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MET 330 Fluid Mechanics
Dr. Orlando Ayala
Spring 2019
Test 1

Take home – Due Monday March 11th 2019 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, and ten (10) other points are based on the basis of technical writing. The other eighty (80) points will come from the problem solutions. For the technical writing I will follow the attached rubric.
3. There is 1 problem with 9 different parts. Each part will be worth (80/9) 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 BLACKBOARD. You must submit only one file and it has to be a pdf file. For the ePortfolio (which is optional) you are supposed to upload this artifact to your Google drive. I will provide more instructions later.
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:

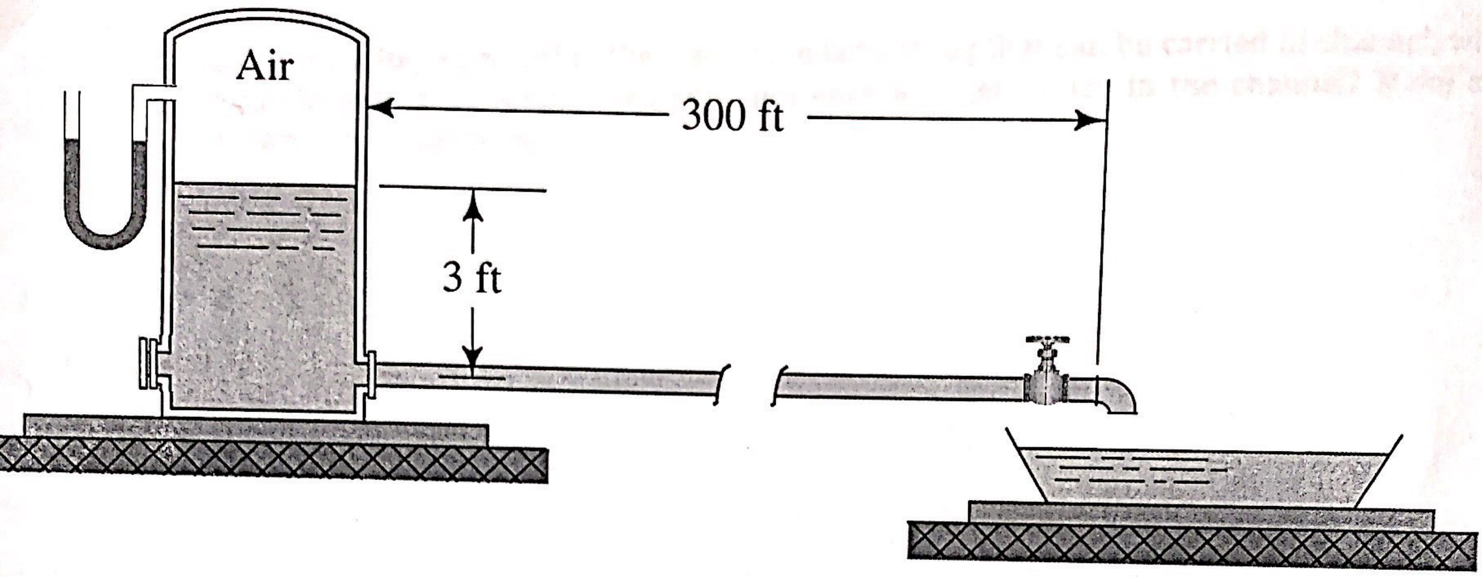
IX. PROHIBITED CONDUCT

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 is ODU related.

1. You are hired to design a system to deliver 60 °F water at a rate of 75 gpm from a pressurized storage tank to a trapezoidal open channel through 300 ft of 1 ½ in Schedule 40 steel pipe as shown in the figure. The purpose of the open channel is to carry hickory wood logs downstream. Please note that the U-tube manometer on the left is a schematic representation only.



a. Determine the air pressure required above the water in the tank to make this happens. Neglect the energy losses due to the valve and the elbow (aka, minor losses) but consider the energy losses due to the straight pipe.

b. What is the water depth (y) in the open channel? The angle of the lateral walls is 60°. The width at the top of the water (T) is T=2.309y (see table 14.3 in the book). The channel slope is 0.1 percent and is made of unfinished concrete.

c. The pipe needs to be supported. Your civil engineer colleague requires to know the relevant forces for the support design. Calculate the total horizontal and vertical forces in the whole system pipe-elbow.

d. Compute the force acting upon the blind flange at the left-hand-side of the tank. The diameter of the blind flange corresponds to a 1 ½ in Schedule 40 steel pipe. What is the force location?

e. What is the largest hickory wood log the open channel can carry? The log has a square cross section. The density of hickory wood is 830 kg/m³. Is it stable?

f. To monitor the air pressure, your client proposes to use a U-tube manometer (as shown in the figure). If using mercury, what should be the minimum dimension of the U-tube measured from the connection to the tank to the lowest point of the U-tube so it works properly.

g. Your client also proposes to use a flow nozzle to measure the flow. For a nozzle diameter to pipe diameter ratio of 0.5, what is the pressure drop across the nozzle?

h. If the valve in the pipe closest suddenly, what is the pressure increment after the sudden closing? The modulus of elasticity of steel is 200 GPa. Is there any change of cavitation in your system?

i. Assuming a log with half of the size of the largest log that can be carried in channel, what is the largest drag force it would experience if it gets stuck in the channel? Make any reasonable assumption.

MET 330 FLUID MECHANICS

JEAN GONZALES

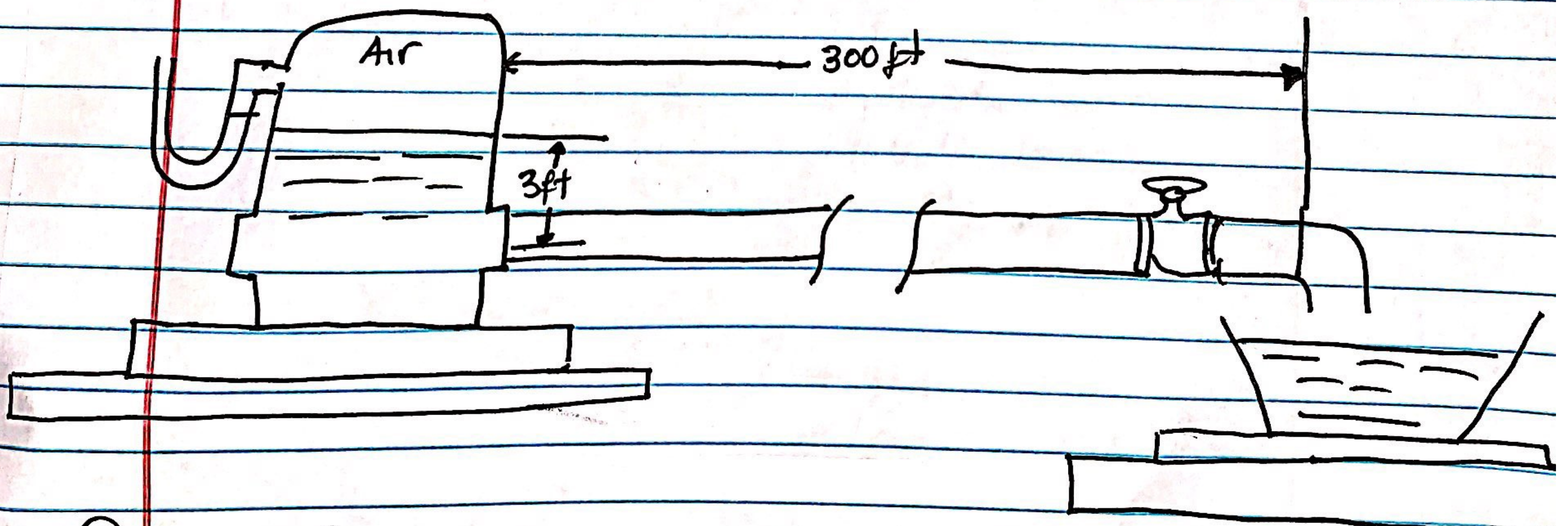
SPRING 2012

TEST 1

① PURPOSE

TO DETERMINE AIR PRESSURED REQUIRED, WATER DEPTH (y) in the open channel, calculate the total horizontal and vertical forces, force location, force acting upon the blind flange, largest hickory wood log the open channel can carry and its stability, minimum dimension of the U-tube, pressure drop across the nozzle, cavitation in the system, and drag force it would experience if it gets stuck.

② DRAWINGS & DIAGRAMS



③ SOURCES

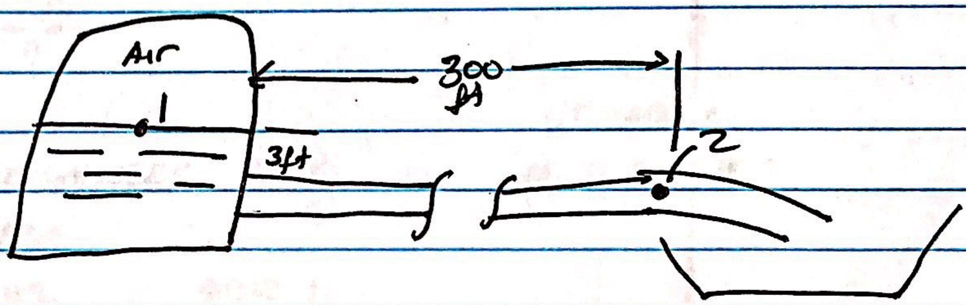
APPLIED FLUID MECHANICS 7th EDITION
ROBERT L. MOTT & JOSEPH UNTENER
PEARSON EDUCATION
978-0-13-255892-1

④ DESIGN CONSIDERATION

- INCOMPRESSIBLE FLUIDS
- SET TEMPRERATURE
- ~~[illegible]~~ PROPERTIES CONSTANT
- FLOW OF THE WATER
- MATERIAL USED.

⑤ DATA AND VARIABLES

Temperature = 60° F
water at a rate = 75 gallons per minute
OPEN CHANNEL 300 ft of $1\frac{1}{2}$ in SCHEDULE 40 steel pipe
HEIGHT = 3 ft
Length = 300 ft
1 gallon = 0.134 ft^3



⑥ PROCEDURES

a.) IN ORDER TO CALCULATE AIR PRESSURE ABOVE WATER START BY USING BERNOULLI'S EQUATION

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

γ = Specific weight of water
v_2 = velocity at point 2
v_1 = velocity at point 1
p_2 = pressure point 2
z_1 = elevation point 1
z_2 = elevation point 2
g = gravity acceleration
h_L = energy loss
A = cross section area
Q = volume flow rate

AT POINT 1 = Ø velocity
AT POINT 2 = Ø velocity

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

SOLVE velocity flow = $v = \frac{Q}{A}$

FROM TABLE $1\frac{1}{2}$ in steel pipe = 0.1342 ft
area flow = 0.01414 ft^2

a.) cont...

$$\frac{1\ gal}{min} = \frac{1}{449}\ \frac{ft^3}{s}$$

$$v = \frac{Q}{A} = \frac{\left(\frac{75}{449}\right)}{0.01414}$$

$v = 11.81\ ft/s$

NOW USE REYNOLD NUMBER $N_R = \frac{VD}{V}$

$60°F = 1.21 \times 10^{-5}\ ft^2/s$

$$N_R = \frac{11.81 \times 0.1342}{1.21 \times 10^{-5}}$$

$N_R = 1.31 \times 10^5$

$L = 300\ ft$

$D = 0.1342$

NEXT FIND RELATIVE ROUGHNESS $= \frac{D}{\varepsilon}$

$\varepsilon = 1.5 \times 10^{-4}\ ft$ FROM TABLE

$$\frac{0.1342}{1.5\times10^{-4}} = \frac{0.1342}{1.5\times10^{-4}} = 894.6$$

FINDING THE RELATIVE ROUGHNESS WE CAN FIND THE ENERGY LOSS h_L using the equation $h_L = f \times \frac{L}{D} \times \frac{V^2}{2g}$

$$h_L = f \times \frac{L}{D} \times \frac{v^2}{2g} = 0.021 \times \frac{300}{0.1342} \times \frac{11.81^2}{2 \times 32.18}$$

$h_L = \frac{878.7}{8.6}$ $h_L = 102.17\ ft$

Now, we can find the pressure using the equation after rewriting Bernoullis

$$P_1 = \gamma\left[h_L + (z_2 - z_1) + \frac{v_2^2}{2g}\right]$$

$$P_1 = 62.2\left[102.17 + 3 + \frac{11.81^2}{2 \times 32.18}\right]$$

$$P_1 = 62.2\left[102.70 + 3 + 2.17\right]$$

$P_1 = 6709.51\ lb/ft^2 \times \frac{1\ lb/in^2}{144\ lb/ft^2}$

$P_1 = 46.59\ psi$

$P_1 = 46.59\ psi$

air pressure

b.) ANGLE LATERAL WALLS = 60°

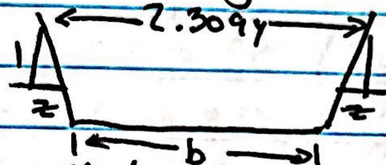
WIDTH TOP OF WATER T = 2.309y

channel slope = 0.1 percent

Equation for trapezoid

~~$y_h = \frac{A}{T} = \frac{0.01414}{2.309y}$~~

~~$h = f \frac{L}{D} * \frac{v^2}{2g}$~~



A = 0.01414

~~Perimeter~~ $= b + 2y\sqrt{1+z^2}$

$$R = \frac{A}{wP}$$

A = Area

wP = wetted perimeter

unfinished concrete = 0.017
Manning n

channel slope = 0.1%

which is supercritical because critical point Fr = 1.0

$$R = \left(\frac{1.49}{n}\right) AR^{2/3}$$

$$Q = KS^{1/2}$$

$$\frac{1.73}{2} y \frac{4}{3} \times .0316$$

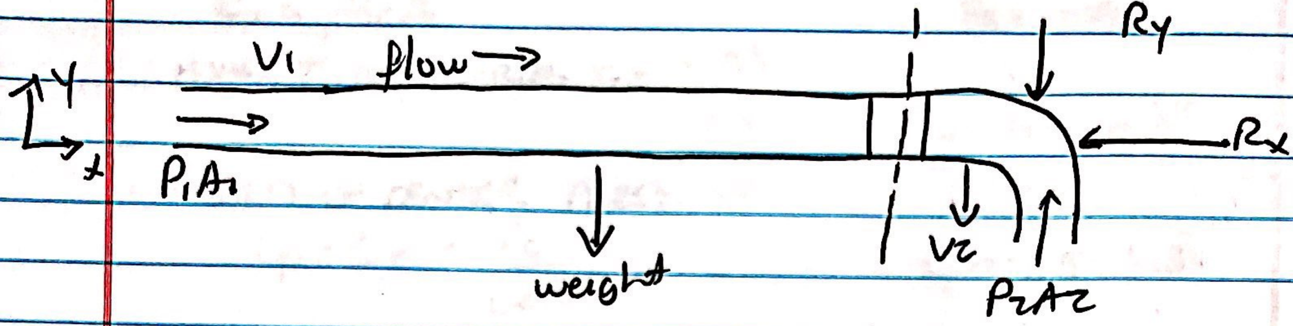
$$.0273 y^{\frac{4}{3}} = .17$$

$$y = \sqrt[3]{(6.118)^4}$$

y = 11.19 ft

c) Calculate total horizontal and vertical forces in pipe elbow system.

Start by drawing forces



[illegible] Fx

$$P_1A_1 - R_x = \rho Q\,(\overset{0}{\cancel{V_{2x}}} - V_{1x})$$

$$R_x = P_1A_1 - \rho Q\left(-\frac{Q}{A_1}\right)$$

$$R_x = P_1A_1 + \rho\,\frac{Q^2}{A_1}$$

$R_x =$ [illegible]

$$R_x = (6709.51\ lb/ft^2)(0.01414) + (1.94) * \frac{(.167)^2}{0.01414}$$

$$\boxed{R_x = 98.69\ lb}$$

Fy $\quad w = mg =$ [illegible] $\dfrac{\rho g}{A\cdot l}$

$$\overset{0}{\cancel{P_2A_2}} - R_y - w = \rho Q\,(-V_{2y} - \overset{0}{\cancel{V_{1y}}})$$

$$-R_y - \frac{\rho g}{A_1 l} = \rho Q\left(-\frac{Q}{A_2}\right)$$

$$R_y = -\frac{\rho g}{A_1 l} + \rho\,\frac{Q^2}{A_2}$$

$$R_y = -\frac{(1.94)(32.18)}{(0.01414)(300)} + (1.94)\,\frac{(0.167)^2}{(0.01414)}$$

$$\boxed{R_y = -18.36\ lb}$$

d) DIAMETER corresponds to $1\frac{1}{2}$ in Schedule 40 steel pipe

$D = 0.1342$

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$F_R = \gamma h_c A$ $\qquad\qquad$ $F_R = ma$

MOMENT OF INERTIA $I_c = \frac{\pi D^4}{64}$ $\qquad$ ~~$\frac{\pi (0.1342)^4}{64}$~~ $\qquad$ $\frac{\pi (D^4 - d^4)}{64}$

LOCATION OF CENTER PRESSURE

$L_p = L_c + \frac{I_c}{L_c A}$ $\qquad$ ~~$I_c = 1.59 \times 10^{-5}$~~

$h = 3\,ft$ $\qquad$ $D = 0.1342$ $1\frac{1}{2}$ schedule 40 steel pipe

Density of water $= \rho_w = 1000\ kg/m^3$ or $28.3\ kg/ft^3$

density of hickory wood $= 830\ kg/m^3$ (question e)

~~water density~~ $\qquad$ ~~g~~ $\qquad$ ~~area~~ $\qquad$ ~~height~~

~~Pressure force~~

Force blind flange ~~F_{BF} = 28.32 × 3.3 × ... × 3~~

~~F_{BF} = 33.6 kg ft/s²~~

$L_p = F_b l$

$33.6 = L_c + \frac{I_c}{L_c A}$

$L_p = 3 + \frac{1.59 \times 10^{-5}}{3 \times .01414} = 3.0004\ ft$

$F_R = \gamma h_c A$

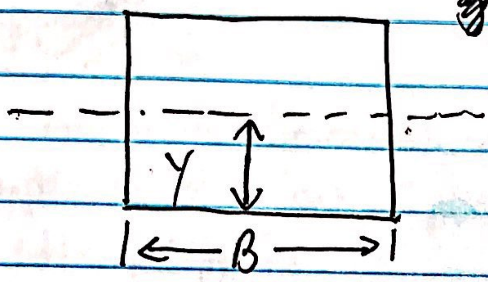
$FR = 11.19 \times 3 \times 0.01414$

$FR = .4746$

$FR = 47.46\ lb$

e) L = length of log
weight of wood = buoyant force
density of wood = 830 kg/m^3
density of water = 1000 kg/m^3 or 28.3 kg/ft^3
So if wood was place in the open channel
cross section = $B \times B$

Picture



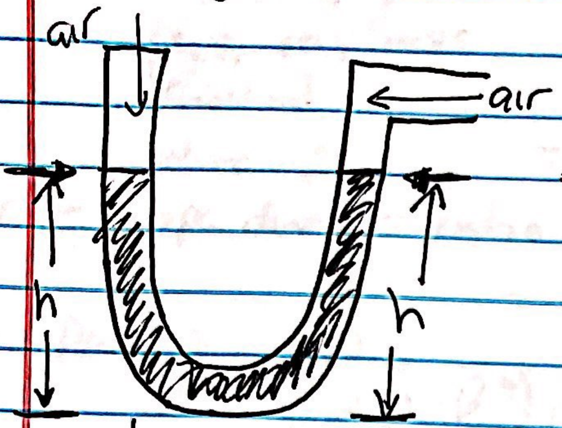
square cross section

$$\frac{\text{density of wood}}{\text{density of water}}$$

$$\frac{830}{1000} = .83 = y$$

yes it is stable
because no matter the size of the wood the density of water will always be greater.

f.) we know the sg of mercury = 13.54
we gotta think about air at atmospheric pressure



sg mercury = 13.54
specific weight γ = 847 or 133.7
(lb/ft³) (kN/m³)

* Find the minimum dimension of the U-tube from the tank to the lowest point U-tube for it to work properly.

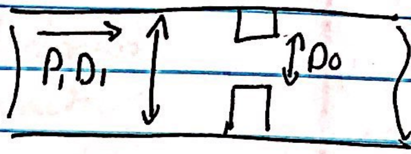
Since it is equal and expose to atmosphere which equals to same pressure

$P_d = \gamma h$ $\gamma = 13.54$
h = liquid height

P_d = pressure
$P_d = P_1$
$= 46.59$ psi
or 6709.51 lb/ft²

$6709.51 = 847h$
$h = \frac{6709.51}{847}$
$h = 7.92$ ft

g.) we know diameter $D = 0.1342$ ft $= 1.61$ inches
length of pipe $L = 300$ ft
pipe roughness $\varepsilon = 894.6$ $Q = .1670$
flow at $60°F$ $A = 0.01414$
volume flow 75 gpm $Y = 11.19$
nozzle – pipe diameter ratio 0.5 $= Dr$



Pressure drop

$$\Delta P = \frac{1}{2}\rho(1-\beta^4)\left(\frac{Q}{Dr\,A_0\,Y}\right)^2$$

$$\beta = \frac{D_0}{D_1}$$

$$\Delta P = \frac{1}{2}(1000)(1-2.72^4)\left(\frac{.1670}{.5 \times 0.01414 \times 11.19}\right)^2$$

$0.5 - .1342 = .3658 = D_0$

$$\beta = \frac{.3658}{0.1342}$$

$\beta = 2.72$

$\Delta P = -75.04$ psi

pressure drop

h.) Find change of cavitation in the system

$E_{steel} = 200\ GPa = 4.18 \times 10^9$
E_0 water $= 316000$ psi

$$C = \frac{\sqrt{E_0/\rho}}{\sqrt{1 + \frac{E_0 D}{E\delta}}}$$

E_0 = bulk modulus (N/m^2)
ρ = fluid density
D = pipe diameter
E = elastic modulus of pipe material $(\frac{N}{m^2})$

$$C = \frac{\sqrt{\frac{316{,}000}{62.42}}}{\sqrt{1 + \frac{316000 \times .1342}{4.18 \times 10^9 \times .12}}}$$

$E_0 = 316{,}000$
$\rho = 62.42$
$D = .1342$
$E = 4.18 \times 10^9$
$\delta = .012$

$Q = .1670$
$A = 0.01414$

$C = 71.148$

[Water hammer → HIGH PRESSURE
CAVITATION → LOW PRESSURE] — lecture notes

$Q = vA$
$.1670 = v\left(\frac{\pi \cdot .1342^2}{4}\right)$
$v = 11.81$ ft/s

Δp = density × cavity × velocity
$\Delta p = 62.42 \times 71.148 \times 11.81$ ft/s
$\Delta p = 52{,}448.89 = 364.09$ psi

364.09 psi .25638 psi

THERE COULD BE CAVITATION CHANCE

i.) I would assume it would have a negative buoyancy and it would not be stable.

$R_x = 98.69\ lb$ Moment of inertia $I_c = 1.59 \times 10^{-5}$

$R_y = 78.36\ lb$

$F_R = 47.46\ lb$

However we don't have the dimension

~~$L_p = 3 + \frac{1.59 \times 10^{-5}}{3 \times .01414}$~~

$$L_p = 3 + \frac{1.59 \times 10^{-5}}{3 \times .01414}$$

$$L_p = 3.0004\ ft$$

Summary

IN SUMMARY THE DESIGN WAS A FAIRLY SIMPLE DESIGN FROM A TANK TO PIPE TO AN OPEN CHANNEL. HOWEVER THE 9 PROBLEMS HELPED ALL OF THE THINGS THAT IS REQUIRED WHEN DESIGNING ANYTHING LIKE THIS. WE WOULD CONSIDER EVERY OPTIONS OUT THERE AND TO THINK FROM THE LENGTH, SIZE, AND FLOW OF THE FLUIDS AND MORE. IN OVERALL THIS WAS A PRETTY STRAIGHTFORWARD PROBLEM THAT REQUIRED A LOT OF THINKING.

MATERIALS

- U tube MANOMETER
- LOGS
- PIPES, ELBOWS
- TANK
- WATER
- NOZZLE

ANALYSIS

ANALYSZING THE DATA GIVEN WE WOULD CONSIDER SUPPORT OF THE PIPES, SINCE WE WERE ABLE TO CALCULATE THE FORCES IN EACH DIRECTION, AIR PRESSURE, FORCE ACTING ON THE FLANGE. ~~[illegible]~~ ~~[illegible]~~ ~~A~~ MORE INFORMATION WOULD REQUIRED IF PLACING DIFFERENT SIZE LOGS INTO A CHANNEL OPEN. HOWEVER, CALCULATING THE WATER DEPTH REALLY HELPED. WE WOULD NEED DIMENSIONS OF THE TRAPEZOID, HEIGHT OF THE TANK. AND IF THERE IS ANY HEIGHT FROM THE ELBOW TO THE CHANNEL.

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