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MET 330 Fluid Mechanics
Dr. Orlando Ayala
Test 2

Take home – Due before midnight on the date shown in CANVAS.

READ FIRST

1. RELAX!!!! DO NOT OVERTHINK THE PROBLEMS!!!! There is nothing hidden. The test was designed for you to pass and get the maximum number of points, while learning at the same time. **HINT: THINK BEFORE TRYING TO USE/FIND EQUATIONS (OR EVEN FIND SIMILAR PROBLEMS)**
2. The total points on this test are one hundred (100). Ten (10) points are from your HW assignments. The other ninety (90) points will come from the problem solutions.
3. There are 2 problems to solve, each worth (90/2) points.
4. What you turn in should be only your own work. You cannot discuss the exam with anyone, except me. Call me, skype me, text me, email me, come to my office, if you have any question.
5. I do not read minds. You should be explicit and organized in your answers. Use drawings/figures. If you make a mistake, do not erase it. Rather use that opportunity to explain why you think it is a mistake and show the way to correct the problem.
6. You have to turn in your test ON TIME and ONLY through CANVAS. You must submit only one file and it has to be a pdf file. For the ePortfolio you are also supposed to upload this artifact to your Google drive. When you are done solving the test, please go ahead and upload it now before you forget.
7. Do not start at the last minute so you can handle anything that could happen. Late tests will not be accepted. Test submitted through email will not be accepted either.
8. Cheating is completely wrong. The ODU Student Honor Pledge reads: "I pledge to support the honor system of Old Dominion University. I will refrain from any form of academic dishonesty or deception, such as cheating or plagiarism." By attending Old Dominion University you have accepted the responsibility to abide by this code. This is an institutional policy approved by the Board of Visitors. It is important to remind you the following part of the Honor Code:

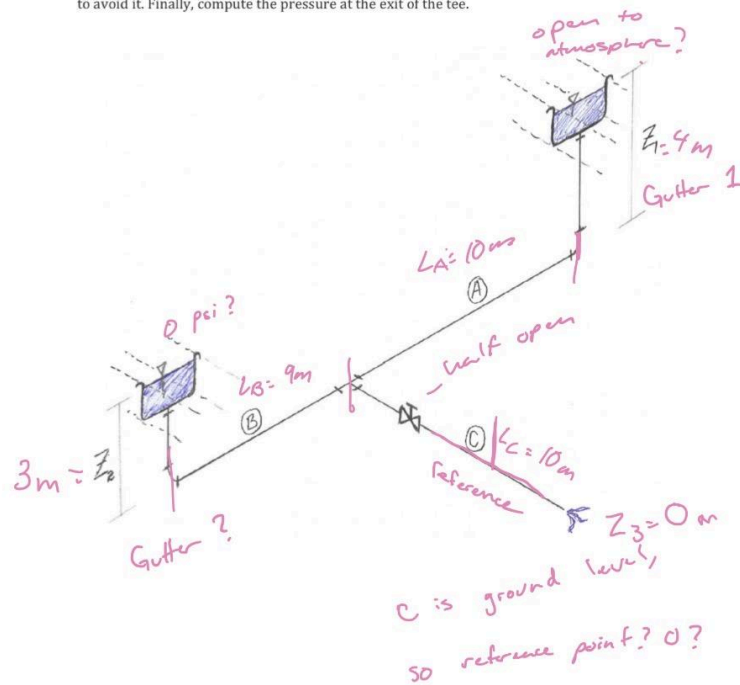
IX. PROHIBITED CONDUCT

A. Academic Integrity violations, including:

1. *Cheating*: Using unauthorized assistance, materials, study aids, or other information in any academic exercise (Examples of cheating include, but are not limited to, the following: using unapproved resources or assistance to complete an assignment, paper, project, quiz or exam; collaborating in violation of a faculty member's instructions; and submitting the same, or substantially the same, paper to more than one course for academic credit without first obtaining the approval of faculty).

With that said, you are NOT authorized to use any online source of any type, unless it is ODU related.

1. In a house there are two elevated gutters along 2 of its sides. Each gutter drains the water through pipes that get connected together to bring the rainwater to ground floor, as shown in the figure (please be aware that this is just a sketch, no real dimensions were intended). The gutters were designed for the worst case scenario: heavy rain. For this case, the whole system gutter-pipes is filled with running water. For some unknown reason, the engineer who designed the system decided to put a valve in the ground level pipe C (this is a bad decision but it is what was found). The lengths of the $\frac{3}{4}$ inch (inner diameter) commercial steel pipes are: $L_A = 10$ m, $L_B = 9$ m, $L_C = 10$ m (this lengths include vertical and horizontal portions of the pipes). The water surfaces in the gutters are elevated at $Z_1 = 4$ m, $Z_2 = 3$ m. The elevation is measured with respect to the ground level horizontal pipe 3. Determine the flow out of the system if the gate valve is half open. Assume that the friction factor is only a function of the relative roughness. Do not neglect the minor losses. Check the velocity criterion ($V_{max} = 3$ m/s). Is it violated? If so, provide some suggestions to avoid it. Finally, compute the pressure at the exit of the tee.



Purpose :

- Determine flow out of system, if gate valve is half open.
- find out if Velocity violates $V_{max} = 3$ m/s, if so, how can that be fixed.
- compute pressure as it exits the tee

Sources

• Mott, Robert L., Untener, Joseph A., 8th edition
Applied Fluid Mechanics

Design considerations

following must be assumed

- Incompressible fluid
- Isothermal process
- Steady State Flow

Data & Variables

inner diameter $D: \frac{3}{4} \text{ in} = .75 \text{ in} = 0.01905 \text{ m}$
cross-sectional Area $A = \frac{\pi}{4} D^2 = 2.85 \times 10^{-4} \text{ m}^2$

$Z_1 = 4 \text{ m}$ (Gutter 1), $Z_2 = 3 \text{ m}$ (Gutter 2)

$Z_3 = 0 \text{ m}$ (Ground exit reference)

friction factor = $f = f_T = 0.0245$

Step 2 Procedure

Branch A

$$k = 0.50$$

$$90^\circ \text{ elbow: } k = 30f_t = 30(0.0245) = 0.735$$

$$\text{Tee: } k = 60f_T = 60(0.0245) = 1.47$$

$$\text{Pipe friction: } f \frac{L_A}{D} = 0.0245 \left(\frac{10}{0.01905} \right) = 12.86$$

$$\sum K_A = 0.50 + 0.735 + 1.47 + 12.86 = 15.565$$

Branch B

$$k = 0.50$$

$$90^\circ \text{ Elbow } k = 0.735$$

$$\text{Tee } k = 1.47$$

$$\text{Pipe friction: } f \frac{L_B}{D} = 0.0245 \left(\frac{9}{0.01905} \right) = 11.577$$

$$\sum K_B = 0.50 + 0.735 + 1.47 + 11.577 = 14.282$$

Pipe C

$$\text{Half open gate: } k = 2.80$$

$$\text{Open Exit: } k = 1.00$$

$$\text{Pipe friction: } f \frac{L_C}{D} = 0.0245 \left(\frac{10}{0.01905} \right) = 12.86$$

$$\sum K_C = 2.80 + 1.00 + 12.86 = 16.66$$

Step 3

$$Z_1 = \frac{V_3^2}{2g} + h_{L,A} + h_{L,C}$$

$$4 = \frac{V_C^2}{2g} + 15.565 \frac{V_A^2}{2g} + 16.66 \frac{V_C^2}{2g}$$

$$4 = 15.565 \frac{V_A^2}{2g} + 17.66 \frac{V_C^2}{2g} \quad (\text{equation 1})$$

$$Z_2 = \frac{V_C^2}{2g} + h_{L,B} + h_{L,C}$$

$$3 = 14.282 \frac{V_B^2}{2g} + 17.66 \frac{V_C^2}{2g} \quad (\text{equation 2})$$

$$V_C = V_A + V_B \quad (\text{Equation 3})$$

Step 4

$$\text{Branch A to exit: } 4 = 15.565 \frac{V_A^2}{2g} + 17.66 \frac{V_C^2}{2g}$$

$$\text{Branch B to exit: } 3 = 14.282 \frac{V_B^2}{2g} + 17.66 \frac{V_C^2}{2g}$$

$$\text{Continuity Equation: } V_A + V_B = V_C$$

$$4 = \frac{15.565}{19.62} V_A^2 + \frac{17.66}{19.62} V_C^2$$

$$4 = 0.7933 V_A^2 + 0.9001 V_C^2$$

$$0.7933 V_A^2 = 4 - 0.9001 V_C^2$$

$$V_A^2 = \frac{4 - 0.9001 V_C^2}{0.7933} \rightarrow V_A^2 = 5.042 - 1.135 V_C^2$$

$$V_A = \sqrt{5.042 - 1.135 V_C^2} \quad (\text{Eq. 4.1})$$

$$3 = \frac{14.282}{19.62} V_B^2 + \frac{17.66}{19.62} V_C^2$$

$$3 = 0.7279 V_B^2 + 0.9001 V_C^2$$

$$0.7279 V_B^2 = 3 - 0.9001 V_C^2$$

$$V_B^2 = \frac{3 - 0.9001 V_C^2}{0.7279} \rightarrow V_B^2 = 4.121 - 1.236 V_C^2$$

$$V_B = \sqrt{4.121 - 1.236 V_C^2} \quad (\text{Eq. 4.2})$$

$$V_A + V_B = V_C$$

$$\sqrt{5.042 - 1.135 V_C^2} + \sqrt{4.121 - 1.236 V_C^2} = V_C$$

$$\sqrt{5.042 - 1.135 V_C^2} = V_C - \sqrt{4.121 - 1.236 V_C^2}$$

$$(\sqrt{5.042 - 1.135 V_C^2})^2 = (V_C - \sqrt{4.121 - 1.236 V_C^2})^2$$

$$5.042 - 1.135 V_C^2 = V_C^2 - 2V_C \sqrt{4.121 - 1.236 V_C^2} + (4.121 - 1.236 V_C^2)$$

$$5.042 - 1.135 V_C^2 = 4.121 - 1.236 V_C^2 - 2V_C \sqrt{4.121 - 1.236 V_C^2}$$

$$0.921 - 0.899 V_C^2 = -2V_C \sqrt{4.121 - 1.236 V_C^2}$$

$$(0.921 - 0.899 V_C^2)^2 = (-2V_C \sqrt{4.121 - 1.236 V_C^2})^2$$

$$0.848 - 1.656 V_C^2 + 0.808 V_C^4 = 4V_C^2 (4.121 - 1.236 V_C^2)$$

$$0.848 - 1.656 V_C^2 + 0.808 V_C^4 = 16.484 V_C^2 - 4.944 V_C^4$$

$$5.792 V_C^4 - 18.140 V_C^2 + 0.848 = 0$$

$$V_C^2 = \frac{-(-18.140) \pm \sqrt{(-18.140)^2 - 4(5.792)(0.848)}}{2(5.792)}$$

$$= \frac{18.140 \pm 12.534}{11.584} = 1.76 \text{ m/s}$$

$$V_A = \sqrt{5.042 - 1.135 (1.76)^2} = 1.23 \text{ m/s}$$

$$V_B = \sqrt{4.121 - 1.236 (1.76)^2} = 0.53 \text{ m/s}$$

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Step 5 Summary

a)

$$Q_c = V_c \times A = 1.76 \text{ m/s} \times (2.85 \times 10^{-4} \text{ m}^2) = 5.02 \times 10^{-4} \text{ m}^3/\text{s}$$

$$Q = 5.02 \times 10^{-4} \text{ m}^3/\text{s}$$

$$b) V_A = 1.23 \text{ m/s} \checkmark$$

$$V_B = 0.53 \text{ m/s} \checkmark$$

$$V_C = 1.76 \text{ m/s} \checkmark$$

these pass the velocity criterion check

to they do not violate the 2m/s limit.

$$c) \frac{P_{tuc}}{\gamma} + \frac{V_c^2}{2g} + Z_{tuc} = \frac{P_3}{\gamma} + \frac{V_3^2}{2g} + Z_3 + h_{L,c}$$

$$\frac{P_{tuc}}{\gamma} = h_{L,c} = \sum k_c \left(\frac{V_c^2}{2g} \right)$$

$$\frac{9810}{1} \cdot \frac{P_{tuc}}{9810} = 16.66 \left(\frac{1.76^2}{2 \times 9.81} \right) \cdot 9810$$

$$P_{tuc} = 25810 \text{ Pa} \quad (25.8 \text{ kPa})$$

Materials

Water, steel pipe

Analysis

All branch velocities are below Maximum limit. If system demands increase over age causes pipe roughness to rise, friction head losses will increase resulting in over pressurization, Joint failure, structural overflow.

Data & Variables

Reservoir Depth: 0.7m

Suction (inlet) length (L_s): 20m

Discharge (outlet) length (L_d): 18m

Annular Column length (L_a): 1.8m

Annular Outer Diameter (D_o): 10cm = 0.10m

Annular Inner Diameter (D_i): 7cm = 0.07m

Target Fountain height (Δz_{jet}): 1m

Sudden expansion Loss Coefficient (K_{ex}): 20

Pump-Motor Combination Efficiency (η) 92% = 0.92

Water 25°C

$$\gamma: 9.78 \text{ kN/m}^3 = 9780 \text{ N/m}^3$$

$$V: 8.94 \times 10^{-7} \text{ m}^2/\text{s}$$

Pipe entrance: $K_{ent} = 0.50$

Suction Elbow: $K_{elbow,s} = 30 \text{ ft}$

Discharge Elbow: $K_{elbow,d} = 30 \text{ ft}$

Sudden Expansion: $K_{expansion} = 2.0$

Pipe Table G.3

Suction line 160 mm OD

OD: 160 mm

Wall thickness: 9.5 mm

ID: 141.0 mm = 0.141 m

$$A_s: 1.561 \times 10^{-2} \text{ m}^2 = 0.01561 \text{ m}^2$$

Discharge line 125 mm OD

- OD: 125 mm

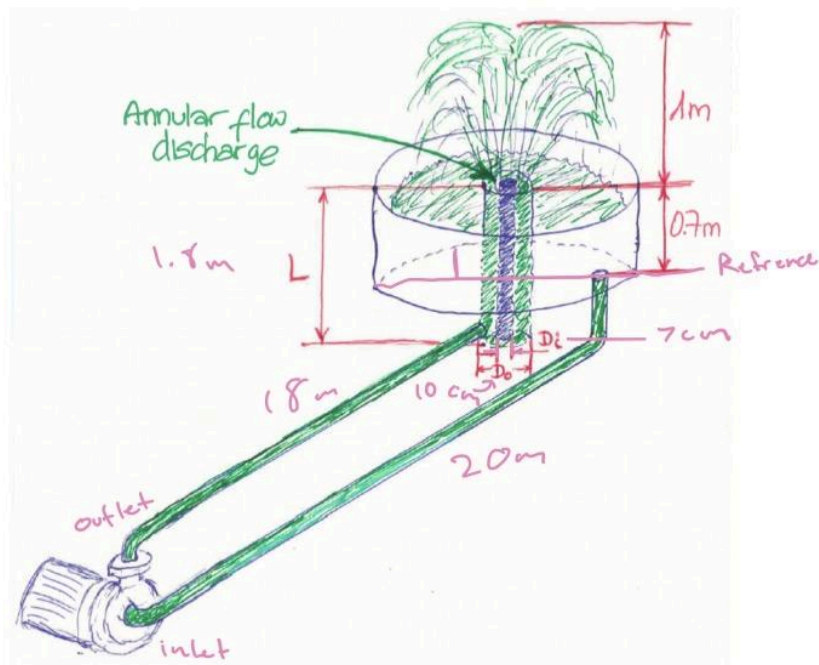
- t : 7.4 mm

- ID_d: 110.2 mm = 0.1102 m

- A_d : $9.538 \times 10^{-3} \text{ m}^2 = 0.009538 \text{ m}^2$

2. You are in charge of designing a new decorative water fountain at ODU. It consists of a water reservoir and piping to and from a pump as shown in the figure (please be aware that this is just a sketch, no real dimensions were intended). You are asked to use only PVC pipes (see Table G3). The outlet line from the pump is 18 m and the inlet line to the pump is 20 m. The outlet line leads to the bottom of an annular flow line. The expansion there has a loss of $K=2$ based on the kinetic energy before the expansion. The annular flow passage has a length $L = 1.80$ m and is bounded by $D_o = 10$ cm and $D_i = 7$ cm (use hydraulic radius for the energy loss calculations of such annular flow passage. Check Chapter 9 and lecture notes). There is negligible loss at the exit of the annulus, which is exposed to the atmosphere. Consider all other minor losses following what is on the sketch. What is the pump power required for the flow configuration shown? If the pump-motor combination has an efficiency of 92%, determine the electrical power requirements.

HINTS: (1) The flow rate should be enough so the water reaches 1 m as sketched. (2) Use the velocity criteria discussed in class to select the PVC pipe diameters.



Purpose

- pump power required to reach the min height of 1 m
- determine electrical power requirements

Sources

- Mott, Robert L., Untener, Joseph A., Applied Fluid Mechanics 8th edition

Design considerations

following must be assumed

- Incompressible fluid
- Isothermal process
- Steady State Flow
- Water at ambient temperature 25°C
- PVC Rating of 16 bar
- Minor losses: Entrance, elbows, expansions

Materials

Pump, water, PVC, tank/fountain

Step 1 Procedure

$$\frac{V_3^2}{2g} = \Delta z_{jet}$$

$$V_3 = \sqrt{2g(1.0m)} = \sqrt{2(9.81m/s^2)(1.0m)} = 4.4294m/s$$

$$A_{annulus} = \frac{\pi}{4} (D_o^2 - D_i^2) = \frac{\pi}{4} [(0.10m)^2 - (0.07m)^2] = 0.0040055m^2$$

$$Q = V_3 \cdot A_{annulus} = (4.4294m/s)(0.0040055m^2) = 0.017742m^3/s$$

Step 2

$$V_1 = \frac{Q}{A_1} = \frac{0.017742m^3/s}{0.01561m^2} = 1.1366m/s$$

$$\frac{V_1^2}{2g} = \frac{(1.1366m/s)^2}{2(9.81m/s^2)} = 0.0658m$$

$$V_2 = \frac{Q}{A_2} = \frac{0.017742m^3/s}{0.009538m^2} = 1.8601m/s$$

$$\frac{V_2^2}{2g} = \frac{(1.8601m/s)^2}{2(9.81m/s^2)} = 0.1764m$$

$$V_3 = 4.4294m/s$$

Step 3

$$\text{Section Major Loss}$$

$$N_{R1} = \frac{V_1 D_1}{\nu} = \frac{(1.1366 \text{ m/s})(0.141 \text{ m})}{8.94 \times 10^{-7} \text{ m}^2/\text{s}} = 1.7926 \times 10^5$$

$$f_1 = \frac{0.25}{\left[\log_{10} \left(\frac{5.74}{N_{R1}^{0.9}} \right) \right]^2} = \frac{0.25}{\left[\log_{10} \left(\frac{5.74}{(1.7926 \times 10^5)^{0.9}} \right) \right]^2} = 0.01625$$

$$h_{L1} = f_1 \left(\frac{L_1}{D_1} \right) \frac{V_1^2}{2g} = 0.01625 \left(\frac{20 \text{ m}}{0.141 \text{ m}} \right) (0.0658 \text{ m}) = 0.1517 \text{ m}$$

Discharge Major Loss

$$N_{R2} = \frac{V_2 D_2}{\nu} = \frac{(1.8601 \text{ m/s})(0.1102 \text{ m})}{8.94 \times 10^{-7} \text{ m}^2/\text{s}} = 2.2927 \times 10^5$$

$$f_2 = \frac{0.25}{\left[\log_{10} \left(\frac{5.74}{N_{R2}^{0.9}} \right) \right]^2} = \frac{0.25}{\left[\log_{10} \left(\frac{5.74}{(2.2927 \times 10^5)^{0.9}} \right) \right]^2} = 0.01543$$

$$h_{L2} = f_2 \left(\frac{L_2}{D_2} \right) \frac{V_2^2}{2g} = 0.01543 \left(\frac{18 \text{ m}}{0.1102 \text{ m}} \right) (0.1764 \text{ m}) = 0.4946 \text{ m}$$

Annular Column Major Loss

$$N_{R3} = \frac{V_3 D_h}{\nu} = \frac{(4.4294 \text{ m/s})(0.03 \text{ m})}{8.94 \times 10^{-7} \text{ m}^2/\text{s}} = 1.4864 \times 10^5$$

$$f_3 = \frac{0.25}{\left[\log_{10} \left(\frac{5.74}{N_{R3}^{0.9}} \right) \right]^2} = \frac{0.25}{\left[\log_{10} \left(\frac{5.74}{(1.4864 \times 10^5)^{0.9}} \right) \right]^2} = 0.01683$$

$$h_{L3} = f_3 \left(\frac{L_3}{D_h} \right) \frac{V_3^2}{2g} = 0.01683 \left(\frac{1.80 \text{ m}}{0.03 \text{ m}} \right) (1.0 \text{ m}) = 1.0098 \text{ m}$$

Step 4

$$h_{L4} = (K_{\text{entrance}} + K_{\text{elbow}}) \frac{v_1^2}{2g} = (0.50 + 0.45) (0.0658 \text{ m}) = 0.0625 \text{ m}$$

$$h_{L5} = (K_{\text{elbow}} + K_{\text{expansion}}) \frac{v_2^2}{2g} = (0.45 + 20) (0.1764 \text{ m}) = 0.4322 \text{ m}$$

$$\sum h_L = h_{L1} + h_{L2} + h_{L3} + h_{L4} + h_{L5}$$

$$\sum h_L = 0.1517 + 0.9446 + 1.0098 + 0.0625 + 0.4322 = 2.1008 \text{ m}$$

Step 5

$$\frac{P_1}{\gamma} + z_1 + \frac{v_1^2}{2g} + h_A - \sum h_L = \frac{P_2}{\gamma} + z_2 + \frac{v_2^2}{2g}$$

$$h_A - 2.1008 \text{ m} = 1.10 \text{ m} + 1.0 \text{ m}$$

$$h_A = 4.2008 \text{ m}$$

Step 6

$$W_{\text{fluid}} = \gamma \cdot Q \cdot h_A$$

$$= 9780 \text{ N/m}^3 (0.017742 \text{ m}^3/\text{s}) (4.2008 \text{ m})$$

$$= 728.91 \text{ W} = 0.729 \text{ kW}$$

$$W_{\text{electrical}} = \frac{W_{\text{fluid}}}{\eta} = \frac{728.91 \text{ W}}{0.92} = 792.29 \text{ W} = 0.792 \text{ kW}$$

Summary

total required pump head for system is 4.2008 m to deliver a Q of 0.017742 m³/s. fluid power & electrical power of 0.792 kW.

Analysis

- 1) note keep velocities low keeps pressures safe. If operating temp, vapor or air bubbles can cause cavitation damage

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I understand that when asked to follow the Honor Code on exams or homework assignments I must follow the rules below.

1. When following the Honor Code a student must work entirely alone on exams.
2. When following the Honor Code a student may not share information about any aspect of the exam with other members of the class, other faculty members, or other people who has not already taken the exam this year, or its equivalent in future years.
3. When following the Honor Code a student must direct all questions concerning the exam or homework assignment to the course instructor or teaching assistant.
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6. When following the Honor Code a student cannot access, neither ask for help, from websites such as coursehero, chegg, and any other similar website, while taking the test.

I understand that failure to follow this Honor Code imply that the professor will immediately report my case for academic dishonesty to the ODU Office of Student Conduct & Academic Integrity.

Student Name: Kim Nguyen

Student Signature: 