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MET 330 Fluid Mechanics
Dr. Orlando Ayala
Fall 2022
Test 1

Take home – Due Tuesday October 4th, 2022, 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 are 2 main different parts, each one is worth 80/2 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 CANVAS. You must submit the test solution in only one file, and it has to be a pdf file. You must also submit the excel spreadsheet. 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:

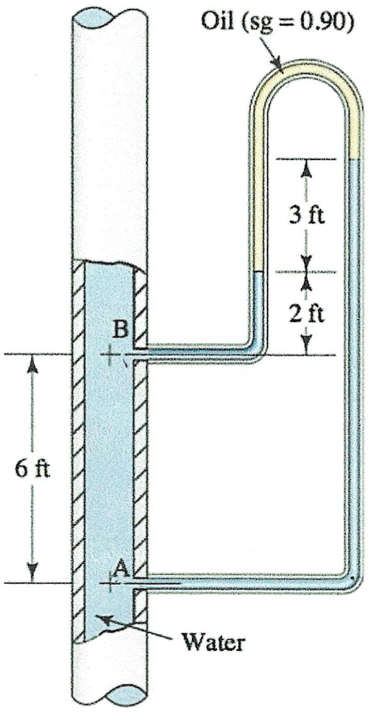
1. *Cheating*: Using unauthorized assistance, materials, study aids, or other information in any academic exercise (Examples of cheating include, but are not limited to, the following: using unapproved resources or assistance to complete an assignment, paper, project, quiz or exam; collaborating in violation 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) For the manometer shown in the figure, the pressure difference between point A and B was calculated and it was found to be 2.7177psi. What would be the deflection in the manometer if instead of using oil with sg=0.90 you use gasoline? What is the minimum height of the manometer so the gasoline does not go into the system?

Using an excel spreadsheet, run the calculations again. Then determine the deflection for the case of using mercury as the manometric fluid.

Please, look at the results you got and make comments about them in the "analysis" section of your solution. Why do they make sense?



2) The system shown in the figure was designed to handle a total of 30 gpm of coolant. The owners of the company realized that the coolant needed for Machines #1 and #2 are different to what they had estimated initially. Instead of 20 gpm and 10 gpm, they actually need 30 gpm for each machine exactly. Thus, they need a new pump to deliver the new total flow rate of coolant. The coolant then flows back to the machines as needed, by gravity. The coolant has a specific gravity of 0.92 and a dynamic viscosity of $3.6x10^{-5}$ $lb.s/ft^2$. The filter has a resistance coefficient (K) of 1.85 based on the velocity head in the suction line.

You are hired to redesign for now only the pumped system, but we do not know what the best pipe size would be for this new flow rate. Here it is what you need to do:

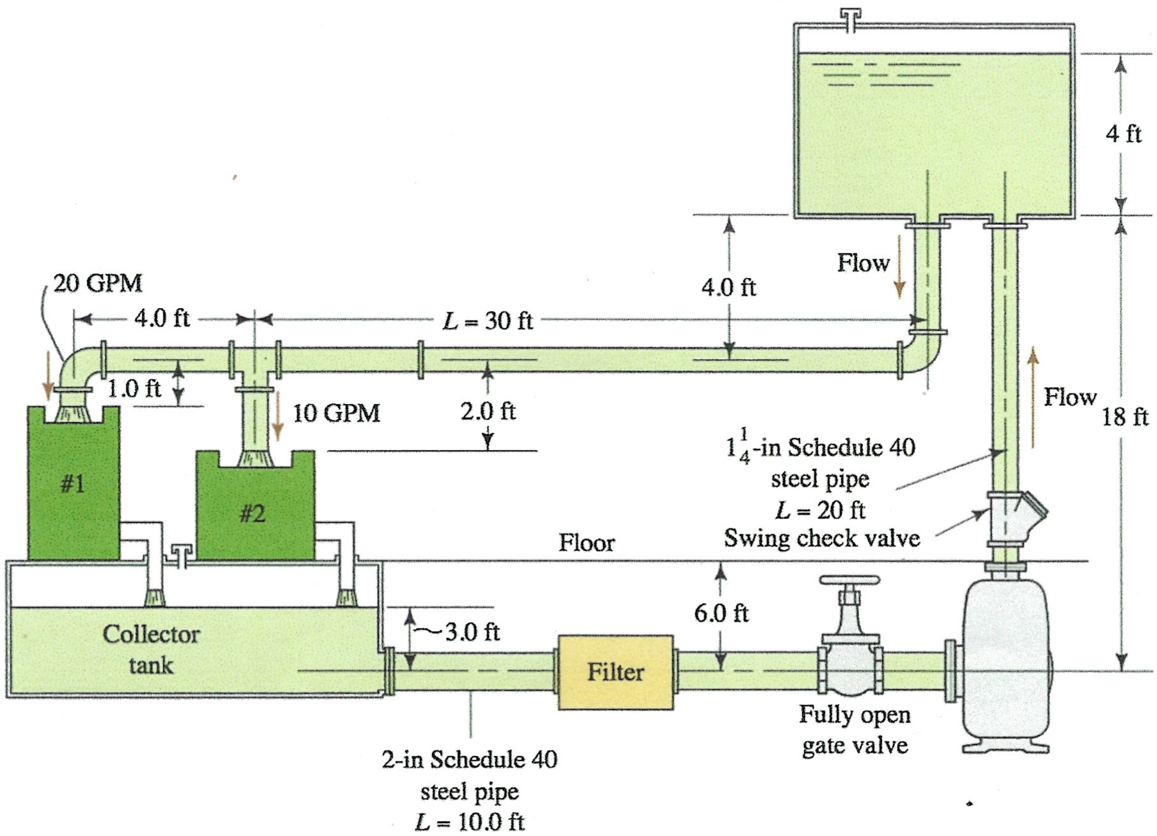
a. Pick a commercial steel pipe Schedule 40 that will give you a mean flow velocity of about 3m/s with the new total flow rate (do not forget there are two machines in the upper system and one pipe in the pumped system).
b. With the selected pipe, compute the pump head and the power delivered by the pump, to the coolant. Also, compute the pressure at the inlet of the pump.
c. Using an excel spreadsheet, run the calculations again.
d. Using an excel spreadsheet, run the calculations again using different steel pipe Schedule 40 sizes. Pick two pipe sizes smaller than the one you selected on part a, and two pipe sizes larger than the one you selected on part a. Keep in mind that the fluid velocity will change for every pipe size while the flow rate is the same for all cases.
e. For each of the pipe sizes, estimate the cost of installation using the pipe cost list below and consider than labor, transportation, and pump costs ammount for about 40% of the pipe cost. Include a 15% extra for unforseen costs. Make a table of the installation costs in excel.

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

f. For each of the pipe sizes, estimate the cost to maintain the system operating for 2 years knowing that the electricity cost is about $730 per kW constantly used during those 2 years. Make a table of the operation costs in excel.

g. Add both costs (operation and installation) and plot on the same graph the cost of installation, the cost of operation, and total cost as a function of nomical pipe diameter.

h. Please, look at the results you got and make comments about them in the "analysis" section of your solution. Why do they make sense? What do you think is the best pipe size to use in this system?



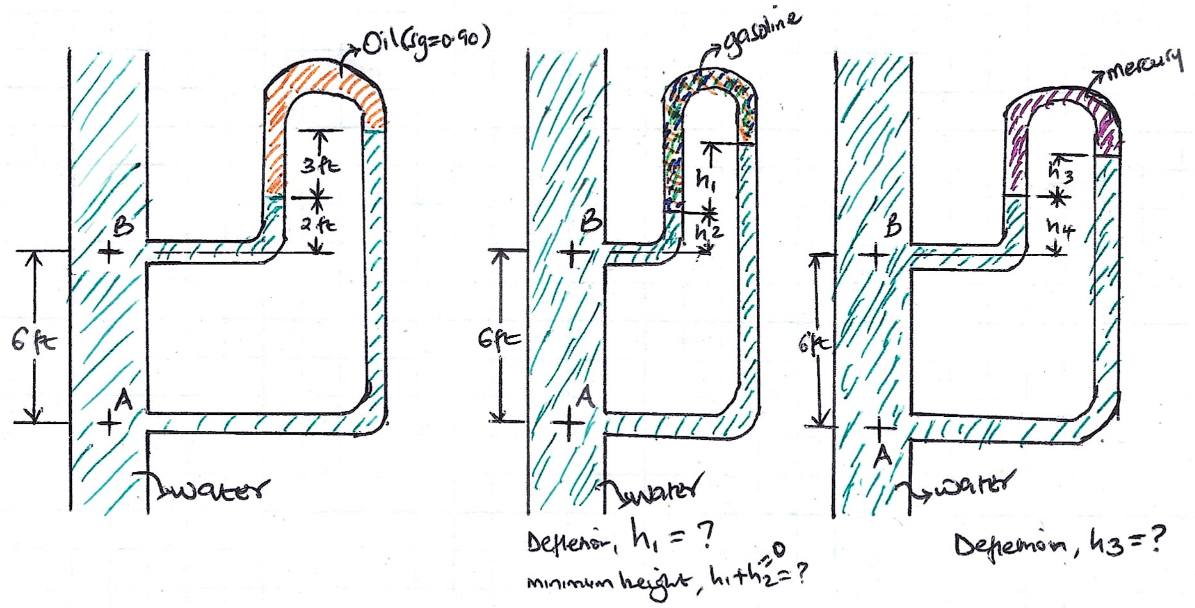
NAFTALY GICHUNGA | MET 330 | TEST 1 | I

PROBLEM 1

PURPOSE:

- Determine the manometer deflection if instead of using Oil with sg=0.90 gasoline was used.
- Determine the minimum height of the manometer so that the gasoline does not go into the system.
- Determine the deflection for the case of using mercury as the manometric fluid

DRAWINGS & DIAGRAMS



SOURCES

- Mott, R. L., & Untener, J. A. (2015) Applied Fluid mechanics. Pearson.

DESIGN CONSIDERATIONS

- Constant properties
- Incompressible fluids
- The fluids do not mix
- Steady state
- T = 77°F

DATA AND VARIABLES

- $\Delta P_{AB} = 2.7177$ psi
- $\gamma_W = 62.2$ lb/ft³
- $\gamma_{Hg} = 844.9$ lb/ft³
- $\gamma_{gasoline} = 42.40$ lb/ft³
- $\gamma_{oil} = 0.9 \times 62.4$ lb/ft³ $= 56.16$ lb/ft³

MATERIALS
- Water
- Gasoline
- Mercury

PROCEDURE
I will first determine the specific weight of the water using the pressure difference between A and B and the manometer readings provided. This will dictate the temperature of the water in the problem.
I will then determine the deflection if gasoline was used in place of the oil with Sg = 0.9. The deflection will determine the minimum height of the manometer.
Lastly I will determine the deflection for the case of using mercury as the manometric fluid.

CALCULATIONS

For the oil with Sg = 0.9:

$$P_A - \gamma_w(6ft) - \gamma_w(2ft) - \gamma_w(3ft) = P_B - \gamma_w(2ft) - \gamma_o(3ft)$$

$$P_A - P_B = \gamma_w(6ft) + \gamma_w(3ft) - \gamma_o(3ft)$$

$$2.7177\,psi = \gamma_w(9ft) - 56.16\,lb/ft^3(3ft)$$

$$\gamma_w = \frac{(2.7177 \times 144)\,lb/ft^2 + 168.48\,lb/ft^2}{9ft}$$

$$\gamma_w = 62.2032\,lb/ft^3 \cong 62.2\,lb/ft^3$$

Specific weight of water of $62.2032\,lb/ft^3$ implies that the temperature is around 77^oF. From here we shall use the properties of the fluids at 77^oF.

If gasolin was used in place of the oil:

$$P_A - \gamma_w(6ft) - \gamma_w(h_2) - \gamma_w(h_1) = P_B - \gamma_w(h_2) - \gamma_g(h_1)$$

$$P_A - P_B - \gamma_w(6ft) = h_1(\gamma_w - \gamma_g)$$

$$h_1 = \frac{\Delta P_{AB} - \gamma_w(6ft)}{(\gamma_w - \gamma_g)}$$

$$= \frac{(2.7177 \times 144)\,lb/ft^2 - 62.2\,lb/ft^3(6ft)}{(62.2 - 42.40)\,lb/ft^3}$$

$$\boxed{h_1 = 0.92\,ft}$$

If mercury was used as the manometric fluid;

$$P_A - \gamma_w(6ft) - \gamma_w(h_4) - \gamma_w(h_3) = P_B - \gamma_w(h_4) - \gamma_{hg}(h_3)$$

$$P_A - P_B - \gamma_w(6ft) = h_3(\gamma_w - \gamma_{hg})$$

$$h_3 = \frac{\Delta P_{AB} - \gamma_w(6ft)}{\gamma_w - \gamma_{hg}}$$

$$= \frac{(2.7177 \times 10^{4})lb/ft^2 - 62.2 lb/ft^3(6ft)}{62.2 lb/ft^3 - 844.9 lb/ft^3}$$

$$\boxed{h_3 = -0.02ft}$$

Summary

The pressure difference between points A and B and the readings provided enabled me to determine the specific weight and thus the temperature of water which was $\gamma_w = 62.2\ lb/ft^3$ at 77°F.

The manometer deflection if gasoline was used instead of oil was $h_1 = 0.92ft$.

This deflection of gasoline is the minimum height of the manometer on the left side so that the gasoline does not go into the system. The minimum height of the manometer on the right side would therefore be (0.92ft + 6ft) = 6.92 ft.

If mercury was used as the manometric fluid, the deflection $h_3 = -0.02ft$, which means that the deflection would be on the right side of the manometer.

ANALYSIS

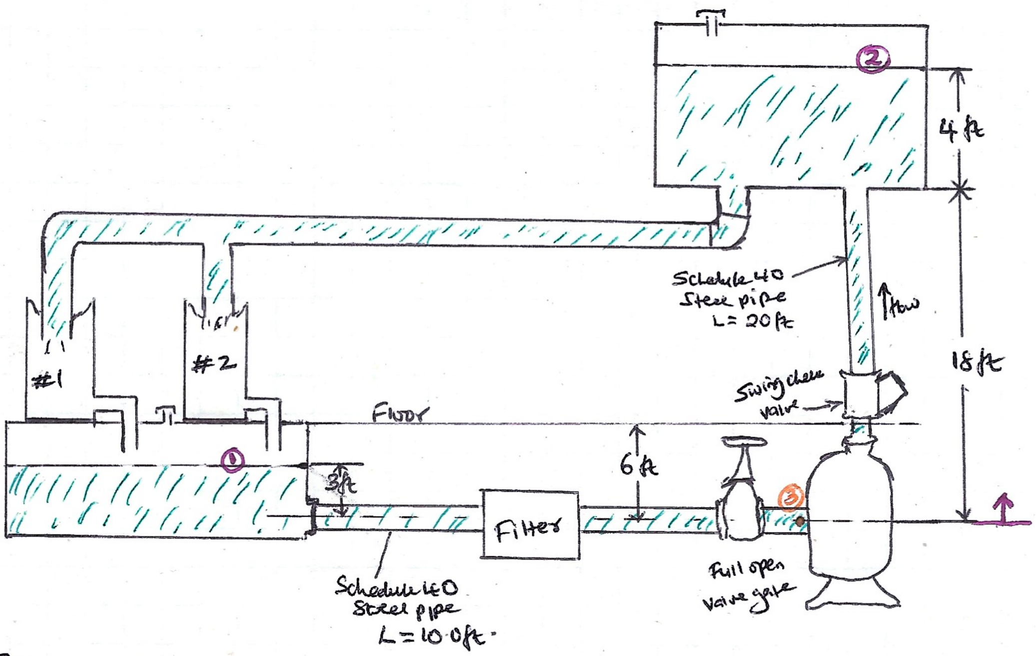
The objective of this problem was to determine the deflection in the manometer when different manometric fluids were used. When gasoline is used, the deflection decreases. If mercury is used as the manometric fluid, the deflection moves to the right side. This means that manometric fluids of greater specific weight that that of the liquid whose pressure is ~~being~~ being determined will deflect towards the point of higher pressure.

PROBLEM 2

PURPOSE:

- Determine the commercial steel pipe schedule 40 that will give a mean flow velocity of about 3m/s with the specified flow rate.
- Determine the pump head, power delivered by the pump to the coolant and the pressure at the inlet of the pump for the selected pipe.
- Determine the pump head, power delivered by the pump to the coolant and the pressure at the inlet of the pump for two sizes smaller than the one selected and two pipes larger than the one selected.
- Estimate the cost of installation for each of the pipe sizes considering that labor, transport and pump costs amount for about 40% of the pipe cost. Including a 15% extra for unforeseen costs.
- Estimate the cost of maintaining the system for two years knowing that electricity costs is about $730 per KW.
- Using a graph determine the relationship between the nominal pipe diameter and the total costs (operation and installation).

DRAWINGS & DIAGRAMS



SOURCES

- Mott, R. L., & Untener, J.A. (2015) Applied Fluid Mechanics. Pearson

DESIGN CONSIDERATIONS

- Steady state
- Incompressible fluid
- Constant properties

DATA AND VARIABLES

$Q = 60$ gpm

Coolant: $sg = 0.92$

$\eta = 3.6 \times 10^{-5}$ lb·s/ft²

- Filter coefficient of resistance (K) = 1.85
- Desired velocity $v = 3$ m/s

MATERIALS

- Coolant with $sg = 0.92$ and dynamic viscosity $= 3.6 \times 10^{-5}\ lb \cdot s/ft^2$
- Filter with resistance coefficient $K = 1.85$
- Commercial steel pipe Schedule 40.

PROCEDURE

I will first use the desired flow rate of 60gpm and a mean flow velocity of about 3m/s to determine the flow area of the pipes. This will help me determine the best pipe size for the pumped system.

I will then use Bernoulli's equation to determine the pump head, power delivered by the pump to the coolant and the pressure at the inlet of the ~~pipe~~ pump.

I will run the same calculations using an excel spreadsheet. Using the spreadsheet I will determine the same parameters for pipes two sizes smaller than the selected pipe and two sizes larger than the selected pipe.

I will lastly determine the cost of installation and maintenance for the five different pipe sizes and compare them using a graph.

CALCULATIONS

a) Desired pipe size

$$Q = VA \qquad Q = 60gpm = 60gpm \times \frac{1 ft^3/s}{449\ gpm}$$

$$= 0.13363\ ft^3/s$$

$$V = 3m/s = 3m/s \times \frac{3.28084\ ft/s}{1m/s}$$

$$= 9.84252\ ft/s$$

$$A = Q/V = \frac{0.13363\ ft^3/s}{9.84252\ ft/s} = 0.013577\ ft^2$$

This flow area corresponds to 1½in Schedule 40 steel pipe with a diameter of 0.1342 ft and a flow area of $0.01414\ ft^2$.
With the desired flow rate, this pipe will generate a mean flow velocity of 9.45 ft/s. I will use this value of velocity in my calculations.

b) Pump head.

$$h_A^{=?} + \frac{p_1}{\gamma}^{=0} + \frac{v_1^2}{2g}^{=0} + z_1 = \frac{p_2}{\gamma}^{=0} + \frac{v_2^2}{2g}^{=0} + z_2 + K_R^{=0} + h_L$$

$$h_A = (z_2 - z_1) + h_L$$

$$z_2 - z_1 = 22ft - 3ft = 19ft.$$

h_L = Pipe losses + Filter losses + Gate valve losses + Check valve losses

- Pipe losses $= f \frac{L}{D} \frac{V^2}{2g}$

$N_R = \frac{VD\rho}{\eta} = \frac{(9.45)(0.1342)(0.92)(1.94)}{3.6\times10^{-5}}$

$= 6.28\times10^4$

$\frac{D}{\varepsilon} = \frac{0.1342}{1.5\times10^{-4}} = 895$

$= 0.023\times \frac{30ft}{0.1342ft} \times \frac{(9.45ft/s)^2}{2\times32.2ft/s^2}$ $\quad f \cong 0.023$

Pipe losses $= \underline{7.13\ ft}$.

- Filter losses $= K\frac{V^2}{2g}$

$= 1.85 \times \frac{(9.45ft/s)^2}{2\times32.2ft/s^2} = \underline{2.57\ ft}$

- Gate valve losses $= K\frac{V^2}{2g}$

$= 340\times0.02\times\frac{(9.45ft/s)^2}{2\times32.2ft/s^2}$

$= \underline{9.43\ ft}$

- Check valve losses $= KV^2/2g$

$= 100\times0.02 \times\frac{(9.45ft/s)^2}{2\times32.2ft/s^2}$

$= \underline{2.77\ ft}$

$h_L = 7.13ft + 2.57ft + 9.43ft + 2.77\ ft$

$\underline{h_L = 21.9\ ft}$

$h_A = 19ft + 21.9\ ft$

$= 40.9\ ft$ ... Pump head.

Power delivered by the pump to the coolant:

$P_A = h_A \gamma Q$

$= (40.9ft)(0.92\times62.4lb/ft^3)(0.13363\ ft^3/s)\left(\frac{1hp}{550\ lb\ ft/s}\right)$

$P_A = 0.5705hp \times \frac{0.7457kw}{1hp}$

$\underline{P_A = 0.4254\ kW}$

Pressure at the inlet of the pump

$$h_A^{\,=0} + \frac{p_1^{\,=0}}{\gamma} + \frac{v_1^{2\,=0}}{2g} + z_1 = \frac{P_3}{\gamma} + \frac{V_3^2}{2g} + z_3^{\,=0} + h_R^{\,=0} + h_L$$

$$P_3 = \gamma\left(z_1 - \frac{V_3^2}{2g} - h_L\right)$$

$z_1 = 3\,ft.$

$$\frac{V_3^2}{2g} = \frac{9.45^2}{2\times 32.2} = 1.39\,ft$$

h_L = Pipe losses (10ft) + filter losses + Gate valve losses

$$= \left[0.023\times\frac{10ft}{0.1342ft}\left(\frac{9.45^2}{2\times32.2}\right)\right] + 2.57ft + 9.43ft.$$

$$= 14.37\,ft.$$

$$P_3 = 0.92\times 62.4\,lb/ft^3\,(3ft - 1.39ft - 14.37ft)\times\frac{1ft^2}{144in^2}$$

$$P_3 = -5.087\,psi$$

e) Estimate of installation cost

Pipes cost $= 30ft \times \frac{\$33.95}{6ft}$

$= \$169.75$

Plus labor, transportation and pump cost

$= \frac{140}{100}\times 169.75$

$= \$237.65$

Plus unforseen costs $= 1.15\times 237.65$

$= \$273.30$ ← Total installation cost.

f) Estimate of operation cost

$= \frac{\$730}{1KW}\times 0.4254\,KW$

$= \$310.54$ ← Total operation cost

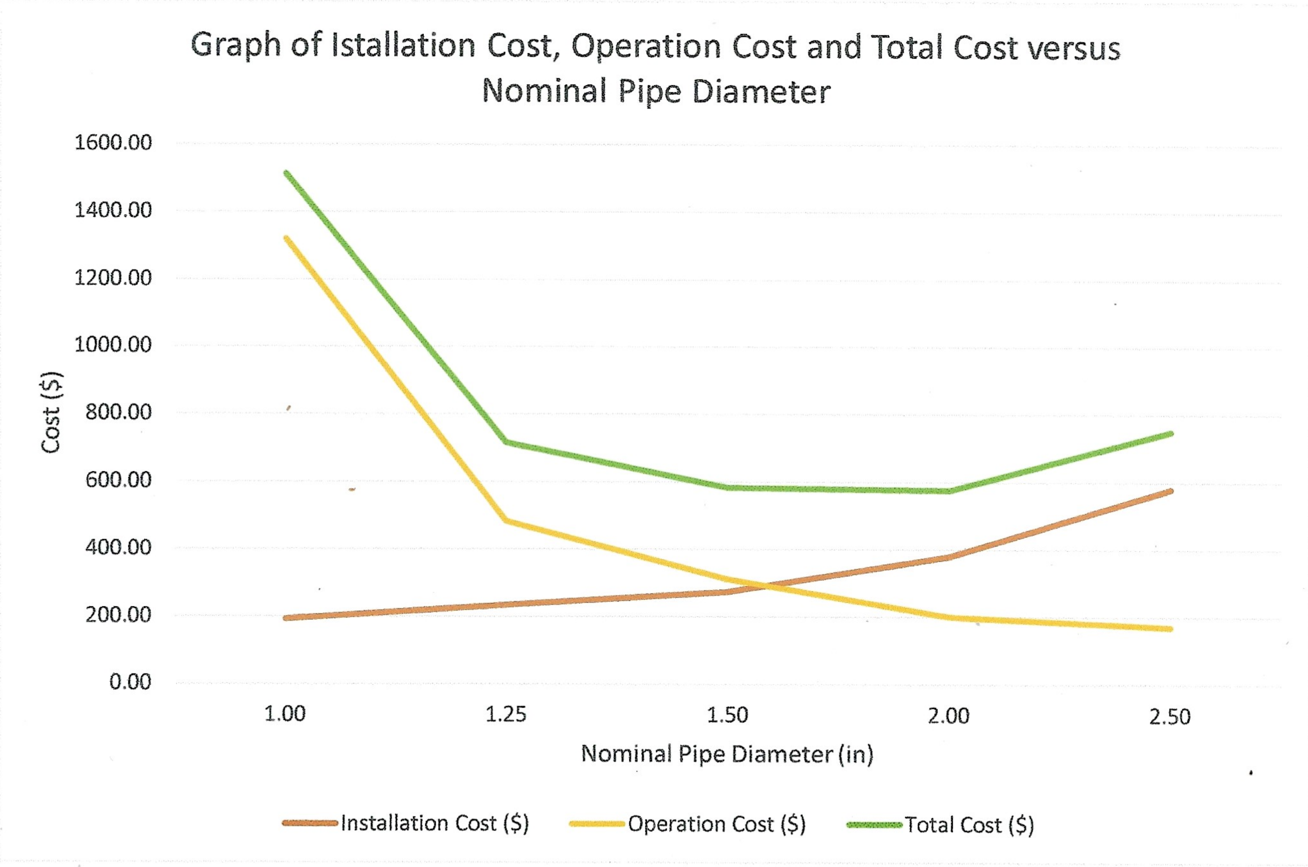
g) Total cost (operation + installation)

Total cost $= \$273.30 + 310.54$

$= \$583.84$

Table of installation cost, operation cost, and total cost for the five different nominal pipe diameters.

Nominal Pipe Diameter (in)	Installation Cost ($)	Operation Cost ($)	Total Cost ($)
1.00	192.80	1320.41	1513.21
1.25	232.81	482.65	715.46
1.50	273.30	310.55	583.84
2.00	377.95	199.25	577.19
2.50	579.20	169.52	748.71



SUMMARY

A commercial steel pipe Schedule 40 that would give a mean flow velocity of about 3m/s with a flow rate of 60mpg is one with a nominal diameter of 1½in.

ANALYSIS

From the calculation, it is evident that the velocity in the tubes decreased as the size of the pipes increased. This was due to the fact that with a constant flow rate, an increase in the area of flow results in a reduced mean flow velocity. A decrease in velocity resulted to decreased losses in the pipes, filters, gate valve and check valve and therefore a low power pump was required to run the system. There was ~~also~~ also a decrease in the pressure at the pump inlet as the nominal pipe sizes increased.

Cost analysis proved that the installation cost of the pumped system increased with increasing nominal pipe sizes. This was due to the fact that the pipes cost per 1 ft increased with increase in nominal pipe sizes. On the other hand, the operation cost of the system for two years decreased as the nominal pipe size increased. This was due to a decrease in the pressure head values and thus less power delivered to the current.

Based on total cost analysis, there was a significant decrease in total cost with as the nominal sizes increased until 1½-in nominal size and 2-in nominal size. After this the installation cost made the total cost increase. As far as selection of the best pipe size to use in the system with reference to the total cost of installation and operating the system for two years, the pipes with 1½in and 2-in nominal diameters manifested the least total cost with the 2in diameter pipe beating the 1½ diameter pipe's total cost by around $6.