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Submitted 10/3/2022

Exam 1

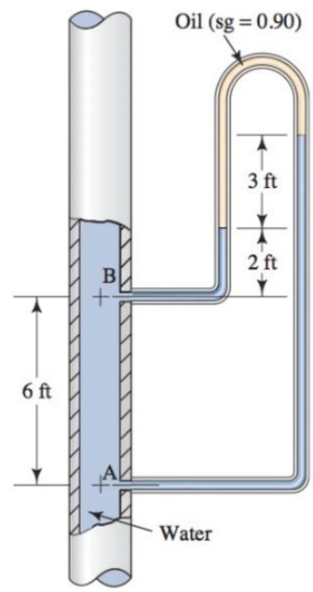
MET 330

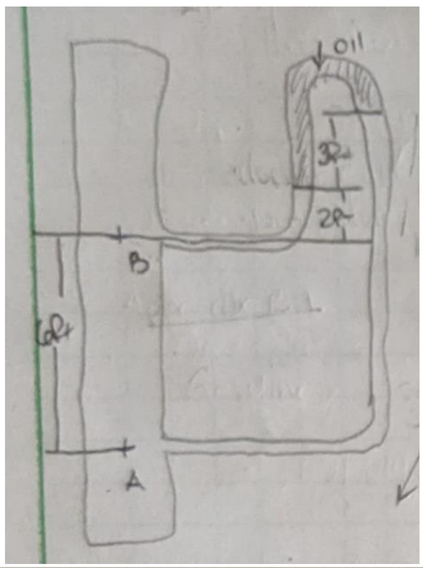
Problem 1

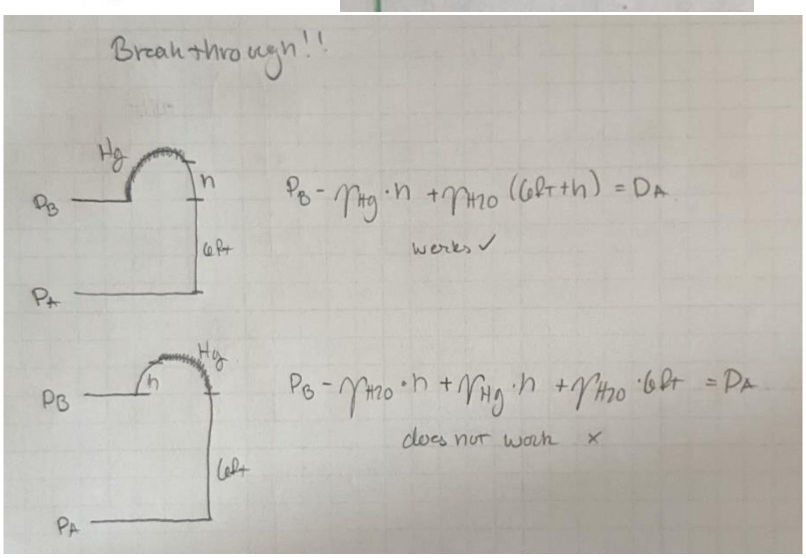
Purpose:

Given the same manometer, calculate the deflection differences for varying fluid (more and less dense than oil) while maintaining the same pressure difference. By understanding the deflection location, you can determine the minimum height necessary for the manometer to prevent the fluid from seeping into the system.

Drawings & Diagrams:







Sources:

Applied Fluid Mechanics, 7th edition by Robert L. Mott and Joseph A. Untener

Design Considerations:

The fluid in the manometer is not moving. The process is isothermal and the fluids provided are all incompressible.

The water between the fluid being used and point B effectively cancels out the same amount of water on the right side of the system, so when calculating the minimum height for the manometer, this may be removed.

That said, the Mercury must be climbed up through whereas the gasoline must be climbed down through. This changes the respective heights for the systems' manometers, as the mercury manometer still needs the U-shape that goes above point B, and the gasoline systems technically does not.

Data and Variables:

$h_{deflection_{oil}} = \mathbf{3}\text{ft}$

$h_1 = \mathbf{6}\text{ft}$

$h_2 = \mathbf{2}\text{ft}$

$sg_{oil} = \mathbf{0.90}$

$\gamma_{oil} = \mathbf{56.16}\text{lb} / \text{ft}^3$

$\gamma_{water@4C} = \mathbf{62.4}\text{lb} / \text{ft}^3$

$\gamma_{water@77F} = \mathbf{62.2032}\text{lb} / \text{ft}^3$

$\gamma_{gasoline} = \mathbf{42.40}\text{lb} / \text{ft}^3$

$sg_{mercury} = \mathbf{13.54}$

$\gamma_{mercury} = \mathbf{869.268}\text{lb} / \text{ft}^3$

$P_a - P_b = \mathbf{2.7177}\text{psi}$

Procedure:

Using the known conditions of oil, deflection, and pressure, determine the current specific weight of water (system may not be at a standard temperature). Knowing that the heights in the system will change with the changing fluids, label known heights and understand what parts are cancelling out (began to understand on page 5 of the calculations). Using this, solve for the new deflection while changing the fluid to gasoline, knowing that the pressure difference stays the same. Repeat this process with Mercury.

Understanding whether you need to move up through the fluid of down (based off positive or negative deflection in your solutions), determine manometer minimum heights for each fluid. For the Mercury, starting at point B, you must move up through the deflection, so this deflection height becomes the minimum height for the left half of the manometer. In turn, the right half must have the same 6ft of water + the height of the left half (water offsetting the mercury deflection).

Calculations:

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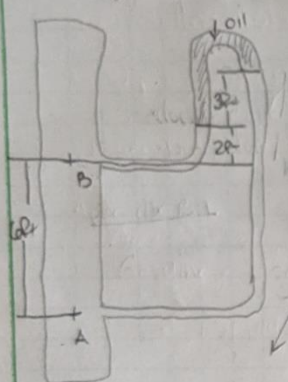
Problem 1

$\Delta p = 2.7177 \text{ psi} = 2.7177 \frac{lb}{in^2} \cdot \frac{144 \, in^2}{1 \, ft^2} = 391.3488 \frac{lb}{ft^2}$.

$sg_{oil} = 0.90$

$\gamma_{oil} = sg \cdot \gamma_{water} @ 4°C = 0.90 \times 62.4 \, lb/ft^3 = 56.16 \, lb/ft^3$.



moving through manometer w/ oil first

$P_B - \gamma_{water} \times 2ft - \gamma_{oil} \times 3ft + \gamma_{water} \times 11ft = P_A$

$\Rightarrow \gamma_{water} \times 9ft - \gamma_{oil} \times 3ft = P_A - P_B$

$\Rightarrow 62.4 \frac{lb}{ft^3} \times 9ft - 56.16 \frac{lb}{ft^3} \times 3ft = 393.12 \frac{lb}{ft^2}$

- close enough for acceptable margin of error.
- but going to solve for γ_{water} and use that value henceforth

$$\frac{P_A - P_B + \gamma_{oil} \times 3ft}{9ft} = \gamma_{water}$$

$$\gamma_{water} = \frac{391.3488 \frac{lb}{ft^2} + 56.16 \frac{lb}{ft^3} \times 3ft}{9ft}$$

$\gamma_{water} = 62.2032 \, lb/ft^3$ — water ~80F

— later verified by email to be 77F

moving to gasoline

- assuming the deflection stays the same and only Δp changes are due to γ_{gas}

$P_B - \gamma_{water} \cdot 2ft - \gamma_{gas} \cdot 3ft + \gamma_{water} \cdot 11ft = P_A$

$\Rightarrow \gamma_{water} \cdot 9ft - \gamma_{gas} \cdot 3ft = P_A - P_B$

$\Rightarrow 62.2032 \frac{lb}{ft^3} \cdot 9ft - 42.40 \frac{lb}{ft^3} \cdot 3ft = P_A - P_B$

From Table B.2 — $\gamma_{gasoline} = 42.40 \frac{lb}{ft^3}$

$\Rightarrow P_A - P_B = 432.6288 \frac{lb}{ft^2} \cdot \frac{1ft^2}{144 in^2} = 3.004 \text{ psi}$

• so, I think my process was wrong.

I was looking for Δp with changing h, but that will just tell me flow within the pipe.

is it more...

$P_A - P_B - \gamma_{water} \cdot 9ft = -\gamma_{fluid} \cdot h$

$P_A - P_B - \gamma_{water} \cdot 6ft = -\gamma_{fluid} \cdot h_1 + \gamma_{water} \cdot h_2$?

~~because~~ if the pressure at A becomes so great it moves the oil 2 more feet, you get

$P_A - P_B - \gamma_{water} \cdot 11ft = -\gamma_{oil} \cdot 5ft$?...

but if the loop of the manometer drops by 2ft, you get.

$P_A - P_B - \gamma_{water} \cdot 8ft = -\gamma_{oil} \cdot 3ft$

so $6ft = h_1$ ← static? I think
$2ft = h_2$
$3ft = h_3$.

original equation (with oil)

~~$P_B - \underbrace{\gamma_{water} \cdot h_2}_{} = \gamma_{oil} \cdot h_3 + \gamma_{water} \cdot h_2 + \gamma_{water} \cdot h_1 = P_A$~~

if h_2 removed, you get above equation

this is difficult. $P_A - P_B$ changes with any height changes

nope, would be

original:

$P_B - \gamma_{water} \cdot h_2 - \gamma_{oil} \cdot h_3 + \gamma_{water} h_3 + \gamma_{water} \cdot h_2 + \gamma_{water} \cdot h_1 = P_A$

if dropping 2ft get.

$P_B - \gamma_{oil} \cdot h_3 + \gamma_{water} \cdot h_3 + \gamma_{water} \cdot h_1 = P_A$

∴ but if P_A & P_B change with h, then deflection would not remain the same.

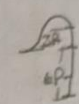
I just do not get what I am trying to do.

so, should I make a table of h_1, h_2, + h_3 values?
but when do I know it has sept into the system?

is it when $\gamma_{oil} \cdot h > \gamma_{H_2O} \cdot h$

that will not happen, the inverse is already true

Well, derp, if I run the oil calc with the hypothetical 2ft drop of pipe, I can see how it affects pressure.



$P_B - \gamma_{oil} \cdot 3ft + \gamma_{water} \cdot 9ft = P_A$

$-56.16 \frac{lb}{ft^3} \cdot 3ft + 62.0832 \frac{lb}{ft^3} \cdot 9ft = P_A - P_B$

$P_A - P_B = 391.3488 \; lb/ft^2$. oh, duh, the 2ft of water cancels itself

- but in this case, the oil should be at B. I am, I think, fundamentally doing something wrong?
  - because how can the pressure be the same and now oil in the mix?

Going to make progress on problem 2 and return.

$P_A - \gamma \cdot 6 - \gamma_{water} \cdot h - \gamma_{gas} \cdot h \qquad = P_B$.

is $h_{gas} > h_{oil}$?

h smaller.

with gas

$P_B - \gamma_{water} \cdot h_1 - \gamma_{gas} \cdot h_2 + \gamma_{water} \cdot h_1 + \gamma_{water} \cdot 6ft + \gamma_{water} \cdot h_2 = P_A$.

$P_A - P_B$ remains $391.3488 \frac{lb}{ft^3}$.

$P_A - P_B = (\gamma_{water} \cdot (6ft - \cancel{h_1} - \cancel{h_3})) - \gamma_{gas} \cdot h_2$

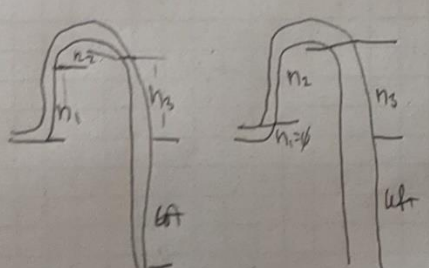
h_1 normally being 2ft
h_3 ~~normally~~ being 1-2ft
h_2 normally being 3ft

h_1 + h_3 effectively cancel

$$\frac{(P_A - P_B) - (\gamma_{water} \cdot 6ft)}{-\gamma_{gas}} = h_2$$

$$\frac{(391.3488 \frac{lb}{ft^2}) - (62.7032 \frac{lb}{ft^3} \cdot 6ft)}{-42.40 \frac{lb}{ft^3}} = -0.4276 ft$$

∴ nope.



error

$P_B - \gamma_{water} \cdot h_1 - \gamma_{gas} \cdot h_2 + \gamma_{water} \cdot h_1 + \gamma_{water} \cdot h_2 + \gamma_{water} \cdot 6ft = P_A$

$P_A - P_B = -\gamma_{gas} \cdot h_2 + \gamma_{water} \cdot h_2 + \gamma_{water} \cdot 6ft$

$P_A - P_B - \gamma_{water} \cdot 6ft = h_2 \cdot (\gamma_{water} - \gamma_{gas})$

$$\frac{P_A - P_B - \gamma_{water} \cdot 6ft}{\gamma_{water} - \gamma_{gas}} = \frac{391.3458 \frac{lb}{ft^2} - 62.2032 \frac{lb}{ft^3} \cdot 6ft}{62.2032 - 42.40 \frac{lb}{ft^3}}$$

$\boxed{h_2 = 0.9155 \ ft}$

♡

$\uparrow 8ft = h_1$ $\quad \uparrow 3ft = h_2$ $\quad \downarrow 2ft = h_1$ $\quad$ no h_3

$\Delta p = \rho \cdot g \cdot h$ $\quad$ if $\rho \downarrow$, $\Delta p =$, $h \uparrow$, $g =$

$\gamma = \rho \cdot g$ $\quad$ Concept: increase h_2 by amount ρ decreases by.

$$\rho_{oil} = \frac{56.16 \frac{lb}{ft^3}}{32.2 \frac{ft}{s^2}} = 1.7441 \frac{lb \cdot s^2}{ft^4} \quad \left(\frac{lb}{ft^3} \cdot \frac{s^2}{ft}\right)$$

$$\rho_{gas} = \frac{42.40 \frac{lb}{ft^3}}{32.2 \ ft/s^2} = 1.3168 \frac{lb \cdot s^2}{ft^4}$$

25% smaller

$h_1 + h_2 = 5ft$

$h_2 = 3ft \longrightarrow 3.75 ft$

$h_1 \rightarrow 1.25 ft$

$P_B - \cancel{\gamma_{water} \cdot 1.25ft} - \gamma_{gas} \cdot 3.75ft + \gamma_{water} \cdot 3.75ft + \cancel{\gamma_{water} \cdot 1.25ft} + \gamma_{water} \cdot 6ft = P_A$

$P_A - P_B = \gamma_{water} \cdot 9.75ft - \gamma_{gas} \cdot 3.75ft$

$= 447.4812$

6/9

↓ is pos, ↑ is neg

$$\cancel{P_B - \gamma_{H2O}\cdot 1.25ft - \gamma_{gas}\, 3.75ft + \gamma_{water}\cdot 5ft + \gamma_{water}\, 6ft = P_A}$$

$$\cancel{P_A - P_B = \gamma_{H2O}\cdot 9.75ft - \gamma_{gas}\cdot 3.75ft}$$

$$\cancel{= 447.4812}$$

• so, it makes sense to me that since ρ↓ between oil and gas, h↑. however, that is not the result I got.

but when I calc pressure with h = 0.9155ft, it checks out. maybe I am considering too fine a picture and not looking at H_2O changes enough.

by h_2↓ for gas, the h_1 of water cancels itself out more

↑ ↓

$\boxed{h_{2_{gas}} = 0.9155ft}$ sticking with it.

Doing the same with Hg. $S_g = 13.54$ $\gamma_{Hg} = 869.268\ lb/ft^3$

$$P_B - \cancel{\gamma_{H2O}\cdot h_1} - \gamma_{Hg}\cdot h_2 + \cancel{\gamma_{H2O}\cdot h_1} + \gamma_{H2O}\cdot h_2 + \gamma_{H2O}\cdot 6ft = P_A$$

$$P_A - P_B - \gamma_{H2O}\cdot 6ft = (\gamma_{H2O} - \gamma_{Hg})\cdot h_2$$

$$h_2 = \frac{P_A - P_B - \gamma_{H2O}\cdot 6ft}{\gamma_{H2O} - \gamma_{Hg}} = \frac{391.3488\ \frac{lb}{ft^3} - 62.2032\ \frac{lb}{ft^3}\cdot 6ft}{62.2032 - 869.268\ lb/ft^3}$$

$$h_{2_{Hg}} = -0.02246ft$$

so, already exceeds the space of the manometer?

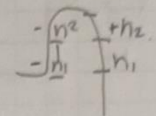
$\Delta P = \rho \cdot g \cdot h$

$\rho_{gas} = 1.3168 \frac{lb \cdot s^2}{ft^4}$ $\rho_{oil} = 1.7441 \frac{lb \cdot s^2}{ft^4}$ $\rho_{Hg} = 26.234 \frac{lb \cdot s^2}{ft^4}$

$\rho_{gas} = \frac{\rho_{oil}}{1.3245}$ $h_{oil} = 3ft.$ ~~$h_{gas} = 3ft \times 1.3245$?~~

$\frac{\Delta P}{g} = \rho \cdot h$ num. $\frac{\Delta P}{g \cdot \rho} = h$

$$\cancel{\frac{391.3488 \frac{lb}{ft^2}}{32.2 \frac{ft}{s^2} \cdot 1.3168 \frac{lb \cdot s^2}{ft^4}}} = h_{gas} = 9.23ft.$$



well, not the whole equation, so not fair.

$$P_B - \cancel{\gamma_{H_2O} \cdot h_1} - \gamma_{gas} \cdot h_2 + \gamma_{H_2O} \cdot h_2 + \cancel{\gamma_{H_2O} \cdot h_1} + \gamma_{water} \cdot 6ft = P_A$$

$$P_A - P_B - \gamma_{water} \cdot 6ft = h_2 \cdot (\gamma_{H_2O} - \gamma_{gas})$$ $h_1 = 5ft - h_2$?

$$h_2 = \frac{P_A - P_B - \gamma_{H_2O} \cdot 6ft}{\gamma_{H_2O} - \gamma_{gas}} = \frac{391.3488 \frac{lb}{ft^2} - 62.2032 \frac{lb}{ft^3} \cdot 6ft}{62.2032 \frac{lb}{ft^3} - 42.40 \frac{lb}{ft^3}} = \boxed{h_{2_{gas}} = 0.9155 ft}$$

remains.

- but what if that is because I am assuming incorrectly?
- like if I assume the water will not travel the $+h_2$ part because the gas displaces so greatly
  - or the water does not travel the $-h_1$ height for a similar reason

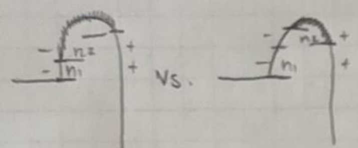
Running through the same process for Mercury results in a negative h_2, which tells me I am either doing the process wrong or the manometer is not tall enough
- the latter should not be true because Hg so much more dense that gasoline that gasoline should displace more

$$h_2 = \frac{P_A - P_B - \gamma_{H_2O} \cdot 6ft}{\gamma_{H_2O} - \gamma_{Hg}} = \frac{391.3488 \frac{lb}{ft^2} - 62.2032 \frac{lb}{ft^3} \cdot 6ft}{62.2032 \frac{lb}{ft^3} - 869.268 \frac{lb}{ft^3}}$$

$$\boxed{h_{2_{Hg}} = -0.02247 ft}$$

- emailed Dr. Ayala the above sheet, verified $h_{2_{gas}}$ & $h_{2_{Hg}}$ correct.

exiting height of the manometer is unknown >6ft.
~ my assumption is that it just has to be bigger than the value for h_2.
because $-h_1$ and $+h_1$ are just water cancelling each other out.
↳ but how does that work for the answer for mercury?
• is the $-h_2$ value saying that the mercury is displacing the water?



Equation would be (I think...)

$$P_B - \cancel{\gamma_{H_2O}} \cdot h_1 - \gamma_{H_2O} \cdot h_2 + \gamma_{Hg} \cdot h_2 + \cancel{\gamma_{H_2O}} \cdot h_1 + \gamma_{H_2O} \cdot 6ft = P_A$$

$$P_A - P_B = \gamma_{H_2O} \cdot (6ft - h_2) + \gamma_{Hg} \cdot h_2$$

$$= 62.2032\tfrac{lb}{ft^3} \cdot (6ft - (-0.022478ft)) + 869.268\tfrac{lb}{ft^3} \cdot (-0.022478ft)$$

$$P_A - P_B = 355.0845\,\frac{lb}{ft^2}$$

mmm, close ~~but~~ wouldn't really call that an acceptable error margin.
however
I think this is the right idea for what the mercury is doing to the water.

I am assuming that minimum manometer height involves everything above the 6ft of water, so all height calcs are +6ft.

Gas

~~removing h_1 should be fine because it effectively cancels itself out. height just needs to be~~

~~$> h_2$ $\quad$ $x > 0.9155ft$ $\quad$ (1ft for round numbers)~~

Mercury

~~assuming the above concept is correct, the mercury requires $-h_2$ to stay filled with water.~~

~~$> |h_2|$~~

~~but also the mercury should not push into the water's 6ft tubing, so $+h_1$ is max distance the manometer may be reduced by~~

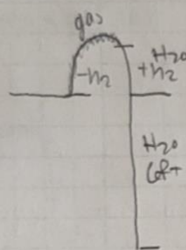
$h_1 > x > |h_2|$

- from pretest feedback, seemingly wants manometer height broken up into right and left halves with 6ft included

<u>so</u>

<u>Gas</u>

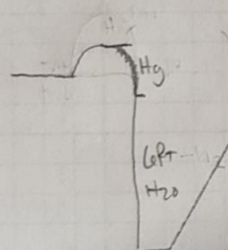
$h_2 = 0.9155 ft$



Right half: $6ft + 0.9156 ft$
$= 6.9156 ft$ minimum.

Left half: $0.9156 ft$.

<u>Mercury</u>



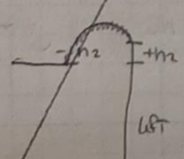
Right half $= 6ft + |-0.02248 ft| = 6.02248 ft$

Left half $= |-0.02248 ft| = 0.02248 ft$

Theory: $6ft - |h_2|$

$P_B + \gamma_{Hg} \cdot h_2 + \gamma_{H_2O}(6ft - h_2) = P_A$.

~~$P_A - P_B =$~~ nope.



Theory: system <u>must</u> go up through Hg.

$P_B - \gamma_{Hg} \cdot h_2 + \gamma_{H_2O}(6ft + h_2) = P_A$.

$P_A - P_B = \gamma_{H_2O}(6ft + h_2) - \gamma_{Hg} \cdot h_2$

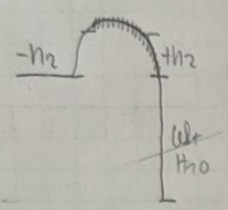
$= 355$

but then why did h_2 come out <u>negative</u>?

does it mean that the mercury must be climbed up through and the gasoline <u>down</u>?

no, <u>yes</u> tested on pg 10.

Gas

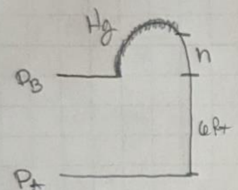


$$P_B - \gamma_{H_2O} \cdot h_2 + \cancel{\gamma_{gas} \cdot h_2} + \gamma_{H_2O} \cdot 6ft = P_A.$$

$$\cancel{P_A - P_B} = \gamma_{H_2O} \cdot (6ft - 0.9155ft) + \gamma_{gas}(0.9155ft)$$

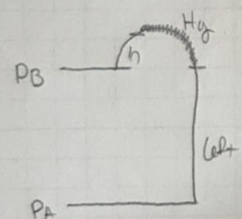
$$= 355.089 \tfrac{lb}{ft^2}$$

Breakthrough!!



$$P_B - \gamma_{Hg} \cdot h + \gamma_{H_2O}(6ft + h) = P_A$$

works ✓



$$P_B - \gamma_{H_2O} \cdot h + \gamma_{Hg} \cdot h + \gamma_{H_2O} \cdot 6ft = P_A$$

does not work ×

I could cry. I finally get it.

<u>so, pipes.</u>

Gas: right half: $\overset{H_2O}{(6 - 0.9155)} + \overset{gas}{0.9155ft}$. > 6ft
left half: cancels out > ~~6ft~~.

Mercury: right half: $(\overset{H_2O}{6ft} + \overset{Hg}{0.022478ft})$ > 6.022478ft
left half: $\underset{H_2O}{(0.022478ft)}$ > 0.022478ft

· these left-half distances are my assuming that if the gas/oil/mercury ends up on the horizontal from A or B, it has seept into the system.

Summary:

Gas is less dense than oil, but this does not mean its displacement is greater for an equal pressure. The gasoline must be additive to the main water (the portion originally at 6ft), whereas the Mercury must cancel this same portion out. The gasoline will displace 0.9155ft (when starts from Point B), whereas the Mercury will displace -0.02247ft (meaning it must be climbed up through in the images presented).

The change between sides of the manometer between Gasoline and Oil means there is a particular tipping point between the specific weight of the two fluids where it will move to the other side of the manometer.

Materials:

Gas: Left half of the manometer only needs to be bigger than 0ft, right half of the device needs to be a total of over 6ft long (5.0845ft of H20 and 0.9155ft of Gasoline).

Mercury: Left half of the manometer only needs to be bigger than 0.02247ft of Mercury, right half of the device needs to be over 6.02247ft long (6.02247ft of H20)

Analysis:

For perspective, my starting point for all calculations was point B. The part I was stumbling over immensely was on page 6, where I obtained that the displacement for Mercury was negative. After reaching out to Dr. Ayala, this was confirmed correct, which meant I did not understand what it meant. On page 10, I came to understand that the Mercury needed to be climbed up through (so negative) whereas the water needed to be climbed down through (positive) to end up with a positive pressure. The negative deflection for Mercury is the same as running the oil calculation on page 1, but it really tripped me up.

Any water between point B and the fluid essentially cancels out on the right side of the manometer (proven repeatedly in generating equations), so when considering minimum necessary manometer height, this factor may be removed.

Using fluids of specific weights between gasoline and oil, the fluid (or fluid and temperature combination?) specific weight that determines which side of the manometer the fluid will land on could be zeroed in.

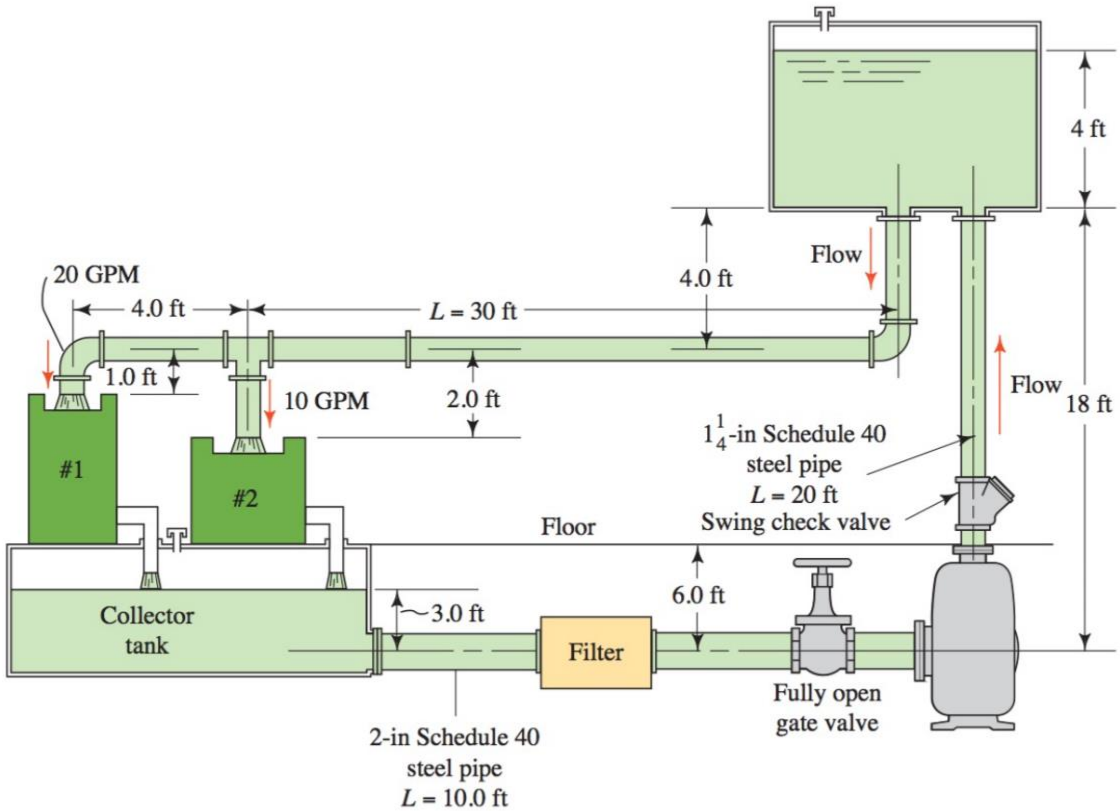
Using a medium like oil (or, I am guessing, closer to the specific weight of water) works better for the manometer for being easier to read. Both the mercury and gasoline deflections were smaller and therefore harder to read, so something like oil works better from the standpoint of taking measurements.

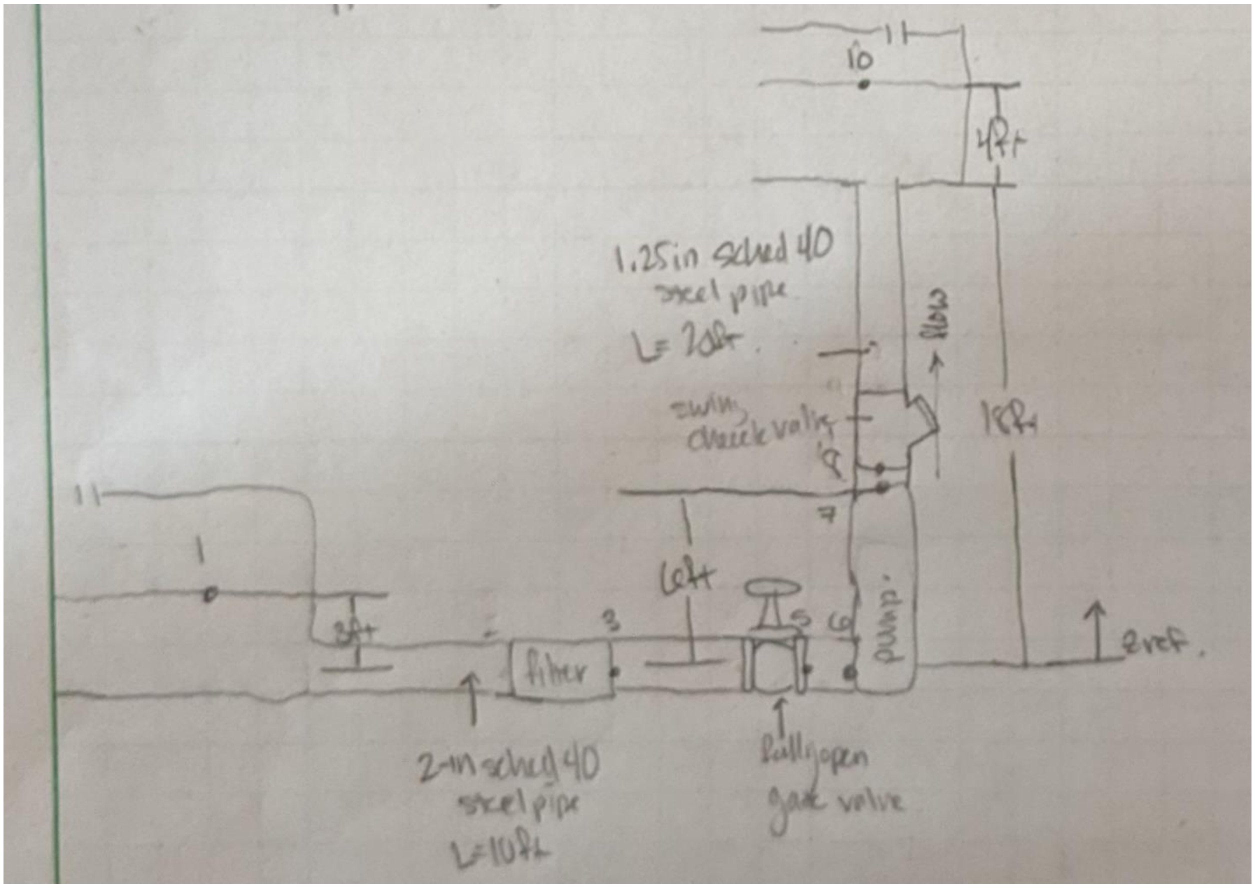
Problem 2

Purpose:

Problem 2 functions as a sampler for the semester-long group project. Being given a flow rate and velocity for the coolant, determine the most appropriate pipe size. Using the actual diameter (as opposed to the ideal), calculate the new velocity and then begin determining the losses along the system (losses due to friction in both the suction and discharge lines, losses due to the valves). Determine the necessary pump head (and from that, pump power) to maintain the desired flow rate and calculated velocity while overcoming the above losses.

Drawings & Diagrams:





Sources:

Applied Fluid Mechanics, 7th edition by Robert L. Mott and Joseph A. Untener

Design Considerations:

Coolant is considered incompressible and isothermal. Flow rate through the system will remain equal to 60gal/min with no deviation. System is steady-state. Replacement pipes design for the new system will center on the same points at the existing 2in and 1.25in pipes, keeping the same z distance. Vents in collector tanks vent to atmospheric pressure.

Anticipated cost for installing the chosen 1.5in system is $268.24 USD, per excel calculations, and is assuming we will keep the already planned for filter, gate valve, and swing check valve. This is also leaving a +15% ceiling for unexpected costs in the installation of the 30ft of piping.

With the chosen piping, the velocity is approximately 9.44ft/s (versus desired 9.843ft/s) but maintains desired flow rate. Any larger and the above pump power can no longer draw enough suction to function. Valves on either side of the pump may not be omitted for safety reasons. If desired for future expansion, a flange may be added on the discharge line of the pump, but new calculations would need to be performed for the energy losses to see if the existing pump could maintain the system.

Data and Variables:

$\gamma_{water@4C} = \mathbf{62.4} lb / ft^3$

$\eta = \mathbf{3.6 * 10^{-5}} \frac{lb * s}{ft^2}$

$Q = \mathbf{60} \frac{gal}{\mathbf{min}}$

$K_{filter} = \mathbf{1.85}$

$V = \mathbf{3} \frac{m}{s}$

$Electricity = \frac{\mathbf{730} USD}{kW * \mathbf{2} Yrs}$

$sg_{coolant} = \mathbf{0.92}$

$L_{suction} = \mathbf{10} ft$

$L_{discharge} = \mathbf{20} ft$

Pipe nominal size (in)	Cost per 6 ft
½	$12.95
¾	$17.95
1	$23.95
1 ¼	$28.95
1 ½	$33.95
2	$46.95
2 ½	$71.95
3	$92.95

Procedure:

Take the desired new flow rate (60gal/min) and convert to ft^3/s. Take the desired velocity of the coolant in the system (3m/s) and convert to ft/2. Dividing flow rate by velocity gives you an ideal area for the pipes, and using that, the inside diameter of the pipe can be determined. In the appendix of the book, go to the schedule 40 pipes and choose the inside diameter most appropriate for the results – I chose the 1.5in schedule 40 piping.

Using the new diameter for the chosen piping, calculate the velocity for this (while maintaining the ideal flow rate) and use that as the velocity for the entire system. Declaring a zreference in the diagram, begin using Bernoulli's to chip away at individual sections of the system.

Starting from point 1 to point 3 (where I declared them), calculated the losses due to the filter. This requires using the provided K, and just note this value down for now. Progressing further down the pipe, calculate the losses due to the gate valve (using tables in chapter 10 to determine the appropriate K value). Again, note this value down. Finally (for the suction line), take between points 1 and 6. Calculate the losses due to friction (using length (10ft), diameter of the chosen pipe, and velocity head). You'll have to calculate the f by using relative roughness (refer to chapter 8, table 8.2 for roughness) and Reynolds' number, and then obtain the f from either moody's chart or the calculation (listed as equation 8-7 in the book).

Now use Bernoulli's between points 1 and 6, along with every loss inbetween (filter, gate valve, and friction along the suction line) to determine the pressure at 6 – which corresponds with the pressure at the pump inlet.

Calculate the losses due to the swing valve (using the K equation from 10.18 in the book). Next, looking between points 1 and 7, calculate the friction loss in the discharge pipe (the Reynolds number will be the same from the calculation along the suction line, but the loss will change because this pipe is 20ft long vs 10ft). After, use Bernoulli's between points 1 and 7, including the discharge friction loss and the swing valve loss) to determine the pressure at the outlet of the pump.

Now, use Bernoulli's between points 1 and 7 to get the pump head. Include all losses along the way (filter, gate valve, suction line friction). Using the pump head, determine power, and convert that power to hp (and separately, kW for future use).

Using excel, run all the above calculations but for +/-2 sizes of the pipes from the one you chose. Using the provided pricing chart (see Drawings & Diagrams for this problem), calculate the installation cost for each of the 5 types of pipes. Using the provided 730USD/kW*2yrs (and the hp we converted to kW earlier), calculate the cost for maintenance for each of the 5 pipe types.

Adding those costs together, make a graph comparing the costs.

Calculations:

Problem 2

$$Q = 60\,\frac{gal}{min} \cdot \frac{1\,ft^3/s}{449\,\frac{gal}{min}} = 0.1336\,\frac{ft^3}{s}$$

$sg = 0.92$

$\eta = 3.6 \times 10^{-5}\,\frac{lb \cdot s}{ft^2}$

$\gamma_{coolant} = 0.92 \times 62.4\,lb/ft^3 = 57.048\,lb/ft^3$.

$K_{filter} = 1.85$

$$\rho = \frac{\gamma}{g} = \frac{57.048\,\frac{lb}{ft^3}}{32.2\,\frac{ft}{s^2}} = 1.7717\,\frac{lb \cdot s^2}{ft^2}$$

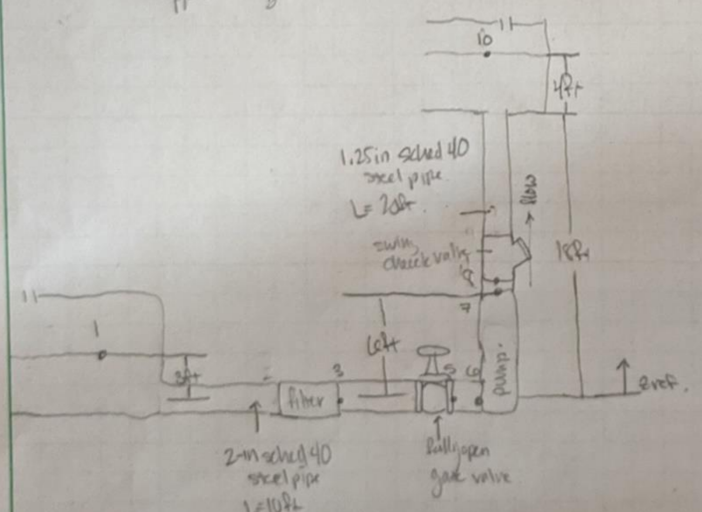
$$V = 3\,\frac{m}{s} \cdot \frac{3.281\,ft}{1\,m} = 9.843\,\frac{ft}{s}$$

$$A = \frac{Q}{V} = \frac{0.1336\,\frac{ft^3}{s}}{9.843\,\frac{ft}{s}} = 0.01357\,ft^2$$

$$A = \frac{\pi \cdot D^2}{4} \Rightarrow \sqrt{\frac{4A}{\pi}} = D = 0.1314\,ft.$$

referring to appendix F. $\boxed{1\tfrac{1}{4}\text{ inch schedule 40 has ID of } 0.1342\,ft}$

• in original design, I am unsure why the two pipes connected to the pump are different sizes.



Equations

$$h_L = f \cdot \frac{L}{D} \cdot \frac{V^2}{2g}$$

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

$Q = V \cdot A$

$A = \frac{\pi \cdot D^2}{4}$

$$Re = \frac{V \cdot D \cdot \rho}{\eta}$$

$$\frac{D}{\varepsilon}$$

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

$$h_L = K \frac{V^2}{2g}$$

valves/fittings

$$K = \frac{L_e}{D} \cdot f_T$$

problem 2

point 1	point 10	point 3
$P_1 = \emptyset$ psig	$P_{10} = \emptyset$ psig	
$V_1 = \emptyset$ ft/s	$V_{10} = \emptyset$ ft/s	
$z_1 = 3$ ft	$z_{10} = 22$ ft	

System

$$h_A + \frac{\cancel{P_1}}{\gamma} + \frac{\cancel{V_1^2}}{2g} + z_1 = \frac{\cancel{P_{10}}}{\gamma} + \frac{\cancel{V_{10}^2}}{2g} + z_{10} + h_{L_{suction}} + h_{L_{filter}} + h_{L_{gate}} + h_{L_{discharge}} + h_{L_{swing}}$$

$$h_A + z_1 = z_{10} + h_{L_{suction}} + h_{L_{filter}} + h_{gate} + h_{discharge} + h_{swing}$$

going for $h_{L_{filter}}$ — points 1-3

$K_{filter} = 1.85$

$$h_{L_{filter}} = K \cdot \frac{V^2}{2g} = 1.85 \times \frac{(9.834\ ft/s)^2}{2 \cdot 32.2\ ft/s^2} = 2.778\ ft$$

will handle suction between 1 and 6

$$\cancel{h_A} + \frac{\cancel{P_1}}{\gamma} + \frac{\cancel{V_1^2}}{2g} + z_1 = \frac{P_3}{\gamma} + \frac{V_3^2}{2g} + \cancel{z_3} + h_{L_{filter}}$$

$$P_3 = \left(z_1 - h_{L_{filter}} - \frac{V_3^2}{2g}\right)\gamma_{coolant} = \left(3ft - 2.778ft - \frac{9.843\ ft^2/s^2}{2 \cdot 32.2\ ft/s^2}\right) \cdot 57.048\ lb/ft^3$$

$P_3 = -73.1595\ \frac{lb}{ft^2}$ · seems correct, given in suction line.

Point 3
$P_1 = -73.1595\ \frac{lb}{ft^2}$
$V_1 = 9.843$ ft/s
$z_1 = \emptyset$ ft

... is? this depends on if we're replacing the suction pipe and discharge and if this velocity is desired for both.

- established that we are replacing both suction & discharge (Thanks, Dr. Ayala!)
- still confused about why the original pipes are different & if we should still do that?
  - is the purpose just to try & match friction losses?
    - because how do I calculate that?

· Dr. Ayala confirmed we should use the calculated diameter for both suction & discharge

:)

after realizing my error on page 5, this should be diameter of 1.5" pipe, not calculated diameter.

Faye.

problem 2.

going for $h_{L_{gate}}$ - between 1 + 5

$$\frac{P_1}{\gamma} + \frac{V_1^2}{2g} + z_1 = \frac{P_5}{\gamma} + \frac{V_5^2}{2g} + z_5 + h_{L_{filter}} + h_{L_{gate}}$$

$$h_{L_{gate}} = K \cdot \frac{V^2}{2g}$$

$K = \frac{L_e}{D} \cdot f_T = 0.16$

$\frac{L_e}{D}$ + f_T from table 10.4 + 10.5

$\frac{L_e}{D} = 8$ $\quad f_T = 0.020$

$$= 0.16 \cdot \frac{(9.843\ ft/s)^2}{2 \cdot 32.2\ ft/s^2}$$

$h_{L_{gate}} = 0.2407\ ft$ ✓

$$P_5 = \left(z_1 - h_{L_{filter}} - h_{L_{gate}} - \frac{V_5^2}{2g}\right) \cdot \gamma_{coolant}$$

$$= \left(3ft - 2.778ft - 0.2407ft - \frac{(9.843\ ft/s)^2}{2 \cdot 32.2\ ft/s^2}\right) \cdot 57.048\ \frac{lb}{ft^3}$$

$P_5 = -86.891\ \frac{lb}{ft^2}$

going for $h_{L_{suction}}$ and P_6 — between points 1 + 6

$$\frac{P_1}{\gamma} + \frac{V_1^2}{2g} + z_1 = \frac{P_6}{\gamma} + \frac{V_6^2}{2g} + z_6 + h_{L_{filter}} + h_{L_{gate}} + h_{L_{suction}}$$

$$h_{L_{suction}} = f \cdot \frac{L}{D} \cdot \frac{V^2}{2g}$$

$$Re = \frac{V \cdot D \cdot \rho}{\eta} = \frac{9.843\ ft/s \cdot 0.13144\ ft \cdot 1.7717\ \frac{lb \cdot s^2}{ft^2}}{3.6 \times 10^{-5}\ \frac{lb \cdot s}{ft^2}}$$

$\epsilon_{steel} = 1.5 \times 10^{-4}\ ft$

$$\frac{D}{\epsilon} = \frac{0.13144\ ft}{1.5 \times 10^{-4}\ ft}$$

$\frac{D}{\epsilon} = 876.2667$

$Re = 63671.154$ · not turbulent flow

from moody chart

$f \approx 0.024$

$$h_{L_{suction}} = 0.024 \cdot \frac{10ft}{0.13144ft} \cdot \frac{(9.843\ ft/s)^2}{2 \cdot 32.2\ ft/s^2} = 2.747\ ft$$ ✓

$$P_6 = \left(z_1 - \frac{V_6^2}{2g} - h_{L_{filter}} - h_{L_{gate}} - h_{L_{suction}}\right) \cdot \gamma_{coolant}$$ ✓

$$P_6 = \left(3ft - \frac{(9.843\ ft/s)^2}{2 \cdot 32.2\ ft/s^2} - 2.778ft - 0.2407ft - 2.747ft\right) \cdot 57.048\ lb/ft^3 = -243.6018\ \frac{lb}{ft^2}$$

$P_G = P_{pump\,inlet} = -243.6017 \frac{lb}{ft^2} \cdot \frac{1ft^2}{144 in^2} = \boxed{-1.692\ psi}$

Between 10 and 8 to get $h_{L_{swing}}$

$$\cancel{\frac{P_{10}}{\gamma}} + \cancel{\frac{V_{10}^2}{2g}} + z_{10} = \frac{P_8}{\gamma} + \frac{V_8^2}{2g} + z_8 + h_{L_{swing}}$$

$h_{L_{swing}} = K \cdot \frac{V^2}{2g}$ $\quad K = 100 \cdot f_T \quad f_T = 0.020$

$K = 2$

$$h_{L_{swing}} = 2 \cdot \frac{(9.843 \frac{ft}{s})^2}{2 \cdot 32.2 \, ft/s^2} = 3.0088 ft.$$

Between 10 and 7 to get P_7 and h_L discharge.

$h_{L_{dis}} = f \cdot \frac{L}{D} \cdot \frac{V^2}{2g} =$

f is same as $h_{L_{suction}}$ f

$f = 0.024$

$$h_{L_{discharge}} = 0.024 \cdot \frac{20ft}{0.13144ft} \cdot \frac{(9.843 ft/s)^2}{2 \cdot 32.2 ft/s^2}$$

$h_{L\,discharge} = 5.4939 ft.$

$$\cancel{\frac{P_{10}}{\gamma}} + \cancel{\frac{V_{10}^2}{2g}} + z_{10} = \frac{P_7}{\gamma} + \frac{V_7^2}{2g} + z_7 + h_{L_{swing}} + h_{L_{discharge}}$$

$$P_7 = \left(z_{10} - z_7 - \frac{V_7^2}{2g} - h_{L_{swing}} - h_{L_{discharge}}\right) \cdot \gamma_{coolant}$$

$$= \left(22ft - 6ft - \frac{(9.843 ft/s)^2}{2 \cdot 32.2 ft/s^2} - 3.0088ft - 5.4939 ft\right) \cdot 57.048 \frac{lb}{ft^3}$$

$P_7 = 341.8818 \frac{lb}{ft^2}$

between 1 and 7 for h_A

$$h_A + \cancel{\frac{P_1}{\gamma}} + \cancel{\frac{V_1^2}{2g}} + z_1 = \frac{P_7}{\gamma} + \frac{V_7^2}{2g} + z_7 + h_{L_{filter}} + h_{L_{gate}} + h_{L_{suction}}$$

$$h_A = \frac{P_7}{\gamma} + \frac{V_7^2}{2g} + z_7 - z_1 + h_{L\,filter} + h_{L\,gate} + h_{L\,suction}$$

$$= \frac{341.8818\,\frac{lb}{ft^2}}{57.048\,\frac{lb}{ft^3}} + \frac{(9.843\,\frac{ft}{s})^2}{2 \cdot 32.2\,\frac{ft}{s^2}} + 6ft - 3ft + 2.778ft + 0.2407ft + 2.744ft$$

$h_A = 16.263ft$ pump head ✓

$$Power_{pump} = \gamma \cdot Q \cdot h_A$$

$$= 57.048\,\frac{lb}{ft^3} \cdot 0.1336\,\frac{ft^3}{s} \cdot 16.263ft$$

$$= 123.9503\,\frac{lb\cdot ft}{s} \cdot \frac{1hp}{550\,\frac{lb\cdot ft}{s}} = \boxed{0.225\,hp}$$ power of pump

Run all of A and B with excel
- not sure if we are just meant to do the entire problem so far in excel..

only upon running excel did I realize I used velocity & idealized diameter for the last 5 pages and not corrected for diameter of chosen pipe.

This will be corrected in my excel sheet. ~ and in the following pages

A,B,C,D ✓
E time.

$$\frac{23.95\,USD}{6ft} \times 1.15 = \frac{27.5425\,USD}{6ft} \div 6 = \frac{4.59\,USD}{ft} \times \frac{30ft}{1} = 137.7125$$

$$\frac{730\,USD}{1KW \cdot 2yrs} \Rightarrow \frac{365\,USD}{1KW \cdot yr}$$

$$\frac{1.341hp}{1KW}$$

$$0.492KW \times \frac{365\,USD}{1KW \cdot yr} \cdot 2yr = 359.16\,USD$$

1.5in schedule 40 pipe has ID = 0.1342 ft. Chosen pipe

$A = \frac{\pi D^2}{4} = 0.01414 ft^2$ ✓ $Q = V \cdot A \Rightarrow V = \frac{Q}{A} = \frac{0.1336 \frac{ft^3}{s}}{0.01414 ft^2} = 9.4484 \frac{ft}{s}$

so chosen pipe data:

$Q = 0.1336 ft^3/s$ $V = 9.4484 ft/s$ $D = 0.1342 ft$

repeating page 2 $h_{L_{filter}}$ calc:

$h_{L_{filter}} = k \cdot \frac{V^2}{2g} = 1.85 \cdot \frac{(9.4484 ft/s)^2}{2 \cdot 32.2 ft/s^2} = 2.5645 ft$

repeating $h_{L_{gate}}$ calc from page 3:

$h_{L_{gate}} = K \cdot \frac{V^2}{2g} = 0.16 \cdot \frac{(9.4484 ft/s)^2}{2 \cdot 32.2 ft/s^2} = 0.2218 ft$

repeating $h_{L_{suction}}$ calc from page 3:

$h_{L_{suction}} = f \cdot \frac{L}{D} \cdot \frac{V^2}{2g}$ $Re = \frac{V \cdot D \cdot \rho}{\eta} = \frac{9.4484 \frac{ft}{s} \cdot 0.1342 ft \cdot 1.7717 \frac{lb \cdot s^2}{ft^2}}{3.6 \times 10^{-5} \frac{lb \cdot s}{ft^2}}$

$\frac{D}{\varepsilon} = \frac{0.1342 ft}{1.5 \times 10^{-4} ft}$ $Re = 62401.9945$

$= 894.667$

from moody chart in chapter 8:

$f \approx 0.025$

$h_{L_{suction}} = 0.025 \times \frac{10 ft}{0.1342 ft} \cdot \frac{(9.4484 ft/s)^2}{2 \cdot 32.2 ft/s^2} = 2.5824 ft$

repeating P6 calc (pressure at pump inlet) from page 3:

$P_6 = \left(z_1 - \frac{V_6^2}{2g} - h_{L_{filter}} - h_{L_{gate}} - h_{L_{suction}}\right) \cdot \gamma_{coolant}$

$= \left(3 ft - \frac{(9.4484 \frac{ft}{s})^2}{2 \cdot 32.2 \frac{ft}{s^2}} - 2.5645 ft - 0.2218 ft - 2.5824 ft\right) \cdot 57.048 \frac{lb}{ft^3}$

$P_6 = -214.2104 \frac{lb}{ft^2} \cdot \frac{1 ft^2}{144 in^2} = \boxed{-1.4876 \text{ psi}}$ pressure at pump inlet repeating $h_{L_{swing}}$ calc from page 4:

$$h_{L_{swing}} = K \cdot \frac{V^2}{2g} = 2 \cdot \frac{(9.4484\ ft/s)^2}{2 \cdot 32.2\ ft/s^2} = 2.7724\ ft$$

repeating $h_{L_{discharge}}$ calc from page 4

$$h_{L_{discharge}} = f \cdot \frac{L}{D} \cdot \frac{V^2}{2g}$$ $\cdot f$ is same as $h_{L_{suction}}$

$$= 0.025 \cdot \frac{20\ ft}{0.1342\ ft} \cdot \frac{(9.4484\ ft/s)^2}{2 \cdot 32.2\ ft/s^2}$$

$$= 5.1647\ ft$$

repeating P_7 calc from page 4:

$$P_7 = \left(z_{10} - z_7 - \frac{V_7^2}{2g} - h_{L_{swing}} - h_{L_{discharge}}\right) \cdot \gamma_{coolant}$$

$$= \left(22\ ft - 6\ ft - \frac{(9.4484\ ft/s)^2}{2 \cdot 32.2\ ft/s^2} - 2.7724\ ft - 5.1647\ ft\right) \cdot 57.048\ \frac{lb}{ft^3}$$

$$P_7 = 380.8915\ \frac{lb}{ft^2}$$

repeating h_A calc from page 5

$$h_A = \frac{P_7}{\gamma} + \frac{V_7^2}{2g} + z_7 - z_1 + h_{L_{filter}} + h_{L_{gate}} + h_{L_{suction}}$$

$$= \frac{380.8915\ \frac{lb}{ft^2}}{57.048\ \frac{lb}{ft^3}} + \frac{(9.4484\ ft/s)^2}{2 \cdot 32.2\ ft/s^2} + 6\ ft - 3\ ft + 2.5645\ ft + 0.2218\ ft + 2.5824\ ft$$

$$\boxed{h_A = 16.4316\ ft.}$$ pumphead

$$P_{pump} = \gamma \cdot Q \cdot h_A = 57.048\ \frac{lb}{ft^3} \cdot 0.1336\ \frac{ft^3}{s} \cdot 16.4316\ ft$$

$$P_{pump} = 125.2353\ \frac{lb\text{-}ft}{s} \cdot \frac{1\ hp}{550\ \frac{lb\text{-}ft}{s}} = \boxed{0.2277\ hp}$$

pump power

Summary:

Choosing the 1.5in schedule 40 steel pipe for all 30ft of the new design is the most cost effective option for replacing the 30ft (suction and discharge) of piping while maintaining close to desired velocity and flow rate.

Materials:

30ft of 1.5inch schedule 40 steel piping should yield a total cost of $268.24 (including cost and installation). Installation has a +15% ceiling for unexpected costs. Cost of the filter, gate valve, and swing check valve were not included as they were already factored into original draft and this is strictly changing the piping. The new pump needs to provide ~0.135hp to maintain desired flow rate

Analysis:

The chosen size for flow rate and velocity is the most cost effective for installation and maintenance. If it were needed for some reason, the 1.25in is a close alternative that raises the velocity by about 33%, but is only marginally more expensive. The 1in demands the highest hp pump and is the least cost effective answer (very high velocity, high friction losses, etc).