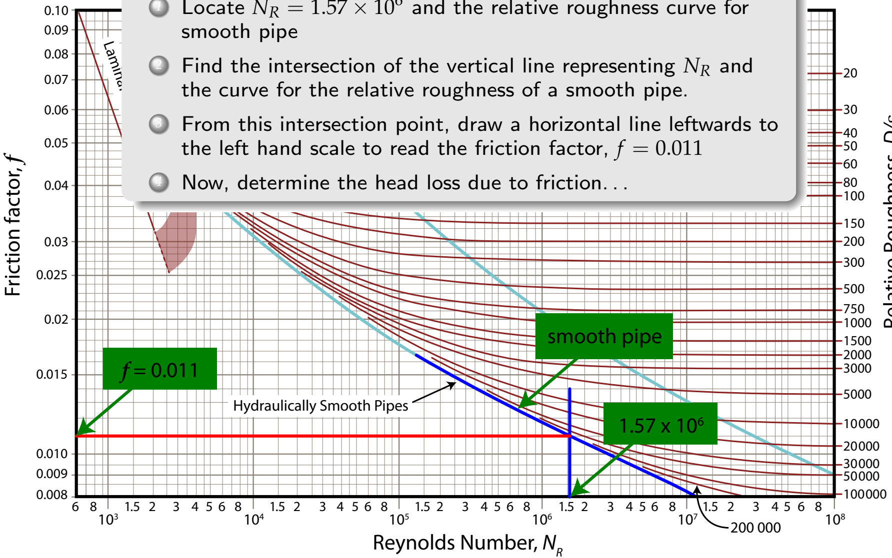
2. Find the intersection of the vertical line representing N_R and the curve for the relative roughness of a smooth pipe.
3. From this intersection point, draw a horizontal line leftwards to the left hand scale to read the friction factor, $f = 0.011$



$N_R = 1.5721 \times 10^6$, smooth pipe

1. Locate $N_R = 1.57 \times 10^6$ and the relative roughness curve for smooth pipe
2. Find the intersection of the vertical line representing N_R and the curve for the relative roughness of a smooth pipe.
3. From this intersection point, draw a horizontal line leftwards to the left hand scale to read the friction factor, $f = 0.011$
4. Now, determine the head loss due to friction. . .



$N_R = 1.5721 \times 10^6$, smooth pipe

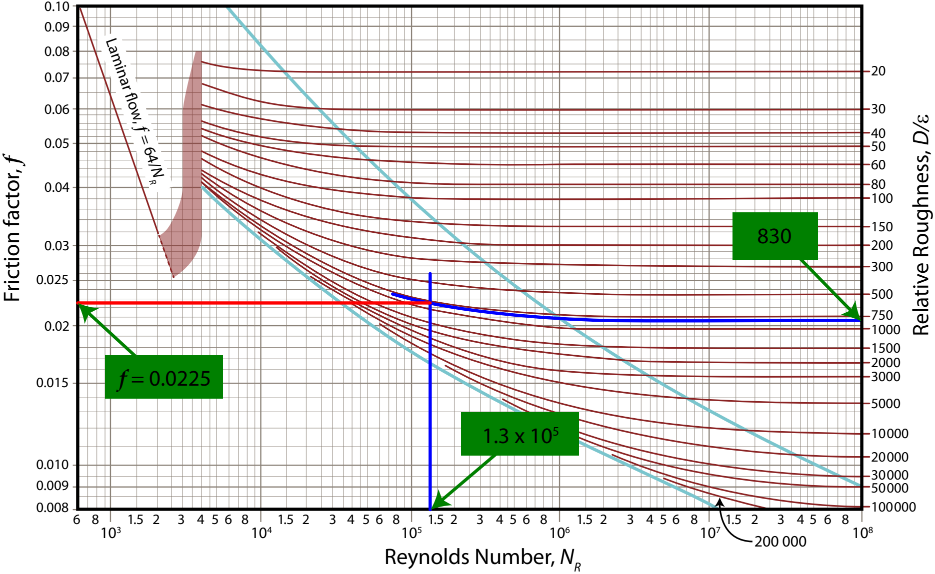
1. Locate $N_R = 1.57 \times 10^6$ and the relative roughness curve for smooth pipe
2. Find the intersection of the vertical line representing N_R and the curve for the relative roughness of a smooth pipe.
3. From this intersection point, draw a horizontal line leftwards to the left hand scale to read the friction factor, $f = 0.011$
4. Now, determine the head loss due to friction...

$$\begin{aligned} h_L &= f \times \frac{L}{D} \times \frac{v^2}{2g} \\ &= 0.011 \times \frac{75\ \text{m}}{1.37\ \text{m}} \times \frac{(1.4918)^2}{19.62}\ \text{m} \\ &= 0.068305\ \text{m} \end{aligned}$$

Ethyl alcohol at 25°C flows through $1\frac{1}{2}$-in Schedule 80 steel pipe at 5 L/s.

Determine the pressure drop, due to friction losses, in a 125 m section of pipe.

What result do you get for f from the Moody Diagram...



Friction factor, f
Reynolds Number, N_R
Relative Roughness, D/ε
Laminar flow, $f = 64/N_R$
$f = 0.0225$
1.3×10^5
830
200 000
0.10
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.025
0.02
0.015
0.010
0.009
0.008
20
30
40
50
60
80
100
150
200
300
500
750
1000
1500
2000
3000
5000
10000
20000
30000
50000
100000
10^3
10^4
10^5
10^6
10^7
10^8

Swamee-Jain Formula for f

$$f = \frac{0.25}{\left[\log\left(\frac{1}{3.7(D/\epsilon)} + \frac{5.74}{N_R^{0.9}}\right)\right]^2}$$

The Swamee-Jain formula is quite accurate, yielding values for f that are within $\pm 1\%$ of the Moody Diagram value.

Ethyl alcohol at 25°C flows through 3-in Schedule 80 steel pipe at 5 L/s.

Determine the pressure drop, due to friction losses, in a 125 m section of pipe.

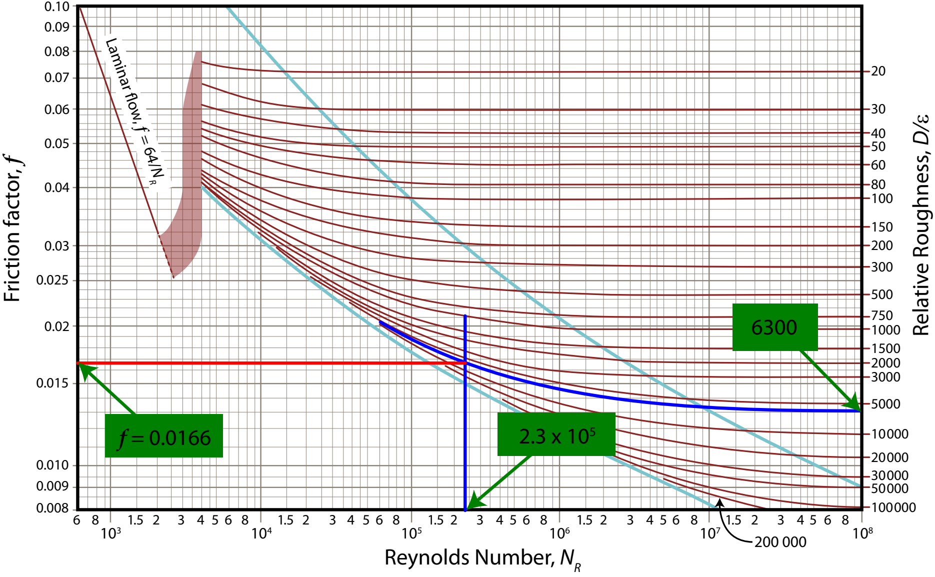
Two Pipes Compared:

	$1\frac{1}{2}$-in	3-in	Ratio:
Diameter	38.1 mm	73.7 mm	≈ 2
Velocity	4.3851 m/s	1.1720 m/s	$\approx \frac{1}{4}$
Velocity Head	0.98031 m	0.070015 m	$\approx \frac{1}{14}$ $\left(\frac{1}{16} \text{ if double}\right)$
Head Loss	72.365 m	2.6125 m	$\approx \frac{1}{28}$

By (approximately) doubling the diameter, the velocity is reduced to one-quarter which, in turn, reduces the velocity head to 1/14th and losses to 1/28th.

A horizontal 12-in Schedule 80 steel pipe transports oil ($\text{sg} = 0.85$, $\eta = 3.0 \times 10^{-3}$ Pa · s) at 185 L/s. The pipe has pumping stations spaced at 6.0 km intervals.

Determine the power required by each pump to maintain the same pressure at each pump outlet if all losses are due to friction.



Friction factor, f
Relative Roughness, D/ε
Reynolds Number, N_R
Laminar flow, $f = 64/N_R$
f = 0.0166
2.3 x 10^5
6300
200 000