MET 330 Fluid Mechanic

Instructor: Professor Ayala

Test 1

10/02/2023

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Section 1

Purpose:

Determining the required pump power (HP) with the given information and exists design drawing.

Drawing/Diagrams of this section of calculation:

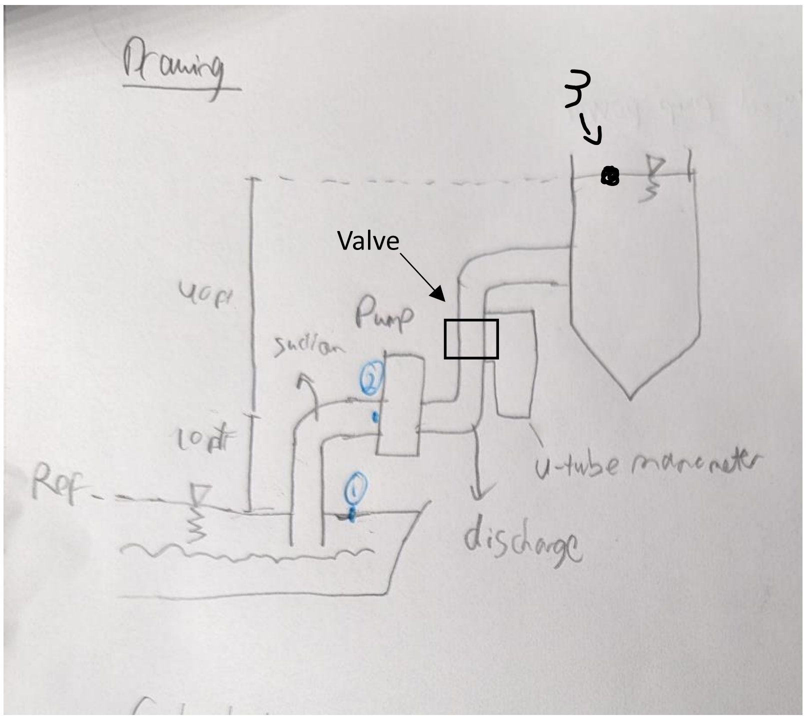


Figure 1. Pipeline design

Sources:

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

Design Considerations:

- Friction loss of elbows will be neglected.
    - Due to the sheer size length in this pipeline (2511 ft length, versus 3 elbows).
- T = 60 ºF
- Incompressible fluids
- Steady state
- Isothermal process

Data and Variables

Length of suction pipe = 11ft, Length of discharge pipe = 2500ft

$\gamma_{\mathbf{water}}$ = 62.4 lb/ft^3

η = 0.6 (Pump)

k_{valve} = 5.3

Q = 3.387 ft^3/s

V (velocity)= 3 m/s = 9.84 ft/s

v (Kinematic viscosity) = 1.21x10^{-5} ft^2/s

Procedure:

Since it is a flowing fluid, Bernoulli's equation, and a reference point will be set at the water line in the open-source water (marked on the drawing).

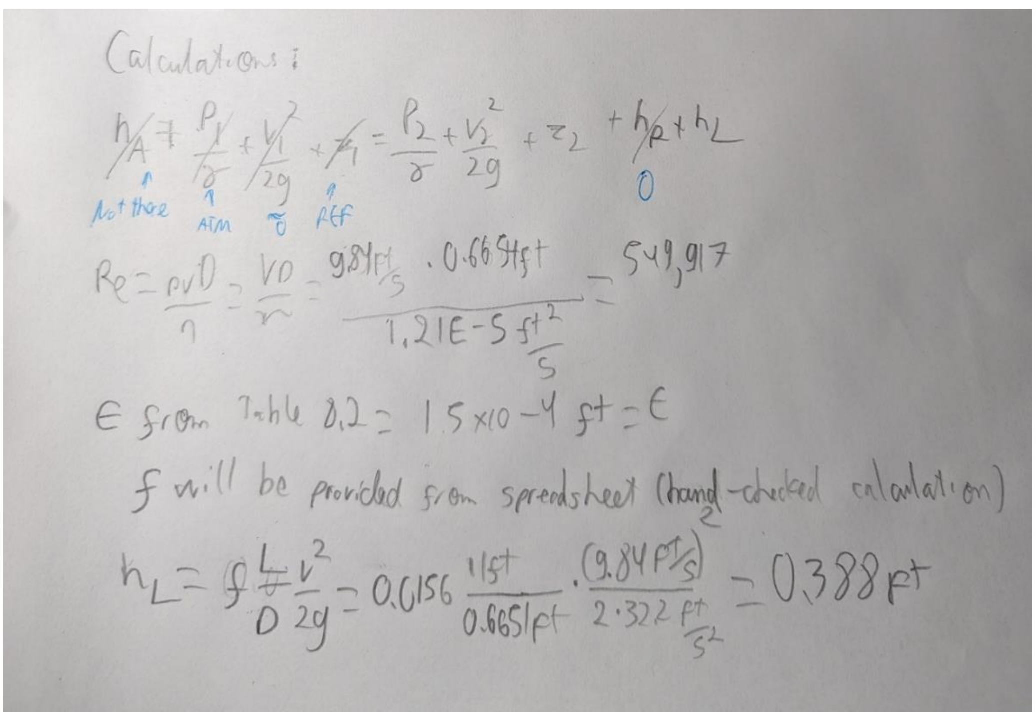
First, I will be picking 2 points to start determining different values of this pipeline system, point 1 will be the waterline of the large open channel since it provides the most known data, and point 2 will be right before the pump to determine the pressure at that point.

But before getting to the calculation, I would have to pick a right pipe size, since this is an industrial application, I will select a standard schedule 40 steel pipe. The problem already designated Flow rate, and Velocity of the moving fluid, by calculating area using Q = V*A equation, I will find an approximation of pipe area it would requires.

Calculations:

$$A = \frac{Q}{V} = \frac{3.387\,\frac{ft^3}{s}}{9.84\,\frac{ft}{s}} = 0.344\,ft^2$$

From Appendix Table F.1 Schedule 40 steel pipe, 8-inch pipe size have 0.3472 ft^2, which is just right above the exact area needed. I will also be creating a spreadsheet with all the data/calculations included in the case of the employer needing to change pipe size.


Calculations:

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

Not there, ATM, ≈0, Ref, 0

$$Re = \frac{\rho v D}{\eta} = \frac{vD}{\nu} = \frac{9.84\frac{ft}{s} \cdot 0.6651ft}{1.21E{-}5\,\frac{ft^2}{s}} = 549{,}917$$

ϵ from Table 8.2 = 1.5×10^{-4} ft = ϵ

f will be provided from spreadsheet (hand-checked calculation)

$$h_L = f\frac{L}{D}\frac{v^2}{2g} = 0.0156\,\frac{11ft}{0.6651ft} \cdot \frac{(9.84\,ft/s)^2}{2 \cdot 32.2\,\frac{ft}{s^2}} = 0.388\,ft$$

Procedure:

After obtaining pressure at P_2, that provided me with more information to work with Bernoulli's equation in order to calculate for pump head using point 2 and point 3(Elevated Open Channel). I will be calculating the friction loss from pipe, along with 2 valves to find pump head prior to completing the Bernoulli's equation. Once h_{L2} is found, I would then solve for pump head (h_A).

With h_A value obtained, the formula for power $P = \frac{\gamma Q h_A}{\eta}$ could then be solved for, then converted to horsepower (HP).

Calculations:

Atm ~0

$$h_A + \frac{P_2}{\gamma} + \frac{V_2^2}{2g} + z_2 = \cancel{\frac{P_3}{\gamma}} + \cancel{\frac{V_3^2}{2g}} + z_3 + h_{L2}$$

f will be provided in spreadsheet (hand-checked)

$$h_{L2} = f\frac{L}{D}\frac{V^2}{2g} + 2\cdot K\left(\frac{V^2}{2g}\right) = 0.0156\,\frac{250\,ft}{0.6651}\,\frac{(9.84\,ft/s)^2}{2\cdot 32.2\,ft/s^2} + 2\cdot(5.3)\left(\frac{(9.84\,ft/s)^2}{2\cdot 32.2\,ft/s^2}\right)$$

$$h_{L2} = 96.4\,ft$$

$$h_A = z_3 + h_{L2} - z_2 - \frac{P_2}{\gamma} - \frac{V_2^2}{2g}$$

$$= 50\,ft - 10\,ft + 96.4\,ft - \frac{-742\,lb/ft^2}{62.4\,lb/ft^3} - \frac{(9.84\,ft/s)^2}{2\cdot 32.2\,ft/s^2}$$

$$h_A = 146.8\,ft$$

$$P = \gamma Q h_A = 62.4\,\frac{lb}{ft^3} \times 3.416\,\frac{ft^3}{s} \times 146.8\,ft = 31291.71\,\frac{lb\cdot ft}{s} \cdot \frac{1\,HP}{550\,\frac{lb\cdot ft}{s}}$$

$$P = \frac{56.9\,HP}{0.60} = 95\,HP$$

Materials

- Water
- 8-in Schedule 40 steel pipe

Summary:

The required pump power was determined to be 95 H.P, along with pipe selection to be 8-in schedule 40 steel pipe. Pump power's suggestion would be 100 H.P+ .

Friction factor (f) was calculated using the spreadsheet, after hand-checked the first calculation.

Spreadsheet sample:

Name:	Aiden Pham
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Constants											
Symbols	*Lsuction*	*Ldischarge*	*n*	*Q*	*v*	*K*	V	*E*	*D*	*D/E*	*γ*
Units	ft	ft		ft^3/s	ft^2/s		ft/s	ft	ft		lb/ft^3
Description	Pipe Length succ	Pipe Length disc	Motor Efficiency	Flow(desired)	kinematic viscosity	Valve resistace co	Velocity (ft/s)	Roughness	Diameter	Relative Rough	Gamma water
Value	11	2500	0.6	3.387	1.21E-05	5.3	9.84	1.50E-04	0.6651	4434.00	62.4

Log(denominator)	left side	right side
15.97630332	6.09541E-05	3.97E-05

Schedule 40 steel pipe			
Symbols		A(pipe)	D(pipe)
Units	in	ft^2	ft
Description	Pipe size	Pipe Area	Diameter(inside)
Value	8	0.3472	0.6651

Variable Calculations		
Q(pipe)	*Re*	f
ft^3/s		
Flow rate(calculated)	Reynold #	Friction Factor
3.416	5.41E+05	0.0156

Problem Calculation					
Symbols	P2	hL(1)	hL(2)	hA	P(Pump)
Units	Pounds square feet	ft	ft	ft	HP
Description	Pressure at point 2	friction loss	friction loss	Pump head	Pump's power
Value	-742.1	0.389	96.40	146.79	94.8

The spreadsheet also will be attached along with this document.

Analysis:

The friction loss of the suction pipe was minuscule compared to discharge pipe (0.3 ft vs 96ft), due to its sheer length, it could have been neglected along with the elbows as well.

The problem could also have been solved by working in reverse using the top open channel as well, since it is open to atmosphere pressure and that is known information that could be used to solve for pump head.

The pipe size is also just barely above the required crossed-section area to allow the flow rate reach the required flow rate of 3.387 ft^3/s. In order to have more leeway in terms of flow rate, the company could considering changing pipe size, or up-sizing the pump power; as there could be things from the open channel that cluttering and clogging up the pipeline/pump itself and thus reduce flow rate.

Section 2

Purpose:

Calculated the theoretical different pressure that would indicate the reading on U-tube nanometer on field to measure the valve's performance.

Drawing/Diagrams of this section of calculation:

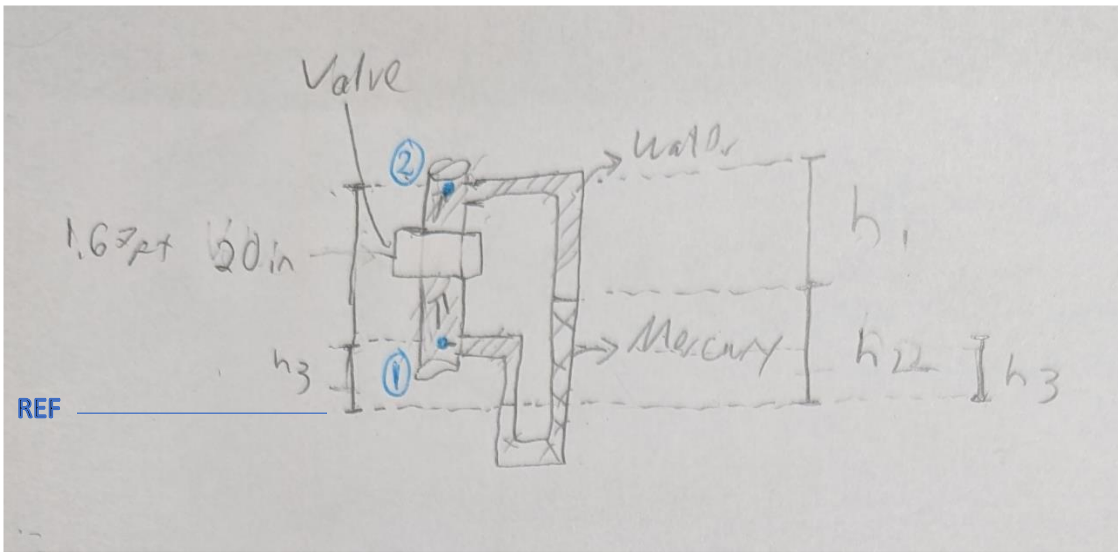


Figure 2. Nanometer and Valve

Sources:

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

Design Considerations:

- T = 60 ºF
- Incompressible fluids
- Steady state flowing
    - Valve will be fully opened and operating
- Isothermal process

Data and Variables

Length of pipe between the two connections of U-tube nanometer = 20 in = 1.67 ft

$\gamma_{water} = 62.4$ lb/ft^3

$\gamma_{mercury} = 847$ lb/ft^3

$k_{valve} = 5.3$

Q = 3.387 ft^3/s

V (velocity)= 3 m/s = 9.84 ft/s

And length variables (h_1,h_2,h_3) from diagram(figure 2)

Procedure:

Since this is a steady state flowing (valve is fully opened), the pressure differences can be calculated by using Bernoulli's equation taking in from point 1 and point 2(Figure 2). In this section of calculation, I will also include the friction losses in the pipe (20 in(1.67 ft) distance between the two connection of U-tube nanometer) along with friction loss from valve(fully opened).

Calculations:

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

$$\frac{\Delta p}{\gamma} = \underbrace{z_2 - z_1}_{20 in} + h_L$$

$$= 1.667 ft + f\frac{L}{D}\frac{v^2}{2g} + K\frac{v^2}{2g} = 1.67 + \frac{v^2}{2g}\left(f\frac{L}{D} + K\right)$$

$$\frac{\Delta p}{\gamma} = 1.67 ft + \frac{(9.84 ft/s)^2}{2 \cdot 32.2 \frac{ft}{s^2}}\left(0.0156 \frac{1.67 ft}{0.6651 ft} + 5.3\right)$$

$$\Delta p = 605 \frac{lb}{ft^2}$$

Spreadsheet sample of ΔP:

	ΔP
HP	lb/ft^2(PSF)
	U-Tube nanometer
4.8	605.1

Procedure:

Inside the manometer, the fluid is not moving so manometry principle can be used to derive an equation to find deflection (h2).

Calculation:

$$P_2 = \gamma_w(h_1) + \gamma_M h_2 - \gamma_w H_3 + P_1$$

$$P_2 - P_1 = \gamma_w(h_1 - h_3) + \gamma_M h_2$$

$$\frac{P_2 - P_1 - \gamma_w(h_1 - h_3)}{\gamma_M} = h_2 \quad (1)$$

from diagram: $1.67ft + h_3 = h_1 + h_2$

$$\Rightarrow h_1 - h_3 = 1.67ft - h_2$$

substitute $h_1 - h_3$ in (1)

$$\frac{P_2 \Delta P_1 - \gamma_w(1.67 ft - h_2)}{\gamma_M} = h_2$$

$$\frac{\Delta p - \gamma_w(1.67ft - h_2)}{\gamma_m} = h_2$$

$$h_2\gamma_m = \Delta p - \gamma_w(1.67ft + \gamma_w h_2 =$$

$$h_2\gamma_m - \gamma_w h_2 = \Delta p - \gamma_w 1.67ft$$

$$h_2(\gamma_m - \gamma_w) = \Delta p - 1.67\gamma_w$$

$$h_2 = \frac{\Delta p - 1.67\gamma_w}{\gamma_m - \gamma_w} = \frac{-605.1 \frac{lb}{ft^2} - 1.67ft \cdot 62.4 \frac{lb}{ft^3}}{(847 - 62.4)\frac{lb}{ft^3}}$$

$$h_2 = 0.638ft$$

Materials:

- Water
- 8-in schedule 40 steel pipe
- Valve (k = 5.3)
- U-tube manometer
- Mercury

Summary:

The **ΔP** was calculated to be 605 lb/ft^2, or 605 psf, or 4.2 psi, this value should be what be read on the U-tube manometer on the field.

And the deflection is calculated to be 0.638 ft (7.7 inch)

Analysis:

There are a lot of unknown variables, so I need to work with what I knew, which is the 1.67 ft distance between the two connection of the manometer. By using that distance, I calculated the pressure differences(ΔP**)** using Bernoulli's equation, since it is a moving fluid inside the pipe.

However, the fluid inside manometer is not moving, so I use this equation:

$\Delta P = \gamma * h$

By using the above equation, the deflection (h_2) can be derived, which calculated to be 0.638 ft (7.7 inch)

Section 3

Purpose:

Using the spreadsheet throughout this problem to calculate the pump power, under different condition, along with creating a table with range of flow rates from 0 to 4ft^3/s to determine the manometer reading for each of those values. Also create a plot of graph of required pump power/flow rate and calculate the flow rate if pump power is half of the original pump power, along with the respective manometer reading.

Procedure:

Tinkering with the spreadsheet to create a table with different flow rate values, and their respectable pump power required, along with manometer reading as required by employee.

Calculation:

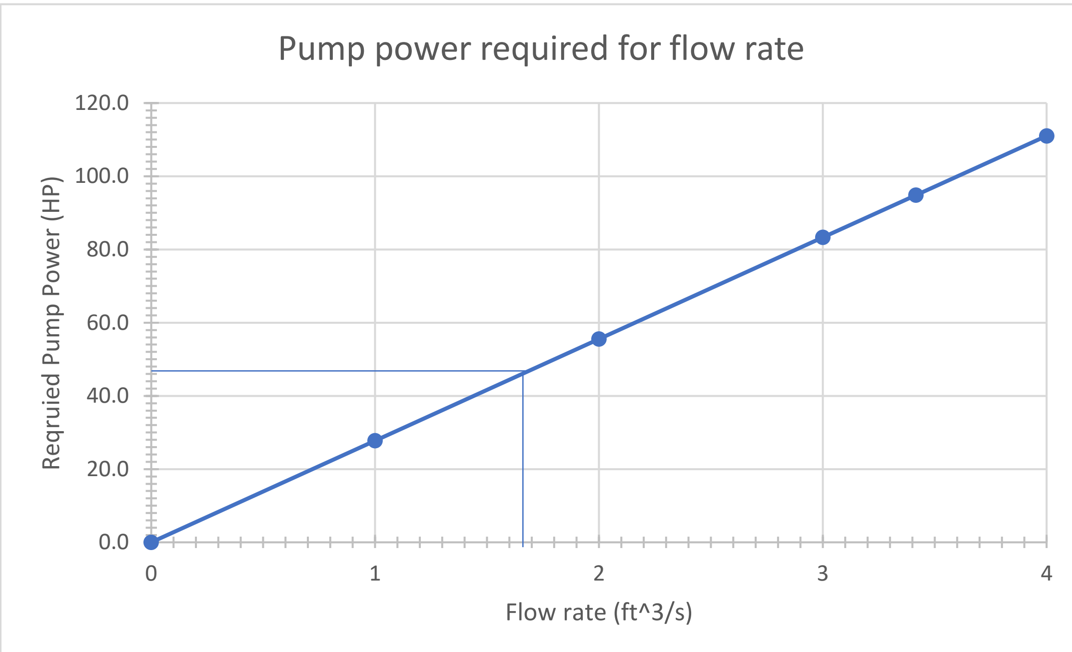
Section 3				
Q	P(pump)	V	ΔP	h2
Q (ft^3/s)	HP	ft/s	lb/ft^2(PSF)	ft
Flow rate	Pump Power	Velocity	U-Tube nanometer	Deflection
0	0.0	0.00	104.2	0.000
1	27.8	2.88	147.1	0.055
2	55.5	5.76	275.9	0.219
3	83.3	8.64	490.5	0.492
3.416	94.8	9.84	605.0	0.638
4	111.0	11.52	790.9	0.875

Spreadsheet for the formula if needed by employee will be attached along with this document.

Procedure:

Create a plot graph of the required pump power vs flow rate, then calculate the flow rate when pump power is half of what was computer before.

Calculation:



Half of required pump power computed before(95 H.P) is 47.5 H.P.

From this graph, at 47.5 HP, the approximate flow rate is ~1.65 ft^3/s

To calculate the manometer reading for 1.65 ft^3/s, I'll input that into the previously created table to find deflection, which turned out to be **0.149 ft**

Section 3				
Q	P(pump)	V	ΔP	h2
Q (ft^3/s)	HP	ft/s	lb/ft^2(PSF)	ft
Flow rate	Pump Power	Velocity	U-Tube nanometer	Deflection
0	0.0	0.00	104.2	0.000
1	27.8	2.88	147.1	0.055
1.65	45.8	4.75	221.0	0.149

Materials:

- Water
- 8-in schedule 40 steel pipe

- Valve (k = 5.3)
- U-tube manometer
- Mercury

Summary:

Different values of deflection and pump power for flow rate from 0 to 4 ft^3/s is listed above in the Calculation spreadsheet. Along with the half required pump power of 95 is 47.5 HP, and its flow rate respectively is 1.65 ft^3/s, along with a deflection in manometer of 0.149 ft (1.8 inch)

Analysis:

The spreadsheet calculating different deflection based on ΔP, and γ_{water} $\gamma_{mercury}$, employee can access this spreadsheet and changing flowrate to any value as needed in cell I29 to I34, the graph is also included in the same sheet as well.