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MET 350

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October 29, 2021

Exam 2

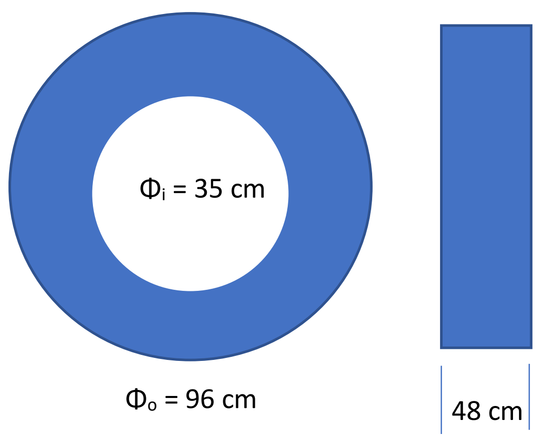
A.

Purpose:

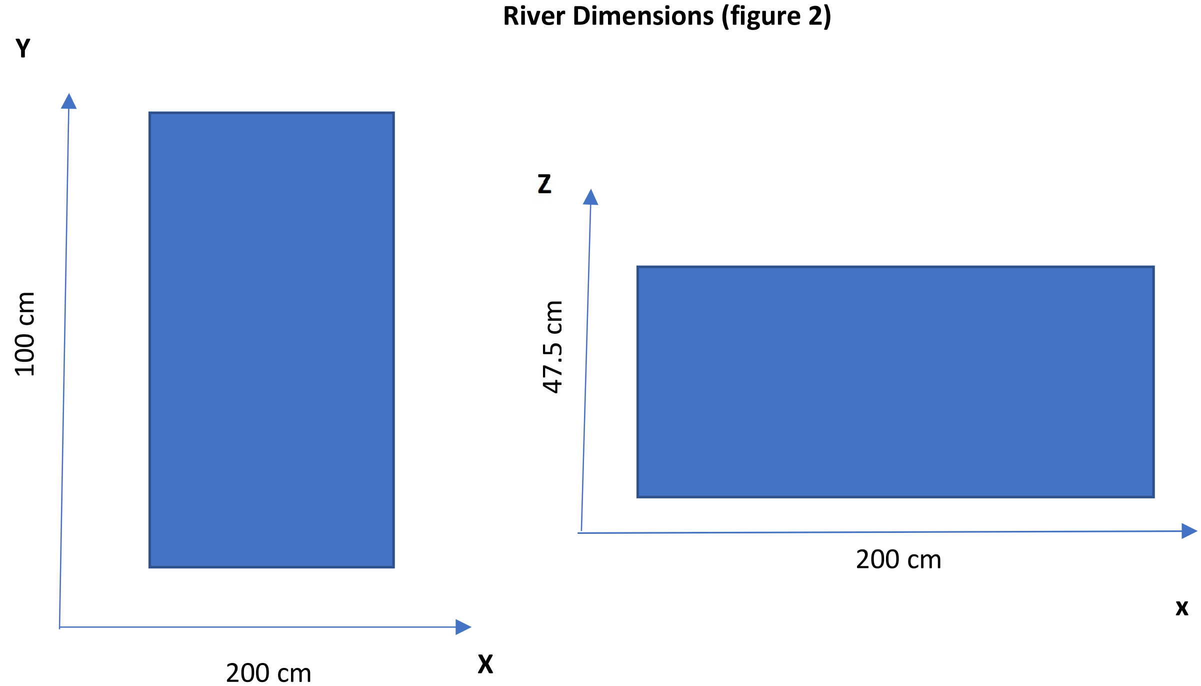
Determine 1) the flow rate of water required to operate a lazy river. Determine 2) the drag force a 5-year-old would experience while floating down the lazy river. Determine 3) how deep a 250 lb person would sink in the water while in a tube and if they would be stable. Determine 4) the force of the water on a 1 m section of the river.

Drawings and Diagrams:

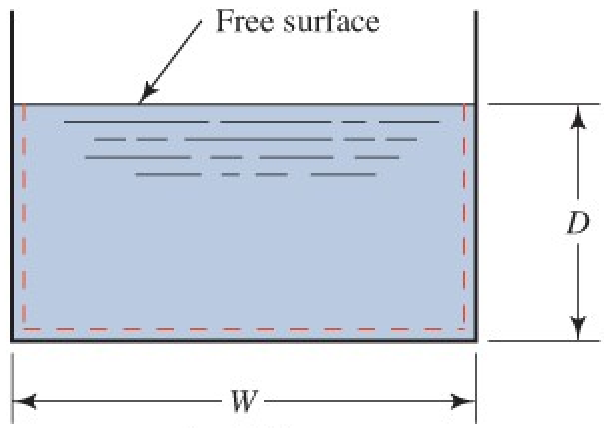
Tube dimensions (figure 1)



River Dimensions (figure 2)



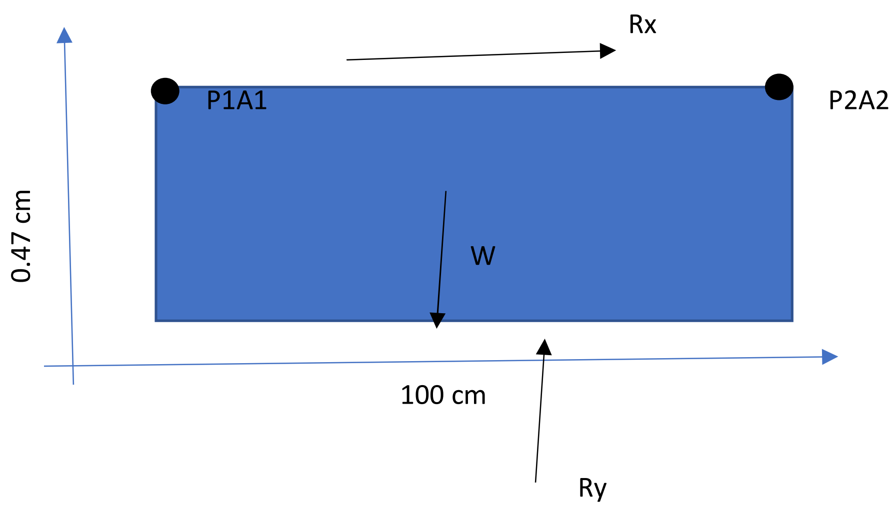
Open Channel Shape (figure 3)



$A = WD$

$WP = W + 2D$

(b) Rectangular channel



Sources:

Disabled World. (2021, June 13). *Average height to weight chart: Babies to teenagers*. Disabled World. Retrieved October 29, 2021, from https://www.disabled-world.com/calculators-charts/height-weight-teens.php#fc.

Holt, K. (2021, March 7). *Kids Pants Size Chart & conversion (boys, Girls & All Ages)*. Mom Loves Best. Retrieved October 29, 2021, from https://momlovesbest.com/kids-pants-size-chart.

Mott, R., Untener, J.A, "Applied Fluid Mechanics", 7th edition, Pearson Education, Inc (2015)

Design Considerations:

- Constant Properties
- Incompressible Fluids
- Water @ 30˚C
- Air @ 30˚C
- Average 3-year-old girl is 93.98 cm tall
- Average 5-year-old girl is 107.9 cm tall
- Average 5-year-old girl weighs 17.9 kg

Data & Variables:

- γ_w= 9.77 kN/m^3
- ρ= 996 kg/m^3
- n= 0.013 (smooth asphalt, common clay drainage tile, trowel-finished concrete, glazed brick)
- g= 9.81 m/s^2
- S= 0.1
- Kinematic viscosity= 8.03 x 10^{-7} m^2/s
- W= 2m
- D= 0.47m
- Circumference of child's waist= 0.5461m
- W_{float}=0.02 kN

Materials:

- smooth asphalt, common clay drainage tile, trowel-finished concrete, glazed brick
- water

Procedure:

1) Determine the area and WP of the open channel using the equation shown in figure 3. Use equation 14-1 from the textbook to determine the hydraulic radius. Use equation 14-8 to find the flow rate of the open channel.
2) Use equation 17-4 from the textbook to determine the Reynold's number of the water using the diameter of the child's waist. Use figure 17.4 from the textbook to determine the drag coefficient of the child. Use Q=VA to determine the velocity of the water. Use equation 17-1 from the textbook to determine the drag force the child experiences.
3) Determine the volume displaced by the body. Use equation 5-1 to determine the buoyance force acting on the 250 lb person. Determine the moment of inertia of the person. Determine

the distance the body sinks into water the weight of the body, the dimensions of the body and the specific weight of the fluid. Find the center of buoyancy and the center of gravity of the body. Determine if the metacenter is above the center of gravity.

4) Apply equation 16-4 form the textbook in both the planar X and Y directions to determine the forces on the walls and floor of the open channel.

Calculations:

1. Flow Rate

$A = WD = 2m \times 0.47m = 0.94 m^2$

$WP = W + 2D = 2m + (2 \times 0.47m) = 2.94 m$

$R = \frac{A}{WP} = \frac{0.94 m^2}{2.94 m^2} = 0.319 m$

$Q = (\frac{1}{n})(AR^{2/3})S^{1/2} = (\frac{1}{0.013})(0.94m^2 \times (0.319)^{2/3}_m \times (.001)^{1/2}$

$Q = 1.069 m^3/s$

2. Drag Force

$V \stackrel{?}{=} \frac{Q}{A} = \frac{1.069 m^3/s}{0.94 m^2} = 1.137 m/s$

$L_{(\text{Diameter of Childs waist})} = 2(\frac{C}{2\pi}) = 2(\frac{0.546 m}{2\pi}) = 0.174 m$

$N_R = \frac{VL}{\nu} = \frac{(1.137 m/s)(0.174 m)}{8.03 \times 10^{-7} m^2/s} = 246216.46$

$C_d \approx 0.95$

$A = D \times L = 0.47m \times 0.174m = 0.0817 m^2$

$F_d = C_d(\frac{\rho V^2}{2})A = 0.95(\frac{966 kg/m^3 \times 1.137 m/s^2}{2})0.0817 m^2$

$= 48.49 kg$

3. Depth 250lb body

$V_d = \pi r^2 h = \pi(0.48^2_m)(0.49 m) = 0.347 m^3$

$I = \pi(\frac{D^4}{64}) = \pi(\frac{0.96 m^4}{64}) = 0.0417 m^4$

$MB = I/V_d = \frac{0.0417 m^4}{0.347 m^3} = 0.12 m$

$W_{total} = W_{body} + W_{float} = 1.112 KN + 0.02 KN = 1.132 KN$

$X = \frac{4W}{\pi D^2 \gamma_w} = \frac{4 \times 1.132 KN}{\pi \times 0.96^2_m \times 9.77 KN/m^3} = \boxed{0.16 M}$

$y_{cb} = \frac{X}{2} = \frac{0.16m}{2} = 0.08m$

$y_{cg} = \frac{h}{2} = \frac{0.48m}{2} = 0.24m$

$y_{mc} = y_{cb} + MB = 0.08m + 0.12m = 0.2m$

$y_{mc} < y_{cg}$, the body will not be stable

4. Forces in the open channel

$R_x = \rho Q \Delta V_x = 966\ kg/m^3 \times 1.069\ m^3/s \times 0\ m/s = \underline{0\ kg}$

$V_w = LWD = 1m \times 0.47m \times 2m = 0.94\ m^3$

$W_w = (V_w)\rho_w = 0.94\ m^3 \times 966\ kg/m^3 = 908.04\ kg$

$R_y = W_w = \underline{908.04\ kg}$

Summary:

With a width of 2 m and a depth of 0.47 meters the water would come up to a 3-year-old girl's waist and have a flow rate of 1.069 m^3/s. The drag force on a 5-year-old child standing in the lazy river would be 48.49 kg. The 250 lb body would sit 0.16 m in the water while floating on a tube and is not stable. The forces on the walls in the 1 m section of the rectangular open channel would be 0 kg. The force on the floor of the 1 m section of the rectangular open channel would be 908.04 kg.

Analysis:

Increasing either dimension of the rectangular open channel will increase the flow rate of the lazy river. From a quick search online the velocity of the water in a lazy river is typically 2-3ft/s. Based on my flow rate the velocity of the lazy river is 3.7 ft/s which is not far from standard. The 250 lb body is not stable because the center of gravity is above the metacenter. The lazy river dose not have forces in the X direction because there is constant velocity and the surface is at atmospheric pressure.

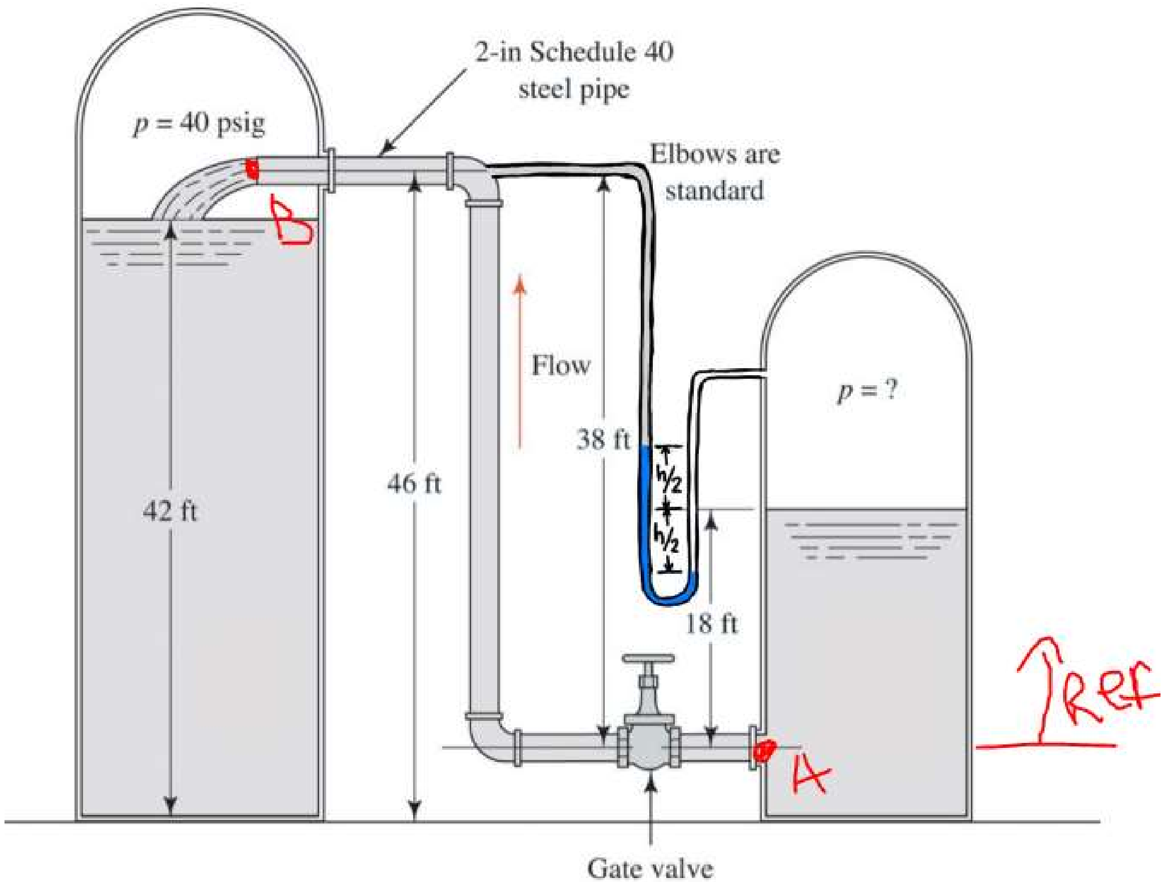
B.

Purpose:

Using the piping system from Exam 1, determine 5) the supports required for the system by calculating the horizontal and vertical forces of the fluid in motion. Determine 6) the pressure drop if a flow nozzle with a ratio of 0.5 is used to measure the flow. 7) check the design for water hammers and cavitation. Also, determine the max pressure when the valve is closed rapidly. Further, determine if the pipe would fail.

Drawings and Diagrams:

Figure 4



Flow Nozzle Figure 5

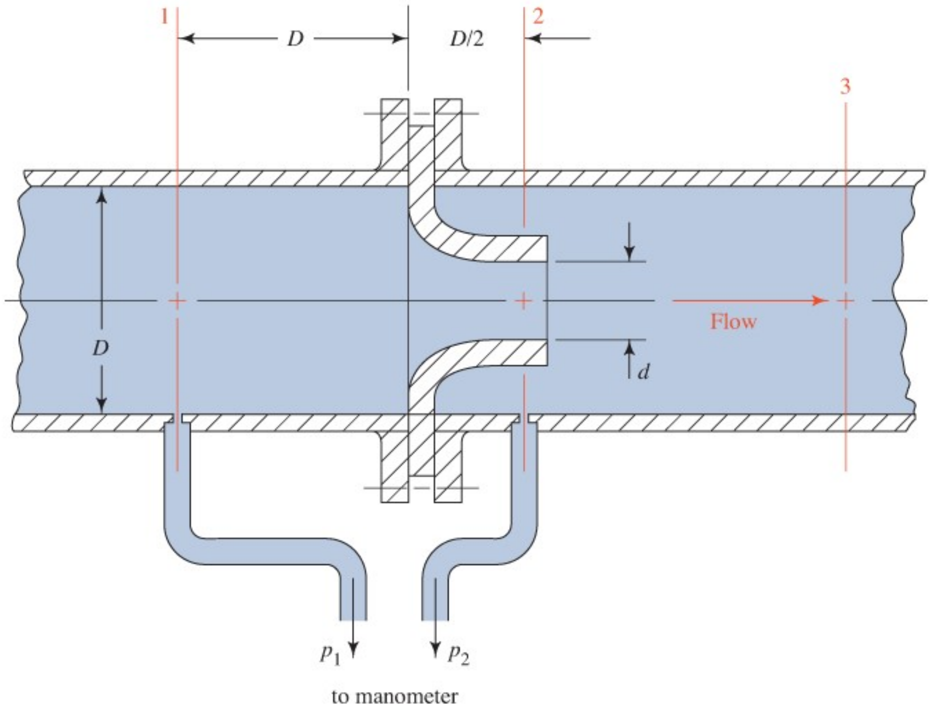
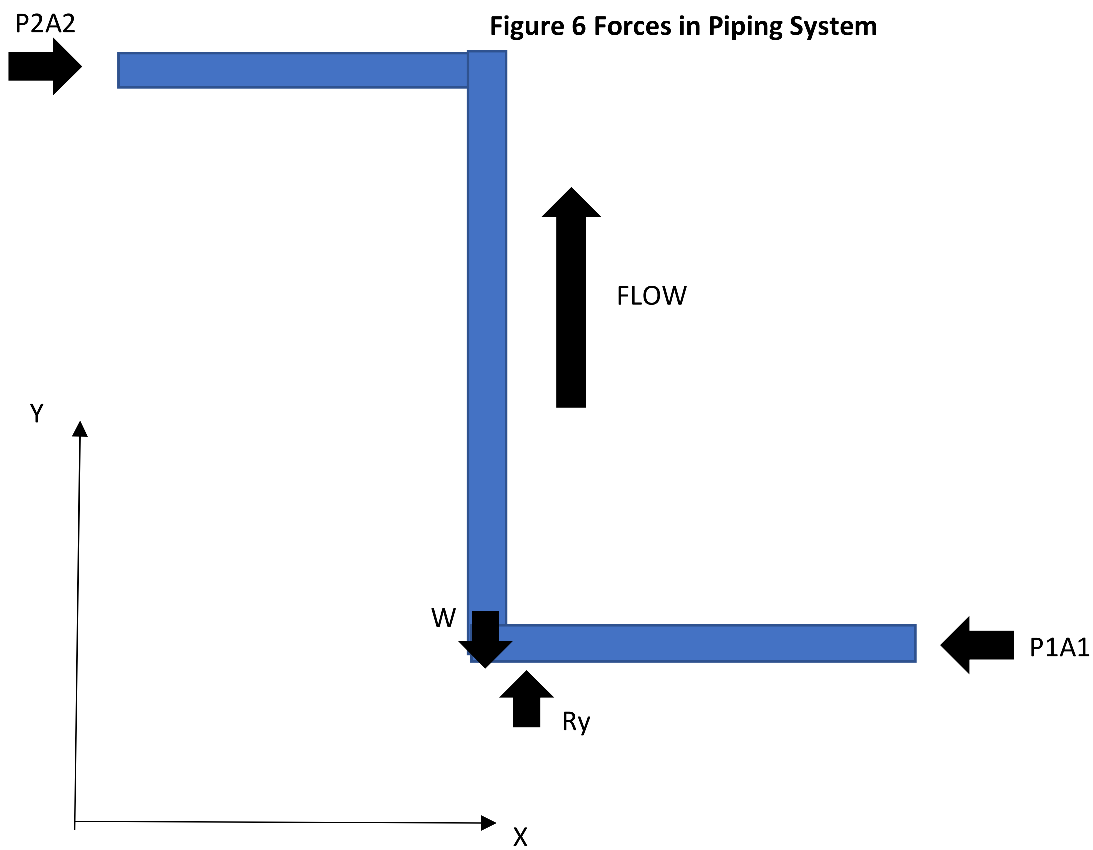


Figure 6 Forces in Piping System



Sources:

Mott, R., Untener, J.A, “Applied Fluid Mechanics”, 7th edition, Pearson Education, Inc (2015)

Design Considerations:

- Constant Properties
- Incompressible Fluids
- Ethyl Alcohol @ 77˚F
- Pressure in inlet tank taken from solution in Exam 1

Data and Variables:

- γ_{ea} = 49.01 lb/ft^3
- ρ= 49.23 lb/ft^3
- v = 4.31 x 10^{-6}
- Q = 0.223 ft^3/s
- A = 0.0233 ft^2
- D_i= 0.1723 ft
- β=0.5
- E= 4177087630 psf
- E_0= 18720000 psf
- S= 20000 psi
- Y= 0.4
- t= 0.01283 ft
- $A_{corrosion}$=0.08 in

Materials:

- Ethyl Alcohol
- Schedule 40 Steel pipes
- SR 90˚ elbows

Procedure:

5) Find energy losses with new flow rate. Use gamma*h equation to determine the pressure at the pipe inlet. Use equation 16-4 to find the forces in the x and y directions of the pipe system.
6) Find the Reynolds number of the fluid. Use equation 15-7 to determine the discharge coefficient of the flow nozzle. Rearrange equation 15-5 to solve for the pressure drop across the nozzle.
7) Determine speed of water when the valve is closed rapidly. Determine the maximum change in pressure when the valve is closed rapidly. Add the operating pressure and maximum change in pressure. Use equation 11. 9 in the textbook to determine what the pipe thickness would have to be using the maximum pressure and compare it to the thickness used in the pipe. Use the cavitation equation given in class to solve for $P_{suction}$ and verify that it is greater than P_{sat}.

Calculations:

from moody
$f = 0.019$
$f_t = 0.0215$

$Re = \frac{VD}{\nu} = \frac{(9.57 ft/s)(0.1723 ft)}{1.37\times10^{-5} ft^2/s}$

$Re = 120000$

$D/\varepsilon = 11434.67$

5. Forces in Pipe System

$V = \frac{Q}{A} = \frac{0.223 ft^3/s}{0.0233 ft^2} = 9.57 ft/s$

$h_{L pipes} = f\frac{L}{D_i}\frac{V^2}{2g} = 0.019\left(\frac{110 ft}{0.1723 ft}\right)\left(\frac{9.57 ft/s^2}{64.4 ft/s^2}\right)$
$= 17.25 ft$

$h_{L ent} = K_{ent}\frac{V^2}{2g} = 0.5\left(\frac{9.57 ft/s^2}{64.4 ft/s^2}\right) = 0.71 ft$

$h_{L elbows} = 2K_{elbow}\frac{V^2}{2g} = 2(30)(0.0215)\left(\frac{9.57 ft/s^2}{64.4 ft/s^2}\right)$
$= 1.83 ft$

$h_{L valve} = K_{valve}\frac{V^2}{2g} = 8(0.0215)\left(\frac{9.57 ft/s^2}{64.4 ft/s^2}\right) = 0.245 ft$

$h_{L total}$ $\Sigma h_{L pipes}, h_{L ent}, h_{L elbows}, h_{L valve} = 20.04 ft$

$P_{tank} = P_2 + (\gamma_{air}(\Delta z + \frac{V^2}{2g} + h_{L total}))/144$

$= 40 psi + \frac{(44.01 lb/ft^3(20 + \frac{9.57 ft/s^2}{64.4 ft/s^2} + 20.04 ft)}{144}$

$= 54.11 psi$

$P_{inlet} = P_{tank} + (\gamma_{tank} h)/144 = 54.11 psi + \frac{(49.01 lb/ft^3 \times 18 ft)}{144}$

$= 60.24 psi$

$P_{outlet} = P_{tank} - \frac{(\gamma_{air}(\Delta z + \frac{V^2}{2g} + h_{L total})}{144} = 40 psi$

$W = \text{Length of Pipes} \times A \times \rho_{air} = 110 ft \times 0.0233 ft^3 \times 49.23 lb/ft^3$

$W = 126.176 lb$

$R_y = W = 126.176\,lb$

$R_x = \dfrac{P_1 - P_2}{A} = \dfrac{60.24\,psi - 40\,psi}{(0.0233 \times 144)} = 6.032\,lb$

6. Pressure Drop in Flow Nozzle

$d = D_i \beta = 0.1723\,ft \times 0.5 = 0.086\,ft$

$N_R = \dfrac{V D_i}{\nu} = \dfrac{(9.57\,ft/s)(0.1723\,ft)}{1.37 \times 10^{-5}\,ft^2/s} = 120000$

$C = 0.9975 - \left(6.53\sqrt{\dfrac{\beta}{N_R}}\right) = 0.9975 - \left(6.53\sqrt{\dfrac{0.5}{120000}}\right)$

$= 0.984$

$A_2 = \pi r^2 = \pi\left(\dfrac{0.086}{2}\right)^2 = 0.0058\,ft^2$

$P_1 - P_2 = \dfrac{\left(\dfrac{\left(\left(\dfrac{A_1}{A_2}\right)^2 - 1\right)\left(\dfrac{Q}{CA_1}\right)^2}{64.4\,ft/s^2}\right)\gamma_{alc}}{144}$

$= \dfrac{\left(\dfrac{\left(\left(\dfrac{0.0233\,ft}{0.0058\,ft}\right)^2 - 1\right)\left(\dfrac{0.223\,ft^3/s}{0.984 \times 0.0233\,ft}\right)^2}{64.4\,ft/s^2}\right)49.01\,lb/ft^3}{144}$

$= 7.49\,psi$

7. Water hammer and Cavitation

$$C = \frac{\sqrt{\frac{E_0}{\rho}}}{\sqrt{1+\left(\frac{E_0 D}{E t}\right)}} = \frac{\sqrt{\frac{14720000\,psf}{49.23\,lb/ft^3}}}{\sqrt{1+\left(\frac{14720000\,psf \times 0.1723\,ft}{4177087630\,psf\,(0.01253\,ft)}\right)}}$$

$= 594.94\ ft/s$

$\Delta P = \rho C V = 49.23\,lb/ft^3 \times 594.94\,ft/s \times 9.57\,ft/s$

$= 1959.55\ psi$

$P_{max} = \Delta P + P_{operating} = 1959.55\,psi + 60.24\,psi$

$= 2019.42\ psi$

$$t_{basic} = \frac{P_{max} D_o}{2SEPY} = \frac{2019.42\,psi\,(2.375\,in)}{2(20000\,psi \times 1 + 2019.42\,psi \times 0.4)}$$

$= 0.115\ in$

$t_{min} = t_{basic} + A_{corrosion} = 0.115\,in + 0.08\,in = 0.195\,in$

$t_{nom} = 1.143\,t_{min} = 1.143(0.195\,in) = 0.223\,in$

$$P_{suction} = \frac{\left(\gamma_{calc}\left(\frac{(P_{outlet} \cdot 144)}{\gamma_{calc}}\right) - 39\,ft - \left(\frac{V^2}{64.4\,ft/s^2}\right) - h_{actual}\right)}{144}$$

$$= \frac{\left(49.01\,lb/ft^3\left(\frac{40\,psi \times 144}{49.01\,lb/ft^3}\right) - 39\,ft - \left(\frac{9.57\,ft/s^2}{64.4\,ft/s^2}\right) - 20.04\,ft\right)}{144}$$

$= 39.59\ psi$

$P_{sat} = 1.8\ psi$

Summary:

The forces in the X direction of the pipe system are 6.03 lb. The forces in the Y direction are 126.176 lbs. The pressure drop caused by the flow nozzle is 7.49 psi. The maximum pressure caused by water hammer is 2019.82 psi and the pipe could fail. There could be cavitation.

Analysis:

The nominal thickness calculated from the maximum pressure from water hammering is 0.22 in which is greater than the systems pipe thickness of 0.154 in, this means the pipe could fail from a water hammer. The suction pressure in the pipe is 39.58 psi which is greater then the saturation pressure at operating temperature, due to this there could be cavitation.

Appendix: Excel work

1		Flow Rate		
	Yw	9.77	kN/m^3	
	p	966	kg/m^3	
	n	0.013		
	g	9.81	m/s^2	
	S	0.001		
	W	2	m	
	D	0.47	m	
	A	0.94	m^2	
	WP	2.94	m	
	R	0.319727891	m	
	Q	1.069148875	m^3/s	
2		Drag Force		
	p	966	kg/m^3	
	Yw	9.77	kN/m^3	
	V	1.13739242	m/s	
	L	0.173829029	m	Diameter of Kid's waist
	viscosity	0.000000803	m^2/s	
	Nr	246216.4631		
	Cd	0.95		
	A	0.081699644	m^2	
	Fd	48.49662963	kg	
3		Depth 250 lb Body Sits		
	Yw	9.77	kN/m^3	
	Vd	0.347435015	m^3	
	I	0.041692202	m^4	
	MB	0.12	m	
	W	1.132	kN	
	X	0.160073528	m	
	ycb	0.080036764	m	
	ycg	0.24	m	
	ymc	0.200036764	m	
		ymc<ycg, Not Stable		

4	Forces in the Open Channel		
	p	966	kg/m^3
	Q	1.069148875	m^3/s
	V2x-V1x	0	m/s
	Rx	0	kg
	V	0.94	m^3
	W	908.04	kg
	Ry	908.04	kg

5	Forces in Pipe System					
	p	49.23	lb/ft^3			
	yea	49.01	lb/ft^3			
	Q	0.223	ft^3/s			
	A	0.0233	ft^3			
	V	9.570815451	ft/s			
	Di	0.1723	ft			
	hL_pipes	17.25333383	ft	Re	1.20E+05	
	hL_ent	0.711184071	ft	D/e	1148.667	
	hL_elbows	1.83E+00	ft	f	0.019	
	hL_valve	2.45E-01	ft	ft	2.15E-02	3.89E-04
	hL_total	20.04380306	ft			
	P_tank	54.11289618	psig			
	P_inlet	60.23914618	psig			
	P_outlet	40	psig			
	W	126.17649	lb			
	Ry	126.17649	lb			
	Rx	6.032172801	lb			

6	Pressure Drop in Flow Nozzle		
	V	9.570815451	ft/s
	Di	0.1723	ft
	d	0.08615	ft
	B	0.5	
	viscosity	1.37E-05	ft^2/s
	Nr	1.20E+05	
	C	9.84E-01	
	A1	0.0233	ft^2
	A2	0.005829086	ft^2
	P1-P2	7.49	psi

7	Water Hammer and Cavitation				
	Eo	18720000	psf		
	E	4177087630	psf		
	p	49.23	lb/ft^3		
	Di	0.1723	ft		
	Do	2.375	in		
	E (quality factor)	1			
	S	20000	psi		
	Y	0.4			
	t	0.01283	ft	0.154	in
	c	598.8900565	ft/s		
	delta_P	1959.581759	psi		
	P_max	2019.820905	psi		
	t_basic	0.115270357	in		
	A_corrosion	0.08	in		
	t_min	0.195270357	in		
	t_nom	0.223194018	in		
	The pipe could fail, t_nom@max pressure>t				
	P_suction	39.58704048	psi		
	P_sat	1.8	psi		
	P_suction< P_sat, there could be cavitation				