1.	/20
2.	/20
3.	/20
4.	/20
5.	/20

Exam 3

CM3110 Spring

Thursday 18 March 2021

Name: SOLUTION

Rules:

- Closed book, closed notes.
- Two-page 8.5" by 11" study sheet allowed, double sided; you may use a calculator; you may not search the internet or receive help from anyone.
- Please text clarification questions to Dr. Morrison 906-487-9703. I will respond if I am able.
- All work submitted for the exam must be your own.
- Do not discuss the contents of the exam with anyone before 11:59pm Thursday, 18 March 2021.
- *Please copy the following Honors Pledge onto the first page of your exam submission and sign and date your agreement to it.*

Honor's Pledge:

On my honor, I agree to abide by the rules stated on the exam sheet.

Signature ______________________________

Date ____________________

Exam Instructions:

i. You may work on the exam for up to two hours and 30 minutes (150 minutes).
ii. Please submit your exam work within 150 minutes of downloading the exam.
iii. Please be neat. Only neat answers will be granted partial credit. Please use a dark pencil or pen so that your work is readable once scanned.
iv. Significant figures always count.
v. Please box your final answers.
vi. Submit your work as a single PDF file; put your name on every page. (Genius Scan is a free app that can create a PDF from photos taken by your phone)
vii. Submit your exam study sheet as a separate PDF file; put your name on the first page (at a minimum)

1. (20 points) Water (25^oC) flows steadily in horizontal smooth coper tubing at $3.1gpm$ $(gallon\ per\ minute)$. What is the pressure drop in $2.5 \times 10^2 m$ of copper tubing of inner diameter $0.015m$? Give your answer in Pa.

2. (20 points) What is the drag on a 2014 Toyota Prius going $7.0 \times 10^1 mph$ (= $102.6667\ ft/s$)? Information on this model is given below. The density of air is $0.0766\ \frac{lb_m}{ft^3}$. Give your answer in lb_f and show how you arrive at your answer.

Vehicle	2014 Chevrolet Volt	2014 Toyota Prius
Drag Coefficient	0.28	0.26
Frontal Area	23.7 square feet	23.9 square feet

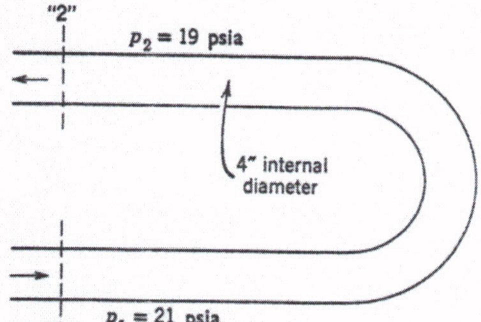
Ref: https://www.caranddriver.com/features/a15108689/drag-queens-aerodynamics-compared-comparison-test/

3. (20 points) Consider the three geometries described below.
   a. What is the hydraulic diameter for each?
   b. In laminar flow, what is the Fanning friction factor for each geometry as a function of Reynolds number?

   1. Circular pipe of radius R
   2. Equilateral triangle of side length a
   3. Wide, narrow slit of gap H and width W

4. (20 points) List and describe three of the seven flow regimes for a fluidized bed. Which regime is the most desirable for chemical engineering purposes? Please limit your answer to about seven sentences at most.

5. (20 points) What is the magnitude of the horizontal force on the fluid in the 180^o bend (return bend) shown in the figure below? The fluid in the bend is water at 68^oF of density $62.4\frac{lb_m}{ft^3}$, and viscosity $1.0\ cp = 0.67197 \times 10^{-3}\frac{lb_m}{ft\ s}$, flowing at $3.0\ ft^3/s$. The bend is made of tubing with a circular cross-sectional area of $0.0872665\ ft^2$ (inner diameter = $4.0\ in$). You may neglect the effect of gravity. The entrance pressure is $21psia$ and the exit pressure is $19psia$. The flow is steady. Show how you arrive at your answer. Give your answer in lb_f.



Ref: Bird, Stewart, and Lightfoot, 1960

Fig. 7.D. Flow in a U-bend; both arms of bend are at the same elevation.

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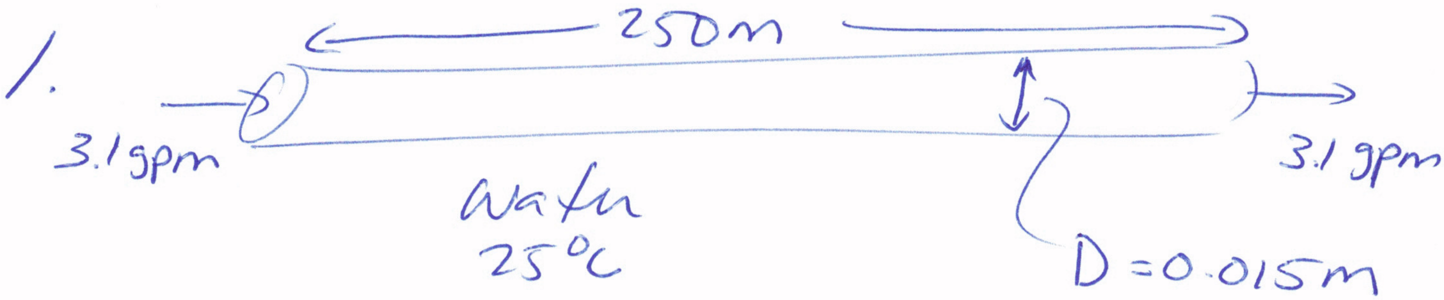
Spring 2021
Morrison

1.



What is ΔP?

MEB

$$\frac{\Delta P}{\rho} + \underbrace{\cancel{\frac{\Delta(v^2)}{2\alpha}}}_{v_1 = v_2} + \underbrace{\cancel{g\,\Delta z}}_{\text{horizontal}} + F = \underbrace{\cancel{\frac{W_{s,on}}{\dot m}}}_{\text{no shafts}}$$

$$\frac{\Delta P}{\rho} = F = 4f\,\frac{L}{D}\,\frac{v^2}{2}$$

$$\Delta P = \frac{\overset{2}{\cancel{4}} f \rho L V^2}{\cancel{2} D}$$

$$\Delta P = \frac{2 f \rho L V^2}{D}$$

$$\underbrace{A = \frac{\pi D^2}{4}}$$

$$V = \frac{Q}{A} = (3.1\ \cancel{gpm}) \frac{m^3/s}{15850.2\ \cancel{gpm}} \left(\frac{4}{\pi (0.015\,m)^2} \right)$$

$$\boxed{V = 1.10676\ m/s}$$

Data correlation for f, need Re:

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

$$= \frac{\left(997.08 \frac{\cancel{kg}}{\cancel{m^3}}\right)\left(1.10676 \frac{\cancel{m}}{\cancel{s}}\right)(0.015\,\cancel{m})}{8.937 \times 10^{-4} \frac{\cancel{kg}}{m\,s}}$$

$$= 18521.8$$

Simplified turbulent:

$$f = \frac{1.02}{4} (\log Re)^{-2.5}$$

$$\boxed{f = 6.777 \times 10^{-3}}$$

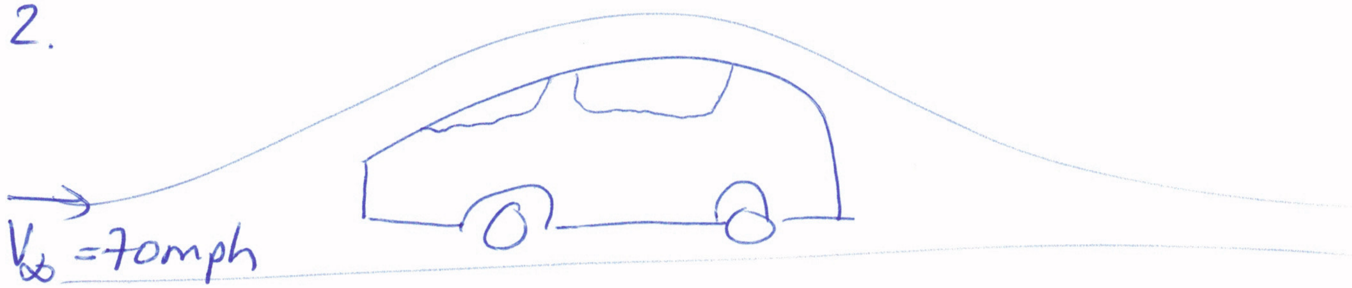
$$\Delta p = \frac{2 f \rho L V^2}{D}$$

$$= \frac{(2)(6.777 \times 10^{-3})(250 \cancel{m})(1.10676 \frac{\cancel{m}}{s})^2 (997.08 \frac{kg}{m^3})}{0.015 \cancel{m}} \times \frac{N s^2}{\cancel{kg} \cdot m}$$

$$= 2.759 \times 10^5 \frac{\cancel{N}}{\cancel{m^2}} \frac{Pa}{\cancel{N}/\cancel{m^2}}$$

$$= \boxed{2.8 \times 10^5 \; Pa}$$

2.



drag = ?

$$C_D = \frac{F_{drag}}{\left(\frac{1}{2}\rho V_\infty^2\right)\left(A_{profile}\right)}$$

$$F_{drag} = C_D\left(\frac{1}{2}\rho V_\infty^2\right) A$$

$$= (0.26)\left(\frac{1}{2}\right)\left(0.0766\ \frac{\cancel{lbm}}{\cancel{ft^3}}\right)$$

$$\times\left(102.6667\ \frac{\cancel{ft}}{\cancel{s}}\right)^2\left(23.9\ \cancel{ft^2}\right)$$

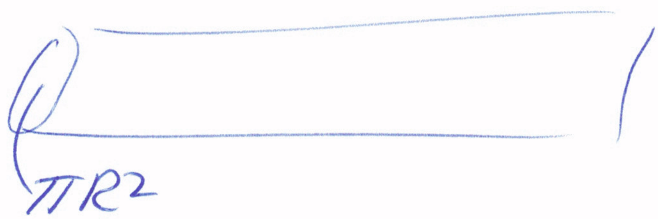
$$\times\left(\frac{1}{32.174}\ \frac{\cancel{s^2}\ lbf}{\cancel{ft}\ \cancel{lbm}}\right)$$

$$= \boxed{78\ lbf}$$

3) Hydraulic diameter

$$D_H = \frac{4A_{xs}}{P} \quad 2\pi R$$

① pipe



$$D_H = \frac{\overset{2}{\cancel{4}}(\cancel{\pi}R^{\cancel{2}})}{\cancel{2}\cancel{\pi}\cancel{R}} = \boxed{2R}$$

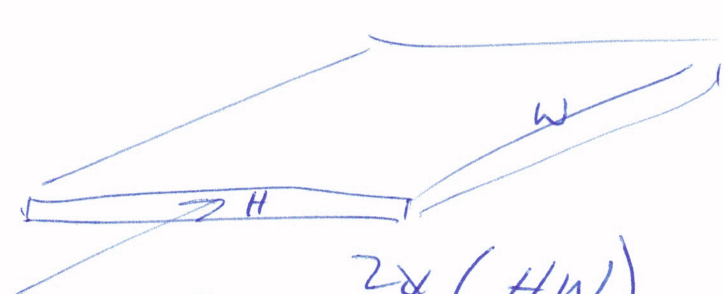
②

$$A_{xs} = \frac{1}{2}a\left(\frac{a}{2}\sqrt{3}\right)$$

$$D_H = \frac{4A_{xs}}{P} = \frac{\left(\cancel{\frac{1}{2}}\frac{a^{\cancel{2}}}{\cancel{2}}\sqrt{3}\right)\cancel{4}}{3\cancel{a}}$$

$$= \frac{a\sqrt{3}}{3} = \boxed{\frac{a}{\sqrt{3}}}$$

③



$$D_H = \frac{\overset{2}{\cancel{4}}(HW)}{\cancel{2}H+\cancel{2}W} = \boxed{\frac{2HW}{H+W}}$$

3b

$$Po = Re_{D_H} f_{D_H}$$ laminar flow

$$f = \frac{Po}{Re_{D_H}}$$

1. $$f = \frac{16}{Re}$$

2. $$f = \frac{13.33}{Re}$$

3. $$f = \frac{24}{Re}$$

4. 1. fixed bed (packed bed) flow through
- stationary particles

2. particulate regime
(fluidized)
The particles are lifted and there is rapid mixing + nearly uniform average density

most desirable

3. Bubbling regime - large gas bubbles traverse the fluidized bed

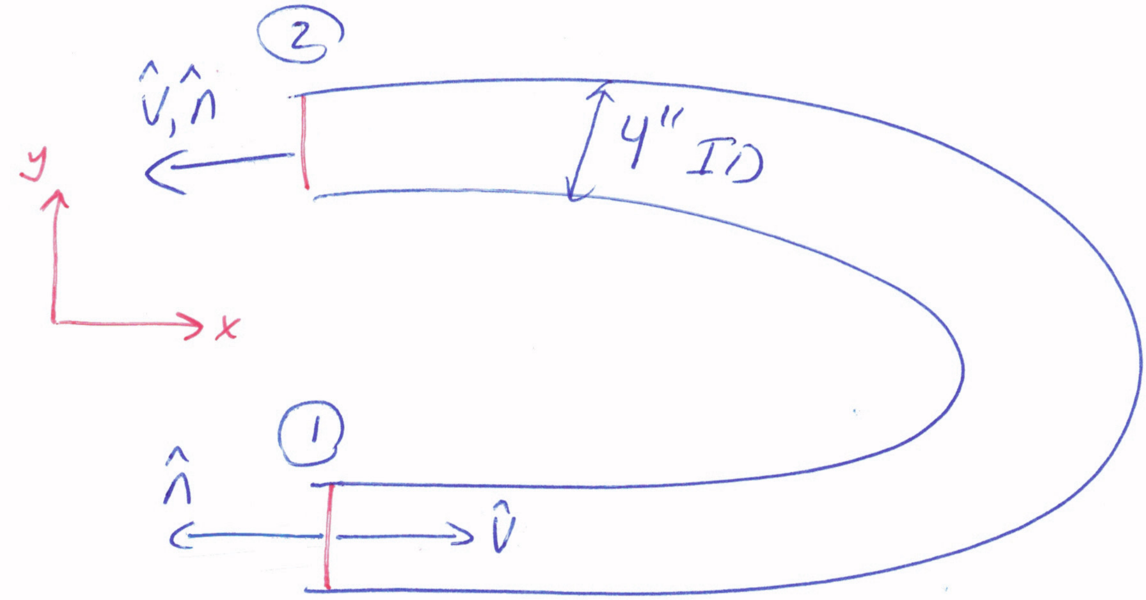
4. Slug flow - bubbles grow larger

5. Turbulent regime. Bubbles + slugs are disrupted + there is good mixing but the mass distribution is not uniform; some of the bed is blown out.

6. fast fluidization
much of the bed is blown out

7. pneumatic conveying - the bed is blown out

5. $P_2 = 19$ psia



$P_1 = 21$ psia

$$\rho = 62.4 \frac{lbm}{ft^3}$$

$$\mu = 1\,\cancel{cp} \cdot \frac{0.67197\ \frac{lbm}{ft\,s}}{10^3\,\cancel{cp}}$$

$$\boxed{\mu = 0.67197 \times 10^{-3}\ \frac{lbm}{ft\,s}}$$

turbulent $\Rightarrow \beta = 1$

point 1 point 2

$$\hat{n} = \begin{pmatrix} -1 \\ 0 \\ 0 \end{pmatrix}_{xyz} \qquad \hat{n} = \begin{pmatrix} -1 \\ 0 \\ 0 \end{pmatrix}_{xyz}$$

$$\hat{v} = \begin{pmatrix} 1 \\ 0 \\ 0 \end{pmatrix}_{xyz} \qquad \hat{v} = \begin{pmatrix} -1 \\ 0 \\ 0 \end{pmatrix}_{xyz}$$

$$\hat{n} \cdot \hat{v} = \cos\theta_1 = -1 \qquad \hat{n} \cdot \hat{v} = \cos\theta_2 = 1$$

$$P_1 = 21 \text{ psia} \qquad P_2 = 19 \text{ psia}$$

$$A = \frac{\pi D^2}{4} = \frac{(\pi)(4 \text{ in})^2 \left(\frac{ft}{12 \text{ in}}\right)^2}{4} = 0.0872665 \text{ ft}^2$$

$$\langle v \rangle = \frac{Q}{A} = \left(3 \frac{ft^3}{s}\right)\left(\frac{1}{0.0872665 \text{ ft}^2}\right)$$

$$\langle v \rangle = 34.37747 \frac{ft}{s}$$

$$Re = \frac{\rho v D}{\mu} = \frac{\left(62.4 \frac{lbm}{ft^3}\right)\left(34.377 \frac{ft}{s}\right)\left(\frac{4}{12} ft\right)}{0.67197 \times 10^{-3} \frac{lbm}{ft\, s}} = 1.1 \times 10^6$$

turbulent

MACROSCOPIC MOMENTUM BAL:

$$\cancel{\frac{dP}{dt}} + \rho A \overbrace{\cos\theta_1}^{+1} \langle v\rangle^2 \begin{pmatrix} -1 \\ 0 \\ 0 \end{pmatrix}_{xyz}$$

steady

$$+ \rho A \overbrace{\cos\theta_2}^{1} \langle v\rangle^2 \begin{pmatrix} -1 \\ 0 \\ 0 \end{pmatrix}_{xyz}$$

$$= +P_1 A \begin{pmatrix} +1 \\ 0 \\ 0 \end{pmatrix}_{xyz} + (+P_2 A) \begin{pmatrix} +1 \\ 0 \\ 0 \end{pmatrix}_{xyz}$$

$$+ \begin{pmatrix} R_x \\ R_y \\ R_z \end{pmatrix}_{xyz} + \cancel{M_{cv}\, g}$$

neglect

$$\begin{pmatrix} -2\rho A \langle v\rangle^2 \\ 0 \\ 0 \end{pmatrix}_{xyz} = \begin{pmatrix} (P_1 + P_2) A \\ 0 \\ 0 \end{pmatrix}_{xyz} + \begin{pmatrix} R_x \\ R_y \\ R_z \end{pmatrix}_{xyz}$$

$$R_x = -2\rho A \langle v \rangle^2 - (P_1 + P_2)(A)$$

$$= -2\left(62.4 \frac{\cancel{lb_m}}{\cancel{ft^3}}\right)\left(0.0872665\, \cancel{ft^2}\right)$$

$$\times \left(34.37747 \frac{\cancel{ft}}{\cancel{s}}\right)^2$$

$$\times \frac{lb_f\, \cancel{s^2}}{32.174\, \cancel{ft}\, \cancel{lb_m}}$$

$$-(21+19)\frac{lb_f}{\cancel{in^2}} \frac{144\, \cancel{in^2}}{\cancel{ft^2}} \cdot \left(0.0872665\, \cancel{ft^2}\right)$$

$$= -400.297 - 502.655$$

$$= -902.95$$

$$R_x = -903\ lb_f$$

$$\boxed{-9.0 \times 10^2\ lb_f}$$

force exerted by the bend on the water (on the C.V.)