Colby C. Burnam
MET 330 Fluid Mechanics
Spring 2021
Exam 3

Part a.

1) **Purpose:** Calculate the pump power.

2) **Drawing & Diagrams:**

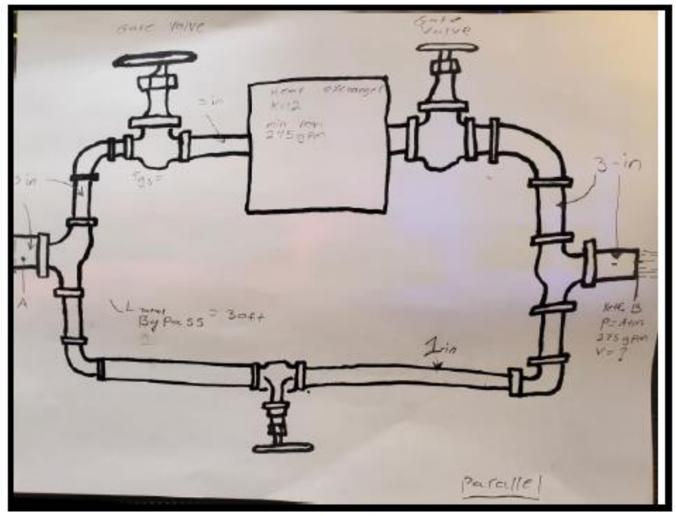

Fig.2 Parallel

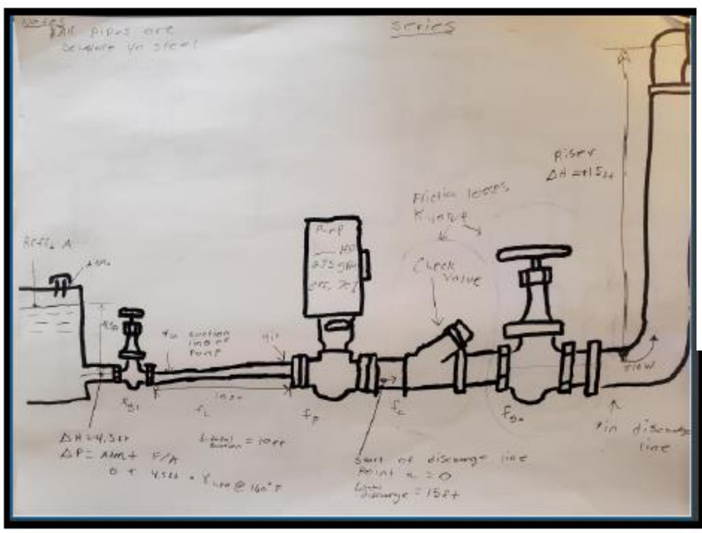

Fig.1 Series

3) **Sources:**
   - Robert L. Mott, Joseph A. Untener "Applied Fluid Mechanics, 7th edition Copyright 2015, 2006, 2000 by Pearson Education, Inc.

4) **Design Considerations:**
   The properties of the pipe and fittings, Schedule 40 Steel Pipe

   - The Specific weight (gamma) of the fluid,
   - The temperature of the fluid
   - Elevation differentials
   - Diameter of pipe
   - Flow rate of system

5) Data & Variables:

Class 1 Series (Tank to Point A)

Reference points for the energy equation:

Objective: Pump Power	Point 1: At surface of lower resvoir			
Problem a.	Point 2: At exit pipe			
System Data:	**SI Metric**	**SI**		**Metric**
Volume flow rate: Q =	275	gal/min	0.6127	m^3/s
Pressure at point 1 =	0	psi	0	kPa
Pressure at point 2 =			3.89E+08	kPa
Velocity at Point 1 =			0	m/s
Velocity at Point 2 = V=Q/A			75.61	m/s
Fluid Properties:		May need to compute v= n/p		
Specific weight =	**61**	**lb/ft^3**	**977.12**	**kN/m^3**
Pipe 1: Scehdule 40 steel Pipe				
Diameter: D =	4	in	0.1016	m
Wall roughness: ε =			4.06E-05	m
Length: L =	10	ft	3.048	m
Area: A=πD^2/4	12.56	in^2	0.00810321	m^2
D/ε =			2.50E+03	
L/D =			30	
Flow velocity =			75.61	m/s
Velocity head =			75.61	m/s
Reynolds No. =	2.63E +05			
Fricton factor: f =	0.016			

Energy Losses in Pipe 1:		Qty
Pipe: K_1 = f(l/D) =	4.80E-01	1
Entrance loss: K_2	1.40E+02	1
Element 3 (Gate Valve) : K_3 =	8	1
Energy Losses in Pipe 2:		Qty
Pipe: K_1 = f(l/D) =	1.02E+00	1
Entrance loss: K_2	139.86	1
Element 3 (Gate Valve) : K_3 =	8	1
Element 4 (Check Valve): K_4 =	100	
Element 5 (Elbow): K_5 =	20	2

g=	9.81	m/s^2			
					Δ Z
Elevation at Point 1 =	4.5	ft	1.37	m	10.5
Elevation at Point 2 =	15	ft	4.57	m	
If Ref. is in pipe: Setv1 = B20 or Set v2 = E20					
Vel head at point 1 =			0	m	
Vel head at point 2 =			75.61	m/s	
	Kinematic viscocity =		4.38x10^{-6}		
Pipe 2: Schedule 40 steel pipe					
Diameter: D =	3	in	0.0762	m	
Wall roughness: ε =			4.06E-05	m	
Length: L =	15	ft	4.572	m	
Area: A=πD^2/4	7.065	in^2	0.004558055	m^2	
D/ε =			1.88E+03		
L/D =			60		**Δ V**
Flow velocity =			75.61	m/s	75.61
Velocity head =			75.61	m/s	
Reynolds No. =			2.63E +05		
Fricton factor: f =			0.017		
hL= K(V^2/2g)					
Energy loss hL1 =	1.40E+02	m	Friction		
Energy loss hL2 =	4.07E+04	m			
Energy loss hL3 =	2.33E+03	m			
Energy loss hL1 =	2.97E+02	m	Friction		
Energy loss hL2 =	4.07E+04	m			
Energy loss hL3 =	2.33E+03	m			
Energy loss hL4 =	2.91E+04	m			
Energy loss hL4 =	5.82E+03	m			
Total energy loss hLtot =	1.21E+05	m	3.98E+05	ft	

Results:

$$h_A = \frac{\Delta P}{\gamma} + \Delta z + \frac{\Delta V\text{^}2}{2g} + h_l$$

Total head on pump: hA =	5.48E+05	m

$$p_A = h_A \gamma Q$$

Power added to fluid: PA =	3.28E+08	kW
Pump efficiency =	70%	

$$P = \frac{P_A}{e_M}$$

Power input to pump: PI =	4.69E+08	kW
	2.29	Hp

p1-p2=γhL	ΔP
p1-p2 = ΔP	3.89E+08 psi

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	Class 1 Parallel (Point A to exit)									
Reference points for the energy equation:										
Objective: Pump Power	Point 1: At surface of lower resvoir									
Problem a.	Point 2: At exit pipe									
System Data: **SI Metric**		**SI**		**Metric**						
Volume flow rate: Q =	275	gal/min	0.6127	m³/s	Elevation at Point 1 =	15	ft		m	Δ Z
Pressure at point 1 =	0	atm	0	kPa	Elevation at Point 2 =	15	ft		m	0
Pressure at point 2 =	0	atm	0	kPa	If Ref. is in pipe: Setv1 = B20 or Set v2 = E20					
Velocity at Point 1 =	0	ft/s	0	m/s	Vel head at point 1 =	0		0	m	
Velocity at Point 2 =	Q=VA, V=Q/A		75.61	m/s	Vel head at point 2 =		ft/s		m/s	
Fluid Properties:			May need to compute v= n/p							
Specific weight =	61	lb/ft³	kN/m³		Kinematic viscocity =	4.38x10⁻⁸				
Branch 1: Scehdule 40 steel Pipe					**Branch 2: Schedule 40 steel pipe**					
Diameter: D =	3	in	0.076	m	Diameter: D =	1	in	0.025	m	
Wall roughness: ε =			4.06E-05	m	Wall roughness: ε =			4.06E-05	m	
Length: L =	8	ft	2.44	m	Length: L =	30	ft	9.14	m	
Area: A=πD²/4	7.065		0.0045	m²	Area: A=πD²/4	0.785	in²	0.0005	m²	
D/ε =			0.0311		D/ε =			0.0027		
L/D =			32.11		L/D =			365.6		ΔV
Flow velocity =		ft/s	75.61	m/s	Flow velocity =		ft/s	75.61	m/s	75.61
Velocity head =		ft	75.61	m/s	Velocity head =		ft	75.61	m/s	
Reynolds No. =			2.63E +05		Reynolds No. =			2.63E +05		
Fricton factor: f =			0.017		Fricton factor: f =			0.022		
Energy Losses in Pipe 1:		Qty								
Pipe: $K_1 = f(l/D)$ =	0.55	1			Energy loss hL1 =	158.87	m	Friction		
Entrance loss: K_2	159.03	1			Energy loss hL2 =	46291.54	m			
Element 3 (Gate Valve) : K_3 =	8	2			Energy loss hL3 =	2328.66	m			
Element 4 (Heat Exchanger) : K_4 =	12	1			Energy loss hL4 =	3493.00	m			
Element 5 (Elbow) : K_5 =	20	2			Energy loss hL5 =	5821.66	m			
Energy Losses in Pipe 2:		Qty								
Pipe: $K_1 = f(l/D)$ =	8.04	1			Energy loss hL1 =	2341.24	m	Friction		
Entran p1-p2=γhL	ΔP				Energy loss hL2 =	46291.54	m			
Eleme p1-p2 = ΔP	3.89E+08	psi			Energy loss hL3 =	2328.66	m			
Eleme					Energy loss hL4 =	5821.66	m			
					Total energy loss hLtot =	114876.84	m			
			Results:		$h_A = \frac{\Delta P}{\gamma} + \Delta z + \frac{\Delta v_f^2}{2g} + h_l$ Total head on pump: hA =			5.41E+05	m	
					$P_A = h_A \gamma Q$ Power added to fluid: PA =			3.24E+08	kW	
					Pump efficiency =	0.7				
					$P = \frac{P_A}{e_M}$ Power input to pump: PI =		kW	4.63E+08	kW	
						2.08 Hp				

Total Hp required	4.37	Hp

6) Procedure:

Determine the Power of the pump

1. Draw a sketch.
2. Identify reference points.
3. Apply Bernoulli's.
    a. Determine Friction Energy Losses hl.
    b. Determine V
    c. Determine Q
    d. Determine Pressure
        i. Determine Hp

7) Calculations:

$$h_A + \frac{p_1}{\gamma} + \frac{V_1^2}{2g} + Z_1 = \frac{p_2}{\gamma} + \frac{V_2^2}{2g} + Z_2 + h_{L_{12}}$$

$$\frac{p_A - p_B}{\gamma} - Z_B = \frac{1}{g}\left(\frac{fL}{D} + K_{valve}\right)\frac{8Q^2}{\pi^2}\frac{1}{D^4}$$

Q = AV

$\frac{\Delta}{\gamma} = k_{\frac{v^2}{2g}}$
$Q = \frac{v}{\Delta t}$
$Q = vA$
$P = \gamma Q h_A$
$P = \frac{kv^2}{2g}\gamma$

Calculation Continued

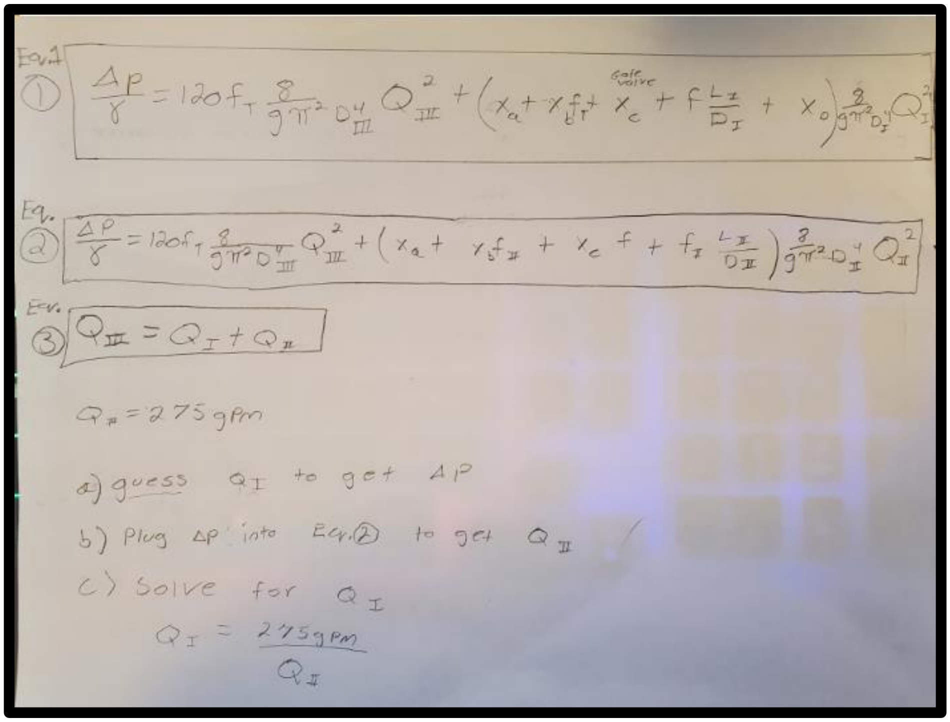

Fig. 3

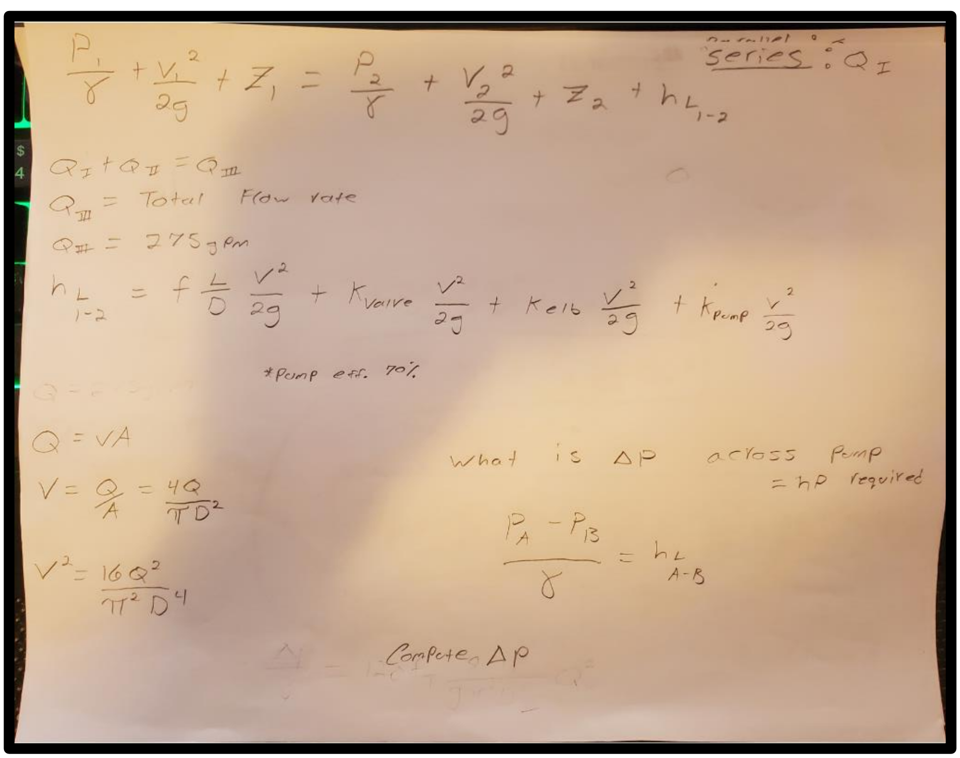

Fig. 4

Calculations Continued

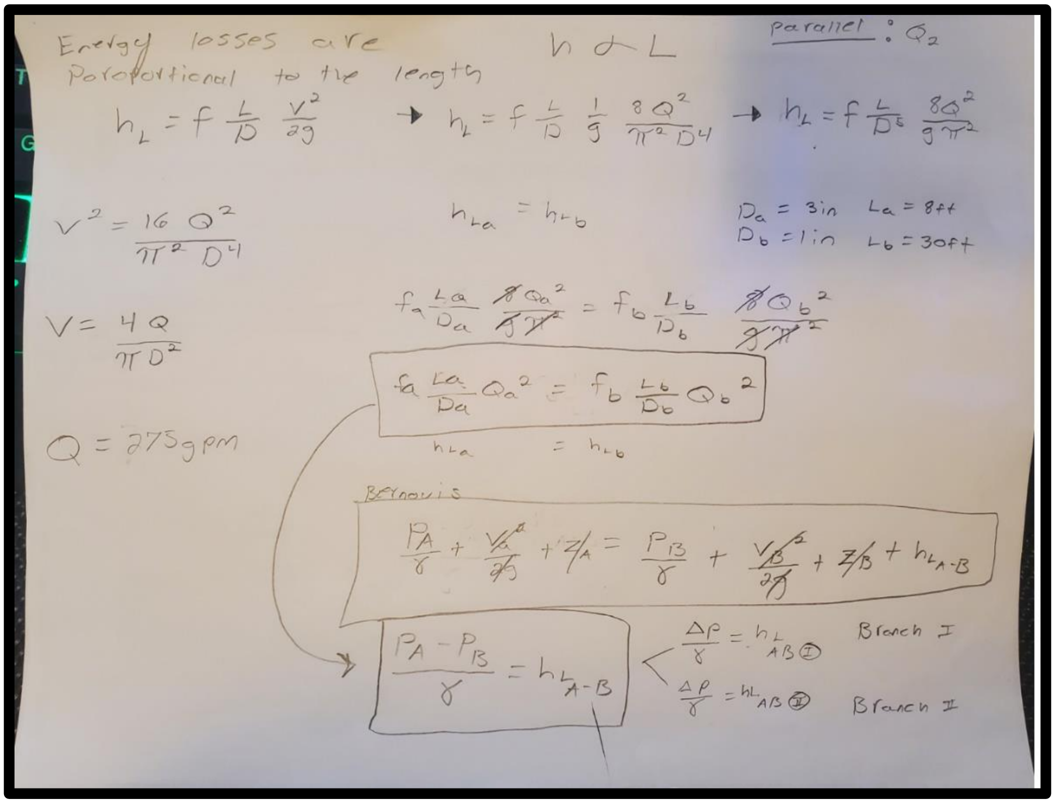

Fig. 5

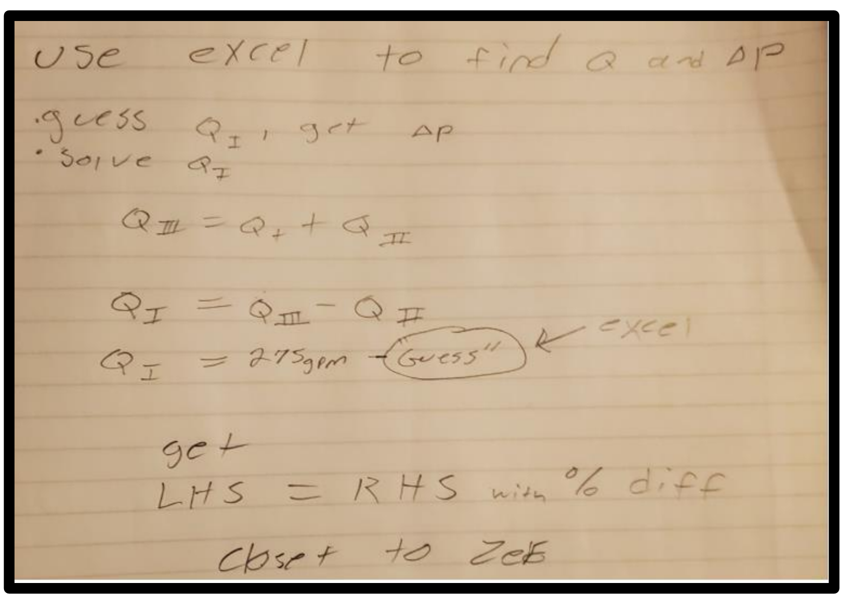

Fig. 6

8) Summary

The summary of this project is to use Bernoulli's law. Using Bernoulli's equation, we can guess Q1 to solve for ΔP. We can use the ΔP to determine the Hp required to produce the ΔP. The pump increases the Velocity by adding kinetic energy to the fluid. This increase in velocity creates a pressure drop. By understanding the pressure drop we can interpret the pump.

9) Materials

- DN 40 Schedule 40 Steel Pipe
- Water @ 160 ℉
- Gate Valves
- Check Valve
- Pump
- Heat Exchanger

10) Analysis

The min required Hp is equal to __4.37__Hp.

Part b.

1) Purpose

<u>Calculate the total flow rate</u> if the gate valve in the bypass is

a) ¼ open
b) ½ open
c) ¾ open
d) Fully open

2) Drawing & Diagrams

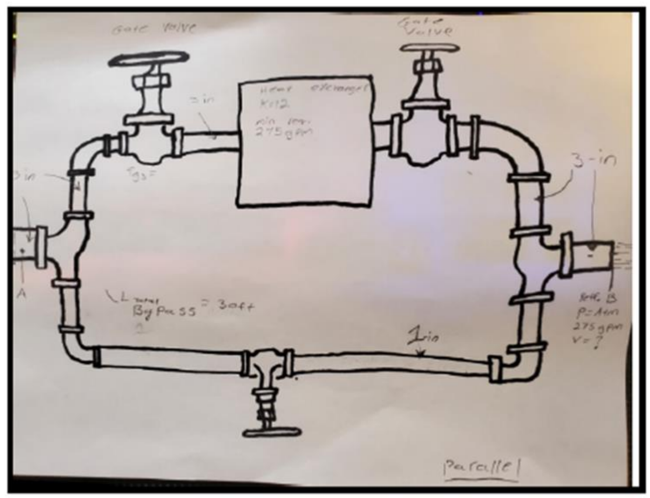

Fig.2 Parallel

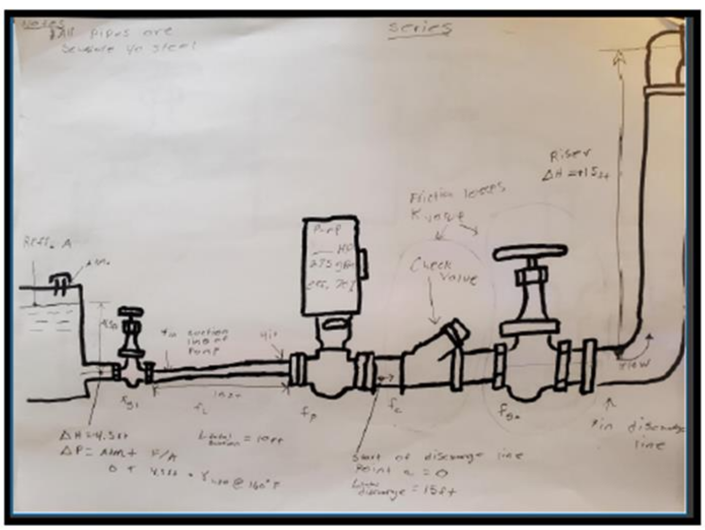

Fig.1 Series

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The properties of the pipe and fittings, Schedule 40 Steel Pipe

- The Specific weight (gamma) of the fluid,
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- Diameter of pipe
- Flow rate of system

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Pressure at point 2 =				3.89E+08	kPa
Velocity at Point 1 =				0	m/s
Velocity at Point 2 = V=Q/A				75.61	m/s
Fluid Properties:			May need to compute v= n/p		
Specific weight =		**61**	**lb/ft³**	**977.12**	**kN/m³**
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Diameter: D =		4	in	0.1016	m
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Length: L =		10	ft	3.048	m
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Velocity head =				75.61	m/s	
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hL= K(V²/2g)

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Results:

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$$P = \frac{P_A}{e_M}$$

Power input to pump: PI =	4.69E+08	kW
	2.29	Hp

p1-p2=γhL	ΔP	
p1-p2 = ΔP	3.89E+08	psi

	Class 1 Parallel (Point A to exit)									
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Problem a.	Point 2: At exit pipe									
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Pressure at point 1 =	0	atm	0	kPa	Elevation at Point 2 =	15	ft		m	0
Pressure at point 2 =	0	atm	0	kPa	If Ref. is in pipe: Setv1 = B20 or Set v2 = E20					
Velocity at Point 1 =	0	ft/s	0	m/s	Vel head at point 1 =	0		0	m	
Velocity at Point 2 =	Q=VA, V=Q/A		75.61	m/s	Vel head at point 2 =		ft/s		m/s	
Fluid Properties:			May need to compute v= n/p							
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Wall roughness: ε =			4.06E-05	m	Wall roughness: ε =			4.06E-05	m	
Length: L =	8	ft	2.44	m	Length: L =	30	ft	9.14	m	
Area: $A=\pi D^2/4$	7.065		0.0045	m^2	Area: $A=\pi D^2/4$	0.785	in^2	0.0005	m^2	
D/ε =			0.0311		D/ε =			0.0027		
L/D =			32.11		L/D =			365.6		Δ V
Flow velocity =		ft/s	75.61	m/s	Flow velocity =		ft/s	75.61	m/s	75.61
Velocity head =		ft	75.61	m/s	Velocity head =		ft	75.61	m/s	
Reynolds No. =				2.63E +05	Reynolds No. =				2.63E +05	
Fricton factor: f =				0.017	Fricton factor: f =				0.022	
Energy Losses in Pipe 1:		Qty								
Pipe: $K_1 = f(l/D)$ =	0.55	1			Energy loss hL1 =	158.87	m	Friction		
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Pipe: $K_1 = f(l/D)$ =	8.04	1			Energy loss hL1 =	2341.24	m	Friction		
Entran p1-p2=γhL	ΔP				Energy loss hL2 =	46291.54	m			
Eleme					Energy loss hL3 =	2328.66	m			
Eleme p1-p2 = ΔP	3.89E+08	psi			Energy loss hL4 =	5821.66	m			
					Total energy loss hLtot =	114876.84	m			
				Results:	$h_A = \frac{\Delta P}{\gamma} + \Delta z + \frac{\Delta v_f^2}{2g} + h_l$ Total head on pump: hA =			5.41E+05	m	
					$P_A = h_A \gamma Q$ Power added to fluid: PA =			3.24E+08	kW	
					Pump efficiency =	0.7				
					$P = \frac{P_A}{e_M}$ Power input to pump: PI =		kW	4.63E+08	kW	
						2.08 Hp				

Total Hp required	4.37	Hp

6) Procedure

To change the Flow rate with the valve, we are effectively changing the K value of the Valve.

7) Calculations

$$\frac{p_A - p_B}{\gamma} - Z_B = \frac{1}{g}\left(\frac{fL}{D} + K_{valve}\right)\frac{8Q^2}{\pi^2}\frac{1}{D^4}$$

$$h_A + \frac{p_1}{\gamma} + \frac{V_1^2}{2g} + Z_1 = \frac{p_2}{\gamma} + \frac{V_2^2}{2g} + Z_2 + h_{L_{12}}$$

$\frac{\Delta}{\gamma} = k_{\frac{v^2}{2g}}$
$Q = \frac{v}{\Delta t}$
$Q = vA$
$P = \gamma Q h_A$
$P = \frac{kv^2}{2g}\gamma$

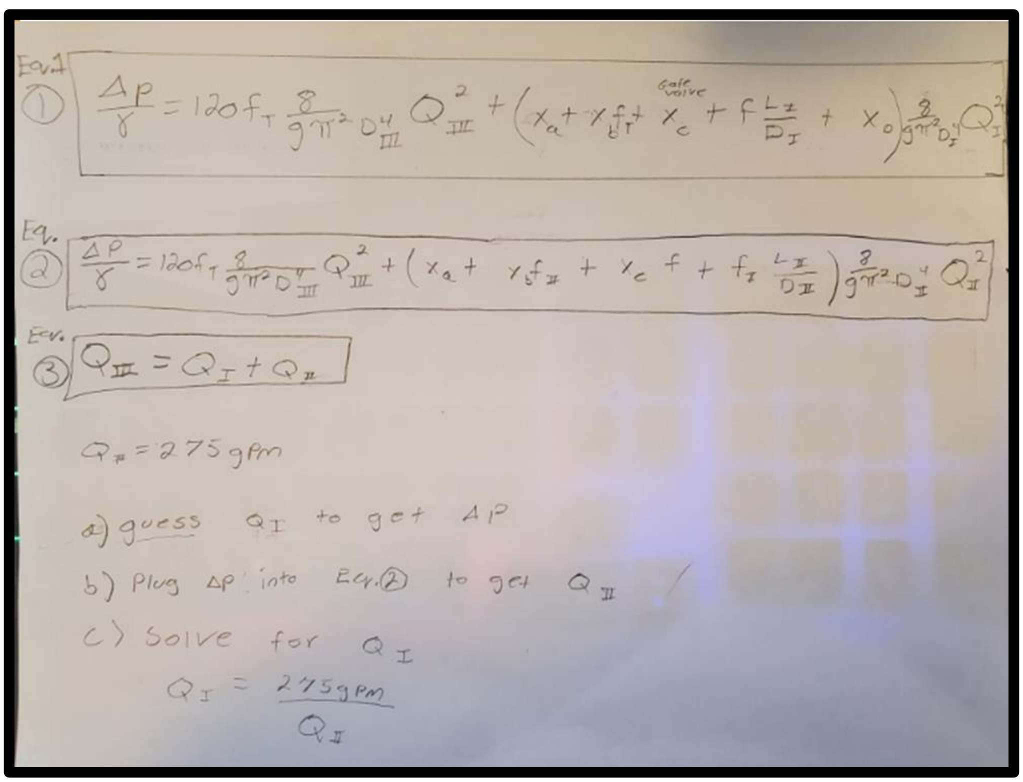

Fig. 3

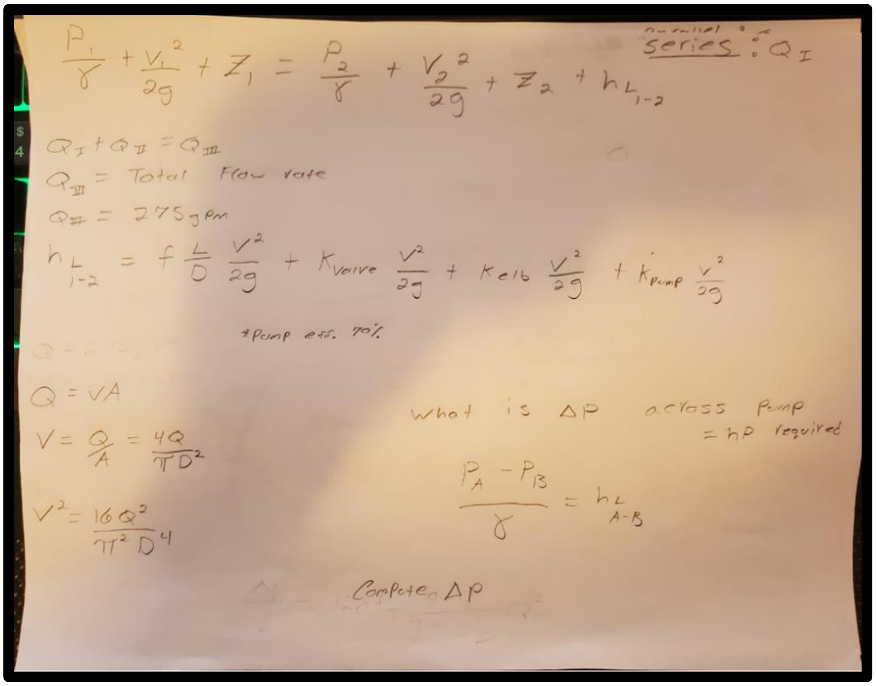
Parallel : Q_{II}
Series : Q_I
$\frac{P_1}{\gamma} + \frac{V_1^2}{2g} + Z_1 = \frac{P_2}{\gamma} + \frac{V_2^2}{2g} + Z_2 + h_{L_{1-2}}$
$Q_I + Q_{II} = Q_{III}$
Q_{III} = Total Flow rate
Q_{III} = 275 gpm
$h_{L_{1-2}} = f\frac{L}{D}\frac{V^2}{2g} + K_{valve}\frac{V^2}{2g} + K_{elb}\frac{V^2}{2g} + K_{pump}\frac{V^2}{2g}$
*pump eff. 70%
$Q = VA$
$V = \frac{Q}{A} = \frac{4Q}{\pi D^2}$
$V^2 = \frac{16Q^2}{\pi^2 D^4}$
What is ΔP across pump = hp required
$\frac{P_A - P_B}{\gamma} = h_{L_{A-B}}$
Compute ΔP

Fig. 4

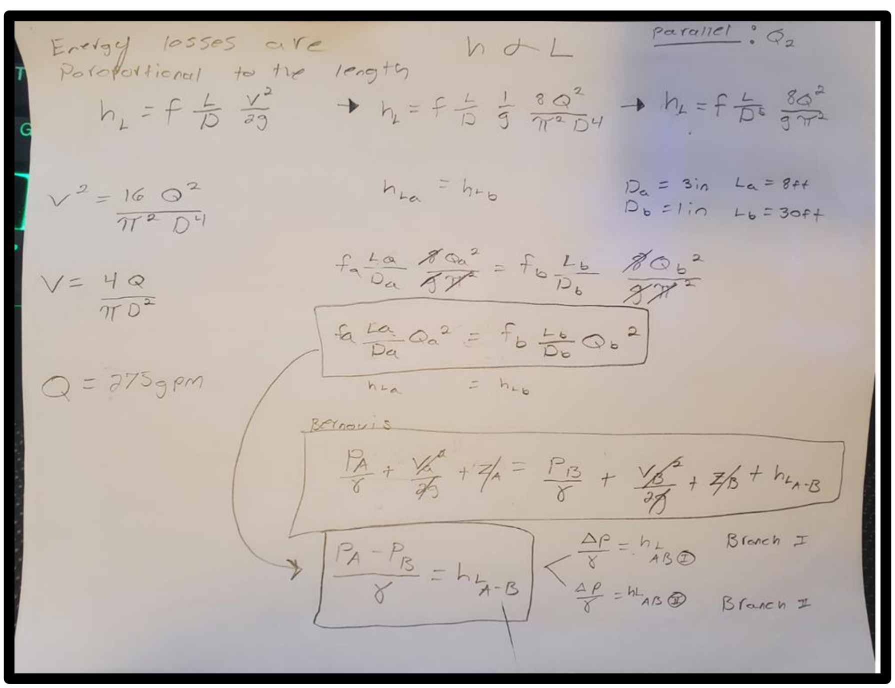
Energy losses are proportional to the length
$h \propto L$
parallel : Q_2
$h_L = f\frac{L}{D}\frac{V^2}{2g} \rightarrow h_L = f\frac{L}{D}\frac{1}{g}\frac{8Q^2}{\pi^2 D^4} \rightarrow h_L = f\frac{L}{D^5}\frac{8Q^2}{g\pi^2}$
$V^2 = \frac{16Q^2}{\pi^2 D^4}$
$h_{L_a} = h_{L_b}$
$D_a = 3in$ $L_a = 8ft$
$D_b = 1in$ $L_b = 30ft$
$f_a\frac{L_a}{D_a}\frac{8Q_a^2}{g\pi^2} = f_b\frac{L_b}{D_b}\frac{8Q_b^2}{g\pi^2}$
$V = \frac{4Q}{\pi D^2}$
$f_a\frac{L_a}{D_a}Q_a^2 = f_b\frac{L_b}{D_b}Q_b^2$
$h_{L_a} = h_{L_b}$
$Q = 275gpm$
Bernoulis
$\frac{P_A}{\gamma} + \frac{V_A^2}{2g} + Z_A = \frac{P_B}{\gamma} + \frac{V_B^2}{2g} + Z_B + h_{L_{A-B}}$
$\frac{P_A - P_B}{\gamma} = h_{L_{A-B}}$
$\frac{\Delta P}{\gamma} = h_{L_{AB(I)}}$ Branch I
$\frac{\Delta P}{\gamma} = h_{L_{AB(II)}}$ Branch II

Fig. 5

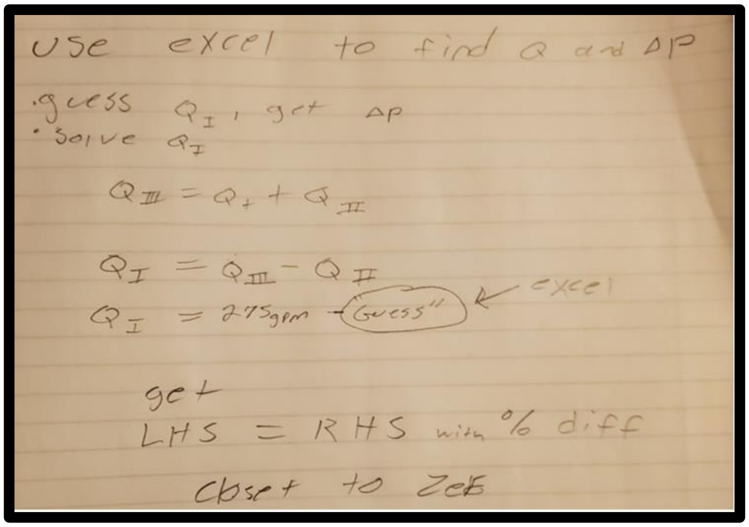

Fig.

8) Summary

To change the valve K value, we need to find the equivalent friction factor of a length of pipe. Le/D

a) ¼ open = 900
b) ½ open = 160
c) ¾ open = 35
d) Fully open = 8

9) Materials

- DN 40 Schedule 40 Steel Pipe
- Water @ 160 ℉
- Gate Valves
- Check Valve
- Pump
- Heat Exchanger

10) Analysis

The Flow rate are as follows,

e) ¼ open =
f) ½ open =
g) ¾ open =
h) Fully open =