Name: Dylan Arnold UID: 01166349

MET 330 Fluid Mechanics
Dr. Orlando Ayala
Summer 2023
Test 2

Take home – Due Sunday July 2nd 2023 before midnight.

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 eighty (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.

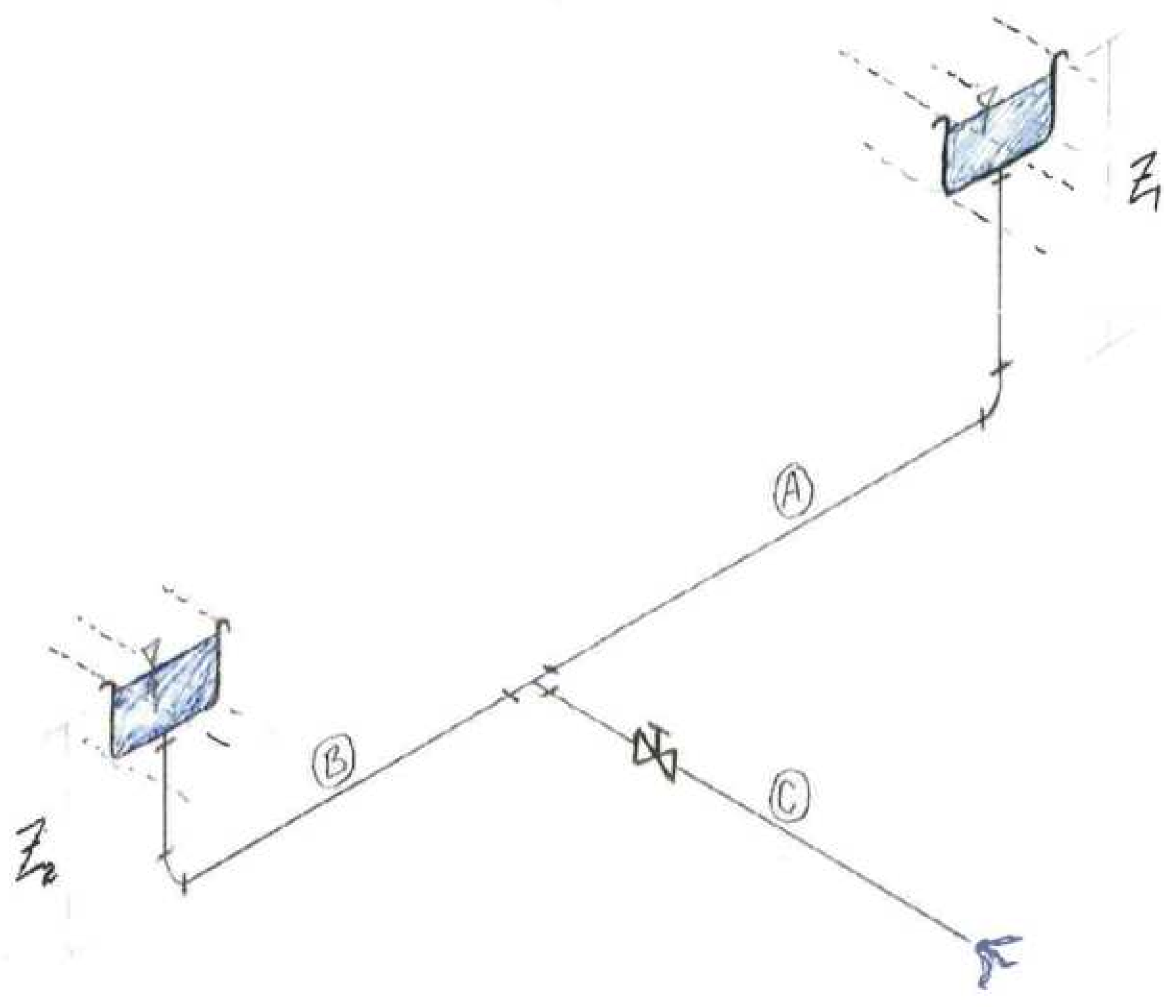
7. Do not start at the last minute so you can handle anything that could happen. Late tests will not be accepted. Test submitted through email will not be accepted either.

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).

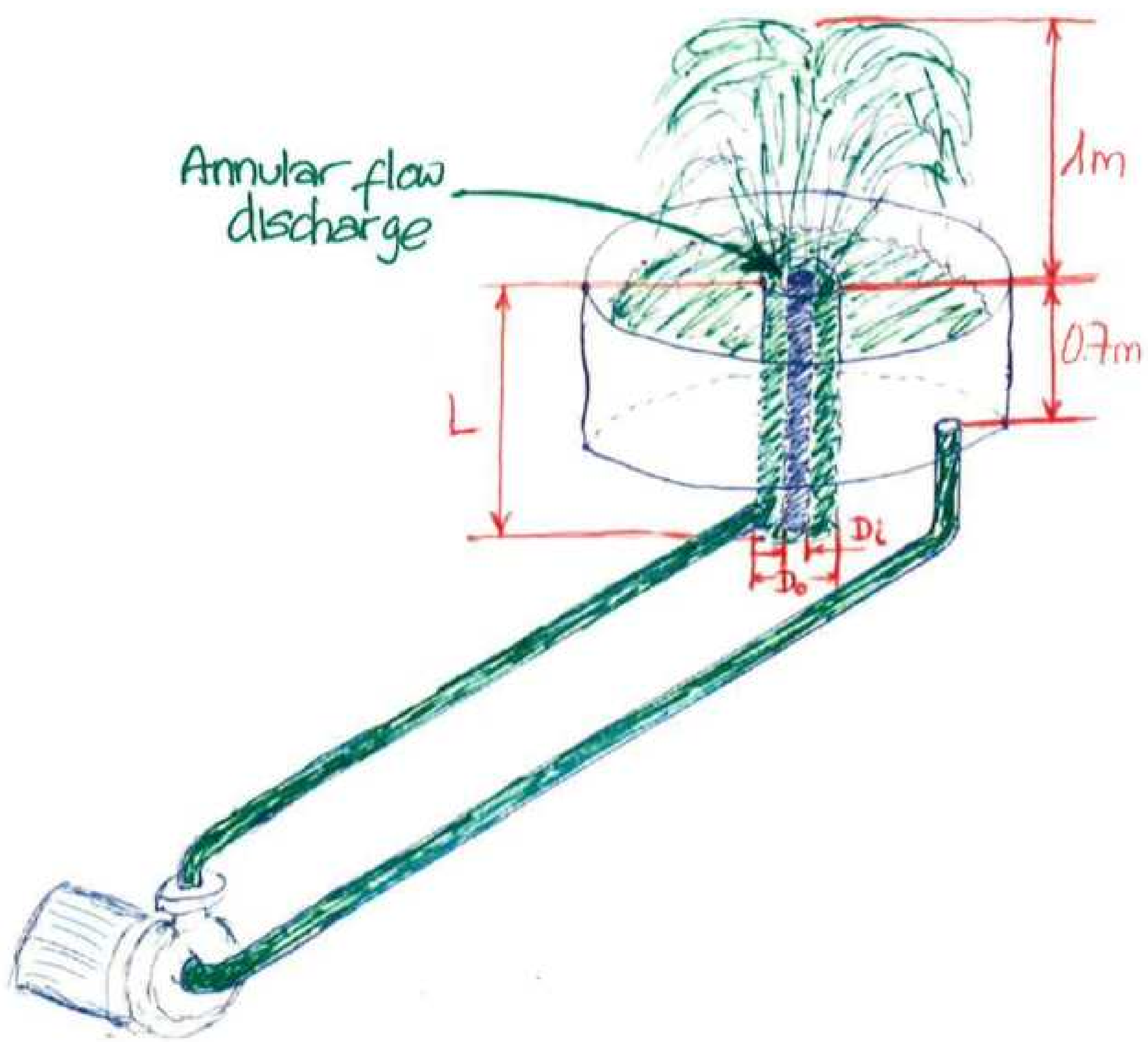
   With that said, you are NOT authorized to use any online source of any type, unless it is ODU related.

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 scketch, 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 ¾ 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 (Vmax = 3 m/s). Is it violated? If so, provide some suggestions to avoid it. Finally, compute the pressure at the exit of the tee.



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 scketch, no real dimensions were intended). You are asked to used 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=7cm (use hydraulic radius for the energy loss calculations of such annular flow passage. Check Chapter 9 and lecture notes). It is also made of PVC. 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.



HONOR CODE

I pledge to follow the Honor Code and to obey all rules for taking exams and performing homework assignments as specified by the course instructor.

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.

4. When following the Honor Code it is the student's responsibility to obtain clarification from the instructor if there are questions concerning the requirements of the Honor Code.

5. When following the Honor Code a student can only access websites related to ODU (such as Blackboard, etc.) while taking the test.

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.

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UID: 01166349

Student Signature: DyA

Date: 07/02/2023

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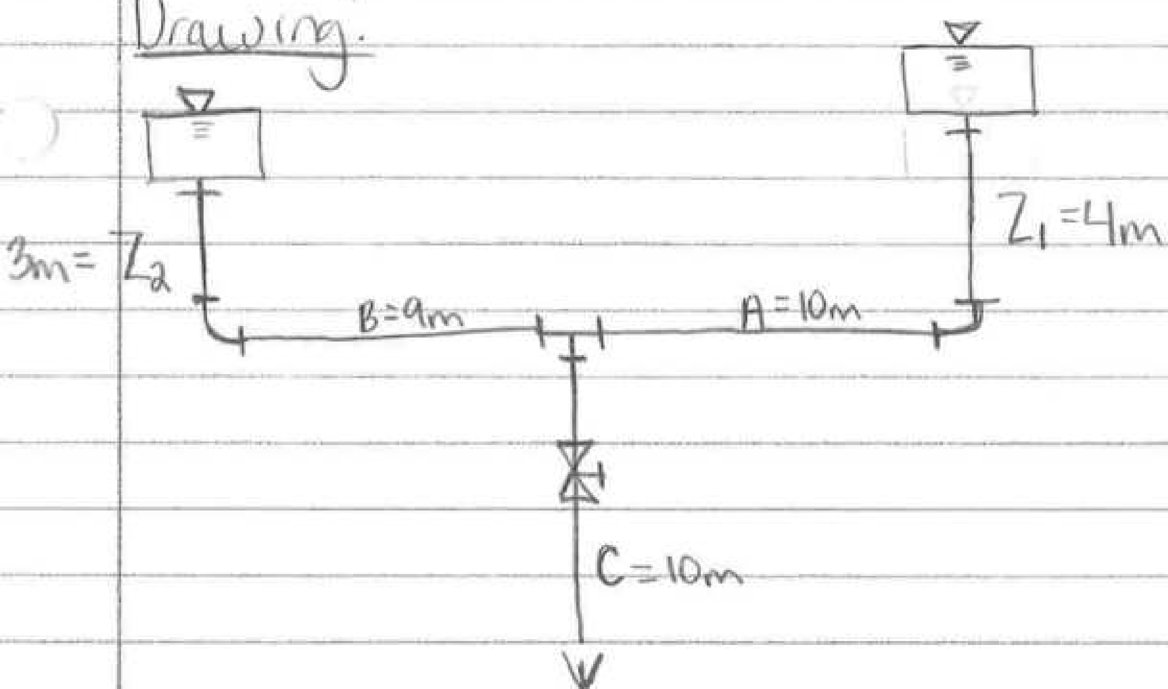
MET 330 Professor Ayala July 2nd, 2023

1. Purpose: To determine flow rate out of the system with gate valve 1/2 open, as well as to verify velocity criteria 3 m/s is not violated. Finally, to wrap up the problem, we are to compute pressure at the exit of the tee.

Drawing:



Sources: Mott + Untener. "Applied Fluid Mechanics" 7th Edition. Pearson Education. 2015

Design Considerations: Gate valve 1/2 open. Isothermal Process. Incompressible fluid (water).

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1 Cont'd: Data and Variables:

$L_A = 10m$ Commercial steel pipe ID = 3/4" 7/8" OD

$L_B = 9m$ ID (m) = 18.92mm or 0.01892m

$L_C = 10m$ $A = 2.812 \times 10^{-4} m^2$

$Z_1 = 4m$ $\varepsilon = 4.6 \times 10^{-5} m$ Table 8.2

$Z_2 = 3m$ $g = 9.81 m/s^2$

$V_{max} = 3 m/s$ $\gamma_{water} = 9.81 kN/m^3$

$Z_3 = 0m$ ν(kinematic) $= 1.15 \times 10^{-6} m^2/s$ (chose 15°C) Table A.1

f only function of relative roughness $f_T = 0.024$ Table 10.5

No neglecting minor losses $Q_C = Q_A + Q_B$

$K_{ENTRANCE} = 0.50$

$K_{elbow} = 30 f_T$

$K_{valve} = 160 f_T$

$K_{TEE} = 60 f_T$

Procedure: Use Bernoulli's equation to find unknowns. Will apply multiple times.
Guess and iterate a Q_C
Use calculated Q's to find velocity + verify against criteria.
Will compute pressure using found values.

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1 Cont'd: $\cancel{\frac{P_1}{\gamma}}^{0} + z_1 + \cancel{\frac{V_1^2}{2g}}^{0} = \cancel{\frac{P_2}{\gamma}}^{0} + \cancel{z_2}^{0} + \frac{V_2^2}{2g} + h_L \qquad z_1 = \frac{V_2^2}{2g} + h_L$

$h_m = \frac{8k}{g\pi^2 D^4} Q^2 \quad h_L = \frac{8fL}{g\pi^2 D^5} Q^2$

$\frac{V^2}{2g} = \frac{8}{g\pi^2 D^4} Q^2$

$h_{entrance} + h_{valve} + h_{tee} + h_{elbow} + h_{LA} + h_{LC}$

$z_1 = \frac{8Q_C^2}{g\pi^2 D_C^4} + f\frac{L_A}{D_A}\frac{8Q_A^2}{g\pi^2 D_A^4} + f\frac{L_C}{D_C}\frac{8Q_C^2}{g\pi^2 D_C^4} +$

$0.5\frac{8Q_A^2}{g\pi^2 D_A^4} + 160f\frac{8Q_C^2}{g\pi^2 D_C^4} + 60f\frac{8Q_C^2}{g\pi^2 D_C^4} +$

$30f\frac{8Q_A^2}{g\pi^2 D_A^4}$

$z_1 = \left(1 + f\frac{L_C}{D_C} + 160f + 60f\right)\frac{8Q_C^2}{g\pi^2 D_C^4} +$

$\left(f\frac{L_A}{D_A} + 0.5 + 30f\right)\frac{8Q_A^2}{g\pi^2 D_C^4}$

$4m = \left(1 + (0.024)\left(\frac{10m}{0.01892m}\right) + 160(0.024) + 60(0.024)\right)\frac{8Q_C^2}{(9.81)(\pi^2)(0.01892)^4}$

$+ \left((0.024)\left(\frac{10m}{0.01892m}\right) + 0.5 + 30(0.024)\right)\frac{8Q_A^2}{(9.81)(\pi^2)(0.01892)^4}$

$18.965\frac{8Q_C^2}{0.0000124} = 1.22 \times 10^7 Q_C^2$

$13.905\frac{8Q_A^2}{0.0000124} = 8.97 \times 10^6 Q_A^2$

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1 Cont'd: $4 = 1.22\times10^{7} Q_C^2 + 8.97\times10^{6} Q_A^2$

$$Z_2 = \frac{V_C^2}{2g} + h_L$$

$h_{ENTRANCE} + h_{valve} + h_{TEE} + h_{elbow} + h_{LB} + h_{LC}$

$$Z_2 = \frac{8Q_C^2}{g\pi^2 D_C^4} + 0.5\frac{8Q_B^2}{g\pi^2 D_B^4} + 160f\frac{8Q_C^2}{g\pi^2 D_C^4} + 30f\frac{8Q_B^2}{g\pi^2 D_B^4} + f\frac{L_B}{D_B}\frac{8Q_B^2}{g\pi^2 D_B^4} + f\frac{L_C}{D_C}\frac{8Q_C^2}{g\pi^2 D_C^4} + 60f\frac{8Q_C^2}{g\pi^2 D_C^4}$$

$$Z_2 = \left(1 + 160f + f\frac{L_C}{D_C} + 60f\right)\frac{8Q_C^2}{g\pi^2 D_C^4} + \left(0.5 + 30f + f\frac{L_B}{D_B}\right)\frac{8Q_B^2}{g\pi^2 D_B^4}$$

$$3m = \left(1 + 160(0.024) + (0.024)\left(\frac{10m}{0.01992}\right) + 60(0.024)\right)\frac{8Q_C^2}{(9.81)(\pi^2)(0.01992)^4} + \left((0.5 + 30(0.024) + (0.024)\left(\frac{9m}{0.01992}\right)\right)\frac{8Q_B^2}{(9.81)(\pi^2)(0.01992)^4}$$

$$18.965\frac{8Q_C^2}{0.0000124} = 1.22\times10^{7} Q_C^2$$

$$12.636\frac{8Q_B^2}{0.0000124} = 8.15\times10^{6} Q_B^2$$

$$3 = 1.22\times10^{7} Q_C^2 + 8.15\times10^{6} Q_B^2$$

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1 Cont'd: $4 = 1.22\times10^{7} Q_C^2 + 8.97\times10^{6} Q_A^2$ (1)

$3 = 1.22\times10^{7} Q_C^2 + 8.15\times10^{6} Q_B^2$ (2)

$$Q_A = \sqrt{\frac{4 - 1.22\times10^{7} Q_C^2}{8.97\times10^{6}}} \quad (1)$$

$$Q_B = \sqrt{\frac{3 - 1.22\times10^{7} Q_C^2}{8.15\times10^{6}}} \quad (2)$$

$Q_C = Q_A + Q_B$ or $Q_A = Q_C - Q_B$ or $Q_B = Q_C - Q_A$

$$Q_C = \sqrt{\frac{4 - 8.97\times10^{6} Q_A^2}{1.22\times10^{7}}} \quad (1)$$

$$Q_C = \sqrt{\frac{3 - 8.15\times10^{6} Q_B^2}{1.22\times10^{7}}} \quad (2)$$

Start iteration

Q_C guesses = $0.75\times10^{-3}\ m^3/s$, $0.5\times10^{-3}\ m^3/s$, $0.25\times10^{-3}\ m^3/s$
and in between 0.5 + 0.25

Final $Q_C = 0.0004845\ m^3/s$

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1 Cont'd: Q_C guess = 0.00075 m^3/s

$Q_A = \sqrt{\frac{4 - 1.22\times10^7(0.00075)^2}{8.97\times10^6}}$ $Q_B = \sqrt{\frac{3 - 1.22\times10^7(0.00075)^2}{8.15\times10^6}}$

NUM! error NUM! error

Q_C guess = 0.00025 m^3/s

Q_A = 0.0006 Q_B = 0.0005

$Q_A + Q_B$ = 0.0011 X

Q_C guess = 0.0004845 m^3/s

Q_A = 0.000356 m^3/s Q_B = 0.000129 m^3/s

$Q_A + Q_B$ = 0.000485 m^3/s ✓

Q_A = 0.000356 m^3/s · 60000 L/min = 21.36 L/min

Q_B = 0.000129 m^3/s · 60000 L/min = 7.74 L/min

$\boxed{Q_C = 0.000485 m^3/s \cdot 60000 \text{ L/min} = 29.1 \text{ L/min}}$

$V = \frac{Q}{A}$ $V_1 = \frac{0.000356}{2.812\times10^{-4}} = 1.27$ m/s

$V_2 = \frac{0.000129}{2.812\times10^{-4}} = 0.46$ m/s

$V_3 = \frac{0.000485}{2.812\times10^{-4}} = \boxed{1.72 \text{ m/s} < 3 \text{ m/s GOOD}}$

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1 Cont'd: Compute Pressure:

$$\frac{\cancel{P_A}}{\cancel{\gamma}}^{0} + \frac{\cancel{V_A^2}}{\cancel{2g}}^{0} + Z_1 = \frac{P_C}{\gamma} + \frac{V_C^2}{2g} + \cancel{Z}^{0 \text{ ground}} + h_{LA}$$

Find P_C $\quad Z_1 = \frac{P_C}{\gamma} + \frac{V_C^2}{2g} + h_{LA}$

$$\left(Z_1 - h_{LA} - \frac{V_C^2}{2g}\right)\gamma = P_C$$

$$\left(4m - 8.97 \times 10^6 Q_A^2 - \frac{1.72^2}{2(9.81)}\right)(9.81) = P_C$$

$$\left(4m - (8.97 \times 10^6)(0.000356)^2 - \frac{1.72^2}{2(9.81)}\right)(9.81) = P_C$$

$$\boxed{P_C = 26.61 \text{ kPa}}$$

Summary: The flow rate for the gutter system is 29.44/min and meets the velocity criteria <3 m/s. The exiting pressure at the tee is 26.61 kPa.

Materials: Commercial steel pipes, water (rain)

Analysis: Value should be moved. Possible gate value could be 1/4 open since we have wiggle room with velocity criteria.

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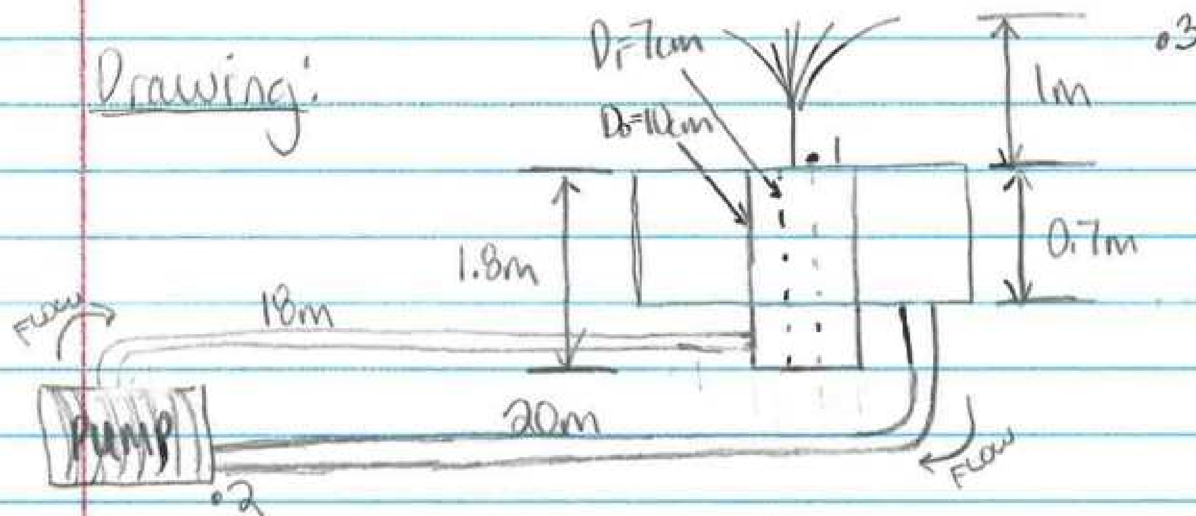
2. Purpose: To find the hydraulic radius to use in the energy loss calculations to find the required pump electrical power to spray fountain water 1m above surface.

Drawing:



Sources: Mott & Untener. "Applied Fluid Mechanics" 7th Edition. 2015. Pearson Education.

Design Considerations: Isothermal Process. Incompressible fluid (water). Fountain must be 1m higher than surface. Pump efficiency is 92%. V_{max}= 3 m/s.

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2 (cont'd) Data and Variables:

Outlet $L = 18m$ Pipe = PVC $K_{elbow} = 30f_t$ $K_L = {}^{L}/_{D}$

Inlet $L = 20m$ $D_0 = 10cm = 0.1m$ $K_{ent} = 0.5$

$K_{exp} = 2$ $D_1 = 7cm = 0.07m$ f_t = ? dependent on pipe size

$L = 1.8m$ (annular flow passage) $\gamma_{water} = 9.81\ kN/m^3$

$L_{tank} = 0.7m$ $h_L = \frac{fLv^2}{D2g}$ $T = 15°C$ $g = 9.81\ m/s^2$

$L_{pump} = 1m$ Total $L = 2.8m$ $\nu_{kinematic} = 1.15 \times 10^{-6}$

$\varepsilon = 3.0 \times 10^{-7}$ Table 8.2 C_h = Design value = 130

$v = 8.85\, C_h R^{0.63} S^{0.54}$ $S = h_L / L$ $Q = Av$

$Q = 0.85\, A C_h R^{0.63} S^{0.54}$ $N_R = \frac{vD}{\nu}$ $D = \sqrt{\frac{\pi v}{4Q}}$

$h_{L\,annular} = L\left(\frac{Q}{1.85 A C_h R^{0.63}}\right)^{1.852}$ $v_2 = \sqrt{2gh}$ $V = \frac{4Q}{\pi D^2}$

$P_A = h_A W$ $W = \gamma Q$

$A = \frac{\pi D^2}{4}$ $P_A = h_A \gamma Q$ $P_A = e_m P_I$

$R = \frac{A}{WP} = \frac{\pi(D^2 - d^2)}{4\pi(D+d)} = \frac{(D_0^2 - D_1^2)}{4(D_0 + D_1)}$ $e_m = \frac{P_A}{P_I} = 0.92$

Procedure: Find velocity using bernoullis equation. Use velocity to find flow rate. Find hydraulic radius formula to use in losses equation. Use losses equation in pump power equation. Verify velocity against criteria to choose PVC pipe sizing.

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$$\frac{P_1}{\gamma} + \frac{V_1^2}{2g} + z_1 = \frac{P_2}{\gamma} + \frac{V_2^2}{2g} + z_2 + h_L$$

$$\cancel{\frac{P_2}{\gamma}}^{\to 0} + \cancel{\frac{V_2^2}{2g}}^{\to 0} + z_2 = \cancel{\frac{P_3}{\gamma}}^{\to 0} + \frac{V_3^2}{2g} + z_3 + \cancel{h_L}$$ negligible per instructions

$$h = z_3 - z_2$$

$$z_2 = \frac{V_3^2}{2g} + z_3 = \text{same as} = V_3 = \sqrt{2gh}$$

$$V_3 = \sqrt{2 \cdot 9.81\,m/s^2 \cdot (2.8m - 0.0m)} = 7.41\,m/s$$

$$Q = AV = \frac{\pi(D_o^2 - D_i^2)V}{4} = \frac{\pi((0.1m)^2 - (0.07m)^2)(7.41)}{4}$$

$$Q = 0.0296\,m^3/s$$

$$R = \frac{A}{WP} = \frac{(D_o^2 - D_i^2)}{4(D_o + D_i)} = \frac{0.1^2 - 0.07^2}{4(0.1 + 0.07)} = 0.0075$$

$$h_L = f\frac{L}{4R}\frac{v^2}{2g}$$

$$N_R = \frac{v(4R)}{\nu} \text{ or } \frac{v(4R)(\rho)}{\eta}$$

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

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Find H_L for <u>all</u> minor losses in system.

$$h_L = \frac{V_3^2}{2g} + h_{L\,annular} + h_{L\,exp} + h_{L\,ent} + h_{L\,inlet} + h_{L\,outlet} + h_{L\,elbow} + h_{L\,elbow}$$

$$= \frac{V_3^2}{2g} + L\left(\frac{Q}{1.85(A)(C_h)(R^{0.63})}\right)^{1.852} + 2\frac{V^2}{2g} + 0.5\frac{V^2}{2g} + f\frac{L_{in}}{D_{in}}\frac{V^2}{2g} + f\frac{L_{out}}{D_{out}}\frac{V^2}{2g} + 30f\frac{V^2}{2g} + 30\frac{V^2}{2g}$$

must find D based on max $V = 3\,m/s$

$$D = \sqrt{\frac{4Q}{\pi V}} = \sqrt{\frac{4(0.0296)}{\pi(3)}} = 0.11m = 110mm$$

Table 6.3

OD = 125mm ID = 110.2mm 16bar = 1600 kPa
$A = 9.538 \times 10^{-3}$ .1102m

Find new V with D value

$$V = \frac{4Q}{\pi D^2} = \frac{4(0.0296)}{\pi(0.1102m)^2} = 3.10\,m/s \text{ exceeds}$$

Choose new D = OD = 125mm ID = 115.4mm 10bar = 1000kPa
$A = 1.046 \times 10^{-2}$ .1154m

$$V = \frac{4(0.0296)}{\pi(0.1154)^2} = 2.83\,m/s$$ ✓ meets criteria

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$$N_R = \frac{v(4R)(\rho)}{n} \quad n = 1.15\times10^{-3}$$

$$= \frac{(2.83)(4)(0.0075)(1000)}{1.15\times10^{-3}} = 73826$$

$$D/\epsilon = 4R/\epsilon = 4(0.0075)/3.0\times10^{-7} = 100000$$

$$f = \frac{0.25}{\left[\log\left(\frac{1}{3.7(100000)} + \frac{5.74}{73826^{0.9}}\right)\right]^2}$$

$$f = \frac{0.25}{13.087} = 0.019$$

$$h_{L\,all} = \frac{v_3^2}{2g} + L\left(\frac{Q}{1.85(A)(C_h)(R^{0.63})}\right)^{1.852} + 2\frac{v^2}{2g} + 0.5\frac{v^2}{2g}$$

$$+ 0.019\left(\frac{L_{out}}{D_{out}}\right)\frac{v^2}{2g} + 0.019\left(\frac{L_{in}}{D_{in}}\right)\frac{v^2}{2g} + 30(0.019)\frac{v^2}{2g} + 30(0.019)\frac{v^2}{2g}$$

$$= \frac{7.41^2}{2\cdot9.81} + 1.8\left(\frac{0.0296}{1.85(1.046\times10^{-2})(130)(0.0075)^{0.63}}\right)^{1.852} + 2\frac{2.83^2}{2\cdot9.81} +$$

$$0.5\frac{2.83^2}{2\cdot9.81} + 0.019\left(\frac{18}{.1154}\right)\frac{2.83^2}{2g} + 0.019\left(\frac{20}{.1154}\right)\frac{2.83^2}{2g} +$$

$$0.57\frac{2.83^2}{2\cdot9.81} + 0.57\frac{2.83^2}{2g}$$

$$= 2.80 + 0.145 + 0.816 + 0.204 + 1.21 + 1.34$$

$$+ 0.23 + 0.23 = 6.975\text{m}$$

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$P_A = h_A \gamma Q = (6.975)(9.81)(0.0296)$

$P_a = 2.02\,kW$

$P_I = \frac{P_A}{e_m} = \frac{2.02\,kW}{0.92} = \boxed{2.196\,kW}$

Summary:
Electrical power at pump required = 2.196 kW
Pipe chosen = OD 125 mm ID 115.4 mm meets the V_{max} spec of 3 m/s. Hydraulic radius at annular passage = 0.0075.

Materials: OD 125 mm ID 115.4 mm PVC
Water @ 15°C

Analysis: V is close to the threshold, so if need be, pipe can be increased ID 118.8 (2.67 m/s), or even go up to OD 160 mm. 2.2 kW pumps are a thing! Makes me feel better about my calculations.