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Elementary Fluid Mechanics CEE 357-02
Fall 2019- November 18
Exam 2

Circle the correct answer or fill in the blank

1. (**2pt**) The region where the velocity profile is constant, the wall shear is constant, and the pressure drops linearly with x (for either laminar and turbulent flow) is referred to as:

(a) the entrance length
(b) pipe entrance
(c) fully developed flow region

2. (**2pt**) Laminar shear is dominant near
(a) the intermediate region called the overlap layer
(b) the region referred to as the wall layer
(c) the region referred to as the outer layer

3. (**2pt**) The accepted design Re value for pipe flow transition to turbulent flow is taken to be________ (number value).

$Re_{d,crit}$ = 2300

Solve and show your work.

4. (**24 pts**) Seawater (30%) is flowing through a 40-cm pipe, 200 m long, with a head loss of 16 m at 20°C. The concrete pipe used to transmit the seawater is smoothed. Solve for the (a) final expected friction factor, (b) average velocity (m/s), and (c) flow rate (m^3/s). (d) Plot the friction factor value on the Moody chart. Correct values will be accepted within 2% margin.

Concrete pipe (smoothed) roughness value (ε) = 0.04 mm
Relative roughness ratio ($\frac{\varepsilon}{d}$) = $\frac{0.04}{400} = 0.0001$

$$f = h_f \frac{d}{L}\frac{2g}{V^2} = (16\ m)\left(\frac{0.40\ m}{200\ m}\right)\left[\frac{2\left(9.81\,\frac{m}{s^2}\right)}{V^2}\right] \qquad or \qquad fV^2 = 0.628\ (SI\ units)$$

Guess a f value to compute a value for velocity (V) from above:

$$V = \sqrt{0.628/f}$$

With a guess of 0.014 (similar to example and other homework problem guesses):

$$V = \sqrt{0.628/0.014} = 6.697\ m/s$$

We calculate a Reynolds number (Re_d) using this V

$$Re_d = \frac{Vd}{\nu} = \frac{\rho_{saltwater\ (30\%)} Vd}{\mu_{saltwater\ (30\%)}} = \frac{\left(6.697\,\frac{m}{s}\right)\ (0.40m)}{1.044\ E-6\ m^2/s} = \frac{1025\ kg/m^3\left(6.697\,\frac{m}{s}\right)\ (0.40m)}{1.07\ E-3\ \ kg/(m\cdot s)}$$

$$Re_d = 2{,}566{,}023$$

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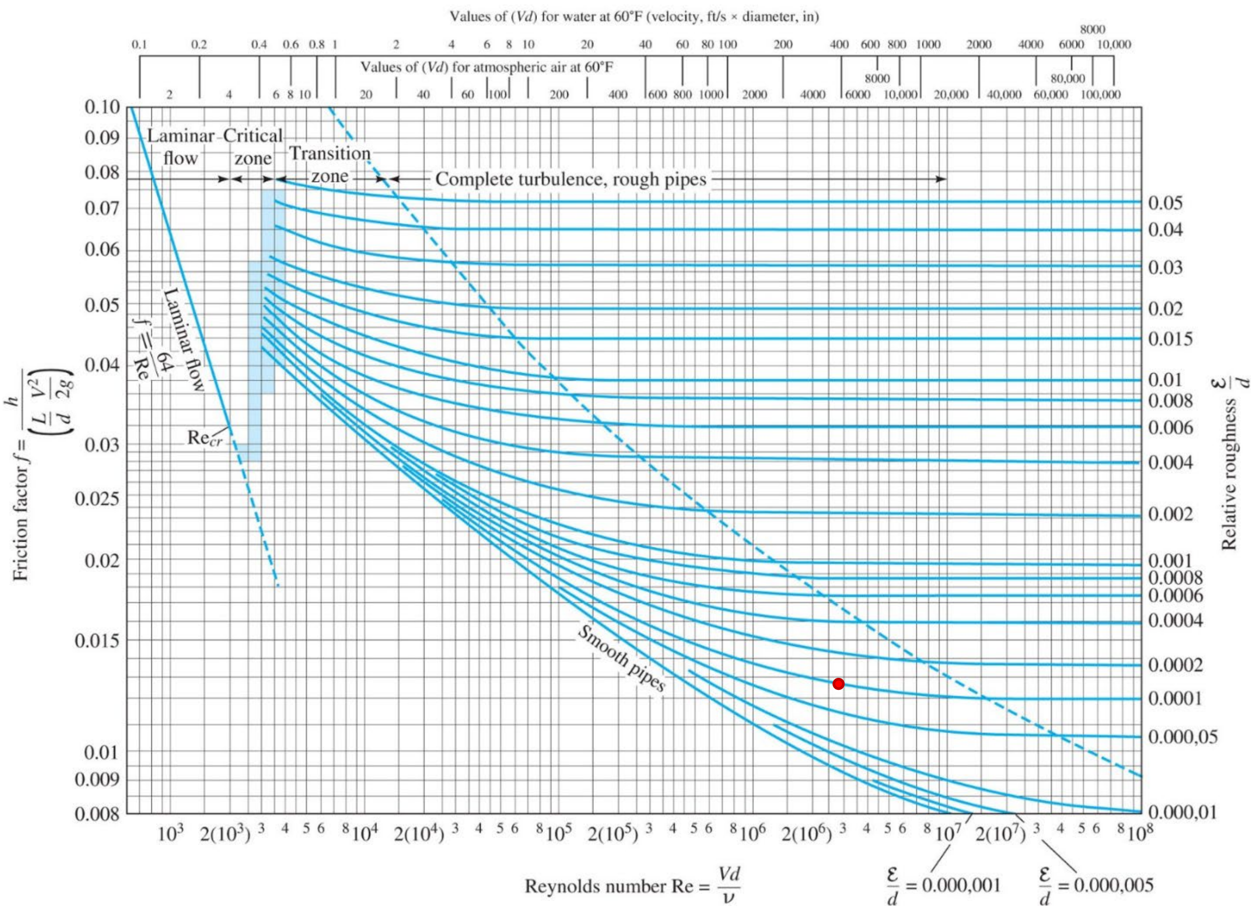

Equation 6.48

$$\frac{1}{f^{1/2}} = -2.0\log_{10}\left(\frac{\varepsilon/d}{3.7} + \frac{2.51}{Re_d f^{1/2}}\right) \qquad or \qquad f = \left[1/\left(-2\log_{10}\left(\frac{\varepsilon/d}{3.7} + \frac{2.51}{Re_d f^{1/2}}\right)\right)\right]^2$$

f= 0.01261 $\pm$0.000252

Equation 6.49

$$\frac{1}{f^{1/2}} \approx -1.8\log_{10}\left[\frac{6.9}{Re_d} + \left(\frac{\varepsilon/d}{3.7}\right)^{1.11}\right] \qquad or \qquad f \approx \left[1/\left(-1.8\log_{10}\left[\frac{6.9}{Re_d} + \left(\frac{\varepsilon/d}{3.7}\right)^{1.11}\right]\right)\right]^2$$

(a) f= 0.01259 $\pm$0.000252 (6pts)

(b) With a new f value of 0.01261 velocity can be updated:

$$V = \sqrt{0.628/0.01261} = 7.056\frac{m}{s} \pm 0.141$$ (6pts)

(c) Average flow rate (Q) m^3/s:

$$Q = V\left(\frac{\pi}{4}\right)d^2 = 7.056\frac{m}{s} \times \left(\frac{\pi}{4}\right)(0.40m)^2 = 0.887\frac{m^3}{s} \pm 0.0177$$ (6pts)

(d) Friction factor plotted above at f=0.0126, $(\frac{\varepsilon}{d}) = \frac{0.04}{400} = 0.0001$, Re= 2,703,577 (6pts)

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Circle the correct answer

5. (**2 pt**) The____________ is the dimensionless parameter used as an experimental value that relates to the effect of roughness on pipe resistance, thereby correlating head loss as proportional to V^2.

(a) Darcy friction factor
(b) Kármán constant
(c) eddy viscosity

6. (**2 pt**) A measure of a pipe's thickness and its resistance to stress caused by internal fluid pressure is known as the _______.

(a) Effective diameter mass flow
(b) Schedule No.
(c) Logarithm law

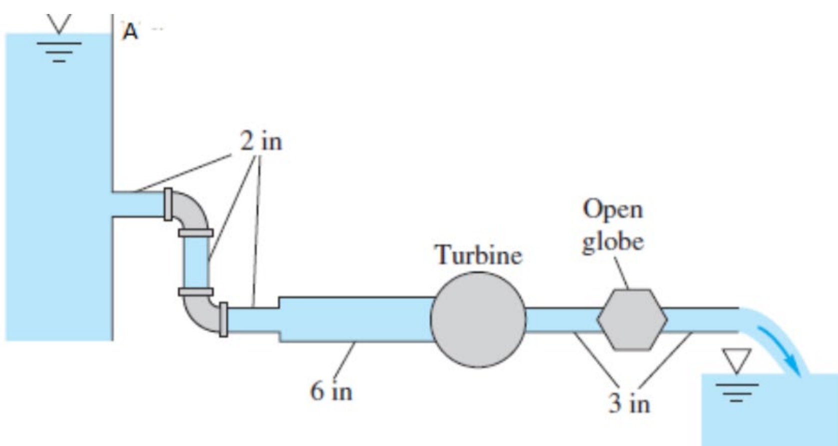
7. (**2 pt**) For noncircular ducts, we customarily replace a parameter in the head loss equation with an approximation for the non-circular geometry which is referred to as _______.

(a) the mixing length
(b) the friction velocity
(c) the hydraulic diameter

Solve and show your work.

8. Minor losses in a pipe. (**28 pts**)

In the figure shown below there are 125 ft of 2-in pipe, 75 ft of 6-in pipe, and 150 ft of 3-in pipe, all new cast iron. There are two 90° elbows and an open globe valve, **all flanged**. If the exit elevation is zero and the elevation at A is 50 ft, what horsepower is extracted by the turbine (in hp) when the flow rate is 0.16 ft^3/s of water at 20 °C? Hint: To save time use Haaland's formula to calculate *f*.



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Properties of water at 20°C, ρ = 1.94 slugs/ft^3, μ = 2.09E-5 slugs/(fts). Roughness ratio and L/d calculations for the three sections of the pipe are: (2pts)

$$2" = \frac{\varepsilon}{d} = \frac{0.00085\ ft}{\left(\frac{2}{12}\right)ft} = 0.0051 \qquad \frac{L}{D} = \frac{125\ ft}{\left(\frac{2}{12}\right)ft} = 750$$

$$6" = \frac{\varepsilon}{d} = \frac{0.00085\ ft}{\left(\frac{6}{12}\right)ft} = 0.0017 \qquad \frac{L}{D} = \frac{75\ ft}{\left(\frac{6}{12}\right)ft} = 150$$

$$3" = \frac{\varepsilon}{d} = \frac{0.00085\ ft}{\left(\frac{3}{12}\right)ft} = 0.0034 \qquad \frac{L}{D} = \frac{150\ ft}{\left(\frac{3}{12}\right)ft} = 600$$

The velocities & Reynolds No.'s of the three pipes and *f* are determined using the following formula:

(2pts) (2pts)

$$V_1 = \frac{0.16}{\pi(2/12)^2/4} = 7.334\frac{ft}{s} \ ; \qquad Re_1 = \frac{1.94\ (7.33)(\frac{2}{12})}{2.09E-5} = 113500\ ; \quad f_1(Haaland) = 0.0314$$

$$V_2 = \frac{0.16}{\pi(6/12)^2/4} = 0.815\frac{ft}{s} \ ; \qquad Re_1 = \frac{1.94\ (0.815)(\frac{6}{12})}{2.09E-5} = 37819\ ; \quad f_2(Haaland) = 0.0264$$

$$V_3 = \frac{0.16}{\pi(3/12)^2/4} = 3.26\frac{ft}{s} \ ; \qquad Re_1 = \frac{1.94\ (3.26)(\frac{3}{12})}{2.09E-5} = 75639\ ; \quad f_3(Haaland) = 0.0286$$

$$K_1 = entrance = 0.5; \quad K_2 = 2"flanged\ 90°\ elbow = 0.39; \quad K_3 = 2"flanged\ 90°\ elbow = 0.39;$$

$$K_4 = expansion \approx 0.79; \quad K_5 = 3"\ open\ globe\ valve = 8.5\ or\ 6.0\ (or\ between); \quad K_6 = exit = 1.0$$

(2pts)

The turbine head equals the elevation difference minus losses, such that (with p_1=p_2= 0, and V_1=V_2≈ 0):

$$\frac{p_1}{\rho g} + \frac{V_1^2}{2g} + z_1 = \left(\frac{p_2}{\rho g} + \frac{V_2^2}{2g} + z_2\right) + \sum h_f + \sum h_m + h_{turbine}$$

$$h_{turbine} = (z_1 - z_2) - \sum h_f - \sum h_m = \Delta z - \frac{V_1^2}{2g}\left(f_1\frac{L_1}{d_1} + \sum K\right) - \frac{V_2^2}{2g}\left(f_2\frac{L_2}{d_2}\right) - \frac{V_3^2}{2g}\left(f_3\frac{L_3}{d_3} + \sum K\right)$$

$$h_{turbine} = (50) - \frac{(7.33)^2}{2(32.2)}[0.0314(750) + 0.5 + 2(0.39) + 0.79] - \frac{(0.82)^2}{2(32.2)}(0.0264)(150) - \frac{(3.26)^2}{2(32.2)}[(0.0287)(600) + 8.5 + 1]$$

$$h_{turbine} = (50) - \{[21.397] + (0.0411) + [4.408]\}$$

$$h_{turbine} = (50) - [25.847] = 24.153$$ (10pts)

Thus, the resulting turbine power is determined using the following formula:

$$P_{turbine} = \rho g Q(h_{turbine}) = (62.4)(0.16)(24.15) = 241.15\ ft\cdot\frac{lbf}{s} \div 550\frac{ft\cdot lbf/s}{hp} = 0.438$$

The power extracted from the turbine is $\mathbf{0.438\ hp \pm 0.009}$ (10pts)

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Circle the correct answer

9. (**2 pt**) Which of the following is NOT a common category of pumps:
(a) Centrifugal
(b) Impulse
(c) Axial Flow

10. (2 **pt**) The *design flow rate Q** is the flow rate at which____________________________.
(a) a pump provides its maximum discharge
(b) a pump provides the highest possible head.
(c) a pump provides its greatest efficiency.

11. (2 **pt**) This U.S. engineer invented the classical venturi device at Holyoke MA during development of the hydroelectric dam: ____________________________.

(a) Giovani Venturi
(b) Robert Manning.
(c) Clemens Herschel

Solve and show your work.

12. Turbomachinery **(30 Pts)**

A pump, **geometrically similar** to the 12.95-in model in the image shown below, has a diameter of 24 in and is to develop 32 hp at BEP when pumping gasoline (not water). Determine (a) the appropriate speed, in r/min, (b) the BEP head, in ft, and (c) the BEP flow rate, in gal/min. For gasoline, ρ = 680 kg/m^3 = 1.32 slug/ft^3. Round the final answers to the nearest whole number.

From the given image, the BEP values are H_{*1}=72 ft; Q_{*1}= 525 gal/min ; η_{*1}=0.80

The power is determined using the following formula:

$$P_1 = \rho\, g\, Q_{*1}\ H_{*1}/\eta = \left(1.94\frac{slugs}{ft^3}\right)\left(32.2\frac{ft}{s^2}\right)\left(525\frac{gal}{min} \div 448.8\ \frac{gal/min}{ft^3/s}\right)(72\ ft)/0.8$$
$$= 6577\ \frac{ft\cdot lbf}{s} = 11.96\ hp$$

(6pts)

Use the scaling laws to find the new speed, head, and flow rate:

$$\frac{P_2}{P_1} = \frac{32}{11.96} = \left(\frac{\rho_2}{\rho_1}\right)\left(\frac{n_2}{n_1}\right)^3\left(\frac{D_2}{D_1}\right)^5 = \left(\frac{1.32}{1.94}\right)\left(\frac{n_2}{1160}\right)^3\left(\frac{24}{12.95}\right)^5,\quad solve\ \ n_2 = 654.79\ rpm\ \approx 655\ rpm \qquad \text{(8pts)}$$

$$\frac{H_2}{H_1} = \frac{H_2}{72} = \left(\frac{n_2}{n_1}\right)^2\left(\frac{D_2}{D_1}\right)^2 = \left(\frac{654.8}{1160}\right)^2\left(\frac{24}{12.95}\right)^2,\quad solve\ \ H_2 = 78.8\ ft\ \approx\ 79\ ft \qquad \text{(8pts)}$$

$$\frac{Q_2}{Q_1} = \frac{Q_2}{525} = \left(\frac{n_2}{n_1}\right)\left(\frac{D_2}{D_1}\right)^3 = \left(\frac{654.8}{1160}\right)\left(\frac{24}{12.95}\right)^3,\quad solve\ \ Q_2 = 1886.4\ \approx 1886\ gal/min \qquad \text{(8pts)}$$

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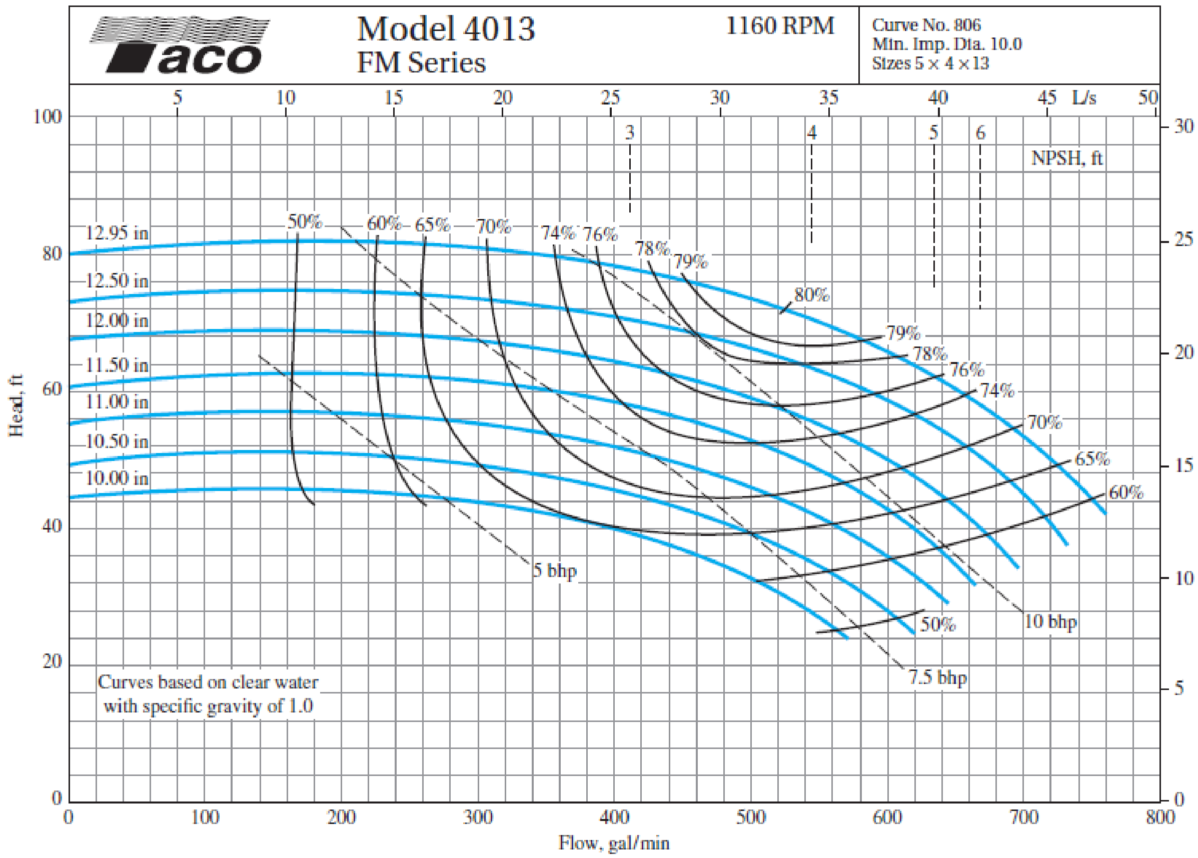

Taco
Model 4013
FM Series
1160 RPM
Curve No. 806
Min. Imp. Dia. 10.0
Sizes 5 × 4 × 13
L/s
NPSH, ft
12.95 in
12.50 in
12.00 in
11.50 in
11.00 in
10.50 in
10.00 in
50%
60%
65%
70%
74%
76%
78%
79%
80%
5 bhp
7.5 bhp
10 bhp
Curves based on clear water
with specific gravity of 1.0
Head, ft
Head, m
Flow, gal/min

Name____

---------------BONUS-----------------------

Bonus (2 points): What is the difference between PDP pumps and dynamic (or momentum-change) pumps?

Dynamic pumps generally provide a higher flow rate than PDPs and a much steadier discharge but are ineffective in handling high-viscosity liquids. Dynamic pumps also generally need priming; if they are filled with gas, they cannot suck up a liquid from below into their inlet. The PDP on the other hand is self-priming for most applications. A dynamic pump can provide very high flow rates but usually with moderate pressure rises. In contrast a PDP can operate up to very high pressures but typically produces low flow rates.

Bonus (3 points): A pump from the family of Fig 11.8 (Non-dimensional plot of Performance) has D = 28 in and n = 18,000 r/min. Estimate the discharge (Q*) for water at 60F (density =1.94 slugs/ft^3) at its best efficiency.

n = 18,000 r/min = 300 r/s

$$Q^* = C_Q n D^3 = (0.115)(300\ r/s)\left(\frac{28in}{\frac{12in}{ft}}\right)^3 = 483.3\frac{ft^3}{s} = 196,699\ gal/min$$

Bonus (3 points): Calculate the "rigorous" specific speed (N') and the "quick/lazy" specific speed (N) for a family of pumps from Fig 11.8.

$$N_s' = \frac{C_{Q*}^{1/2}}{C_{H*}^{3/4}} = \frac{(0.115)^{1/2}}{(5.0)^{3/4}} = 0.104$$

$$N_s = 17{,}182\ N_s' = 17{,}182 * (0.104) = 1740$$