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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.

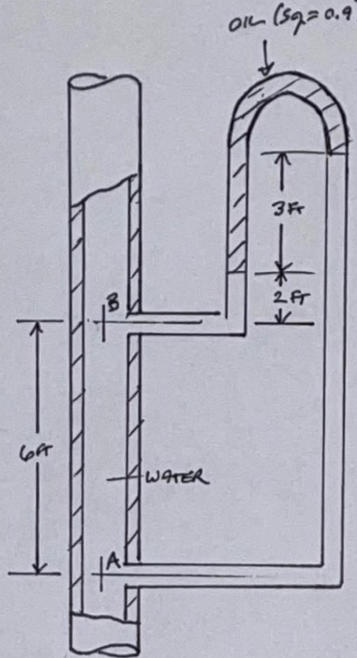
8. Cheating is completely wrong. The ODU Student Honor Pledge reads: "I pledge to support the honor system of Old Dominion University. I will refrain from any form of academic dishonesty or deception, such as cheating or plagiarism." By attending Old Dominion University, you have accepted the responsibility 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 PURPOSE: DETERMINE THE DEFLECTION IN THE MANOMETER IF THE MANOMETRIC FLUID IS GASOLINE. DETERMINE THE MINIMUM HEIGHT THAT THE MANOMETER SHOULD BE SO THE GASOLINE DOES NOT ENTER THE SYSTEM. DETERMINE THE DEFLECTION IF THE MANOMETRIC FLUID IS MERCURY.

DIAGRAM:



SOURCES: 1. MOTT AND UNTENER. APPLIED FLUID MECHANICS. 7TH EDITION. PEARSON. 2015

DESIGN CONSIDERATIONS: BASED ON INFORMATION GIVEN, I WILL ASSUME THE FOLLOWING:

1. THE FLUIDS ARE INCOMPRESSIBLE
2. THE PROBLEM IS ISOTHERMAL
3. FLUIDS WILL NOT MIX
4. THE PROBLEM IS ISOBARIC

DATA + VARIABLES:

$$\Delta P = 2.7177 \text{ psi} \left(\frac{lb}{in^2}\right) \cdot \frac{144 \, in^2}{1 \, ft^2} = 391.349 \frac{lb}{ft^2}$$

$$Sg_{oil} = 0.9 \left(62.4 \frac{lb}{ft^3}\right) = 56.16 \frac{lb}{ft^3}$$

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

$$\gamma_{gas} = 42.4 \frac{lb}{ft^3}$$

$$\gamma_{Hg} = 844.9 \frac{lb}{ft^3}$$

– APPENDIX TABLE B.2, Pg 491

MATERIALS: WATER
GASOLINE
MERCURY (Hg)

PROCEDURE & CALCULATIONS:

FIRST, I WILL DETERMINE THE APPROPRIATE FORMULA. SINCE PRESSURE WILL REMAIN CONSTANT, I CAN USE $\Delta P = \gamma \cdot h$ TO SOLVE FOR THE DEFLECTION IN THE MANOMETER FOR GASOLINE.

$$\Delta P = \gamma \cdot h \rightarrow h = \frac{\Delta P}{\gamma}$$

NEXT, I WILL USE THE GIVEN INFORMATION AND DATA BY FIRST CONVERTING IT TO SIMILAR/LIKE UNITS, THEN PLUGGING IT INTO THE "h" EQUATION ABOVE. OTHER DATA COMES FROM APPENDICES.

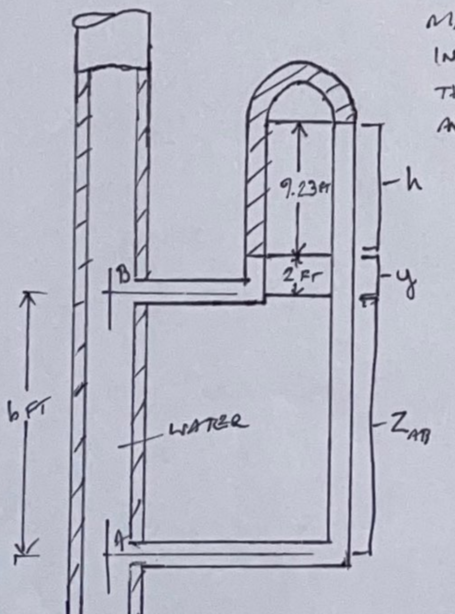
$$\Delta P = 2.7177 \frac{lb}{in^2} \cdot \frac{144 in^2}{1 FT^2} = 391.349 \frac{lb}{FT^2}$$

$\gamma_{gas} = 42.4 \frac{lb}{FT^3}$ (RETRIEVED FROM APPENDIX TABLE B.2, SOURCE 1)

$$h = \frac{\Delta P}{\gamma_{gas}} \rightarrow \frac{391.349 \frac{lb}{FT^2}}{42.4 \frac{lb}{FT^3}} = \underline{9.23 \text{ FT}}$$

THEREFORE, THE DEFLECTION IN THE MANOMETER WITH GASOLINE AS GAGE FLUID WITH A PRESSURE DIFFERENCE OF 2.7177 psi IS $h = 9.23$ FT. TO FIND THE MINIMUM HEIGHT OF THE MANOMETER, I WILL FIRST RE-DRAW THE DIAGRAM WITH THE NEW DEFLECTION AND CALCULATE THE NEW MANOMETER HEIGHT.

I WILL CALL THE DEFLECTION "h", THE DISTANCE FROM B LEG TO MANOMETRIC FLUID "y", AND THE DISTANCE BETWEEN A AND B "Z_{A-B}". IN ORDER TO FIND MINIMUM MANOMETER HEIGHT, I WILL ASSUME THAT 2 FT IS REQUIRED AT "y" IN ORDER TO GET AN ACCURATE READING AND PREVENT OVERFLOW.



$$\text{SO, } H_{MIN} = Z_{A-B} + y + h \rightarrow 6 \text{FT} + 2 \text{FT} + 9.23 \text{FT}$$

$$\underline{H_{MIN} = 17.23 \text{ FT}}$$

IF THE TOTAL HEIGHT OF THE MANOMETER WAS 15.23 FT, (IF $y = 0$ FT), THEN THE MANOMETRIC FLUID COULD OVERFLOW INTO THE B LEG.

IN ORDER TO FIND THE DEFLECTION IF THE MANOMETRIC FLUID WAS MERCURY, I USED THE SAME FORMULA AS BEFORE.

$$\Delta P = \gamma \cdot h \rightarrow h = \frac{\Delta P}{\gamma}$$

THIS TIME, I USED THE SPECIFIC WEIGHT OF MERCURY FROM APPENDIX TABLE B.2, SOURCE 1. I ALSO USED THE SAME PRESSURE DIFFERENCE SINCE WE WERE NOT PROVIDED WITH TYPE OR SIZE OF PIPING, OR DIFFERENT PRESSURES.

SO,

$$h = \frac{\Delta P}{\gamma_{Hg}} \rightarrow \frac{391.349 \frac{lb}{ft^2}}{844.9 \frac{lb}{ft^3}} = \underline{0.46\ FT}$$

NOTE: THIS CALCULATION CAN ALSO BE SEEN IN ATTACHED EXCEL SPREADSHEET.

SUMMARY:

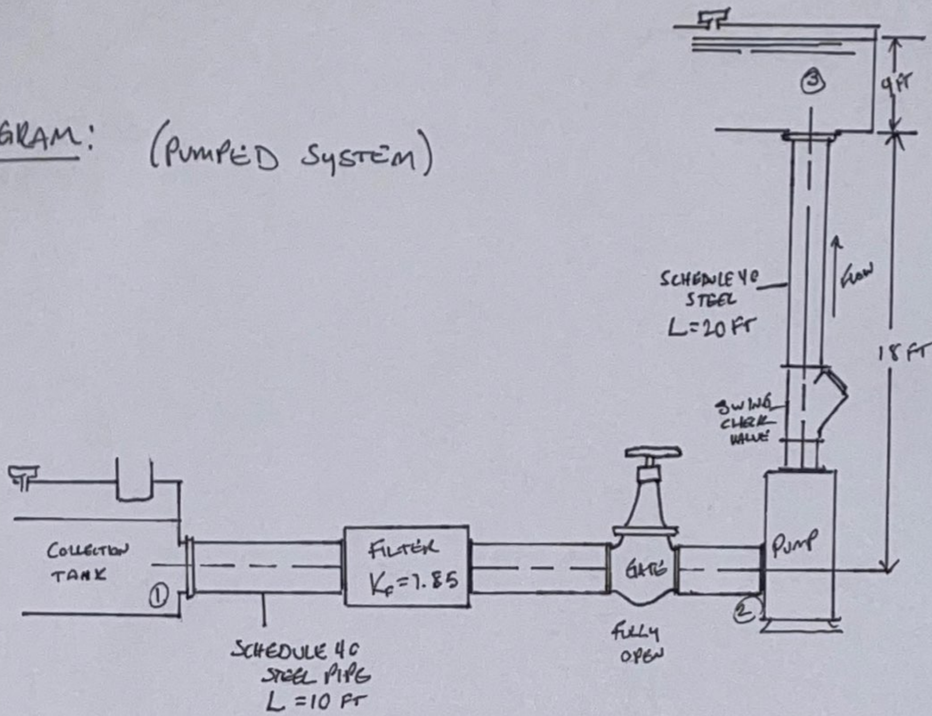
THE ORIGINAL MANOMETER WITH OIL AS GAGE FLUID HAD A DEFLECTION OF $h = 3$ FT. REPLACING THE FLUID WITH GASOLINE CHANGED THE DEFLECTION TO $h = 9.23$ FT. IF THE GASOLINE WAS TO BE USED, THE MINIMUM HEIGHT OF THE MANOMETER WOULD HAVE TO BE 17.23 FT (ASSUMING 2 FT LENGTH IS REQUIRED FROM B BASED ON ORIGINAL DIAGRAM GIVEN). IF THE GAGE FLUID IS REPLACED WITH MERCURY, THE TOTAL DEFLECTION WOULD DROP TO 0.46 FT.

ANALYSIS:

THE DEFLECTION WITH GASOLINE IS MORE THAN TRIPLE THE DEFLECTION WITH OIL. THIS IS BECAUSE GASOLINE HAS A LOWER SPECIFIC WEIGHT THAN THE OIL, AND BECAUSE A DIFFERENTIAL MANOMETER READING IS NOT A LINEAR OCCURRENCE. THEREFORE, THE MANOMETER HEIGHT WOULD NEED TO BE INCREASED IF USING A LIGHTER GAGE FLUID. ALTERNATIVELY, THE DEFLECTION OF THE GAGE FLUID WAS SUBSTANTIALLY LESS WHEN USING MERCURY. THIS MAKES SENSE BECAUSE THE SPECIFIC WEIGHT OF MERCURY IS NEARLY 20 TIMES THAT OF GASOLINE, WHICH MEANS THE DEFLECTION WOULD BE MINIMAL WITH THE GIVEN PRESSURE DIFFERENCE.

(2) PURPOSE: TO REDESIGN THE PUMPED SYSTEM BASED ON THE NEW REQUIRED FLOW RATE OF THE MACHINES IN THE GRAVITY-FED SYSTEM.

DIAGRAM: (PUMPED SYSTEM)



SOURCES: 1. MOTT AND UNTENER. APPLIED FLUID MECHANICS. 7TH EDITION. PEARSON. 2015.

DESIGN CONSIDERATIONS: BASED ON GIVEN INFORMATION, I WILL ASSUME:

1. FLUID IS INCOMPRESSIBLE
2. THE FLUID SYSTEM IS ISOTHERMAL
3. PRESSURE IS 0 AT BOTH TANKS, VENTED TO ATM
4. ~~LAMINAR FLOW?~~ → CANT DETERMINE PRIOR TO CALCULATIONS
5. DOUBLE REQUIRED FLOW RATE (30gpm → 60 gpm)

DATA AND VARIABLES:

$Q = 30 \frac{GAL}{MIN}$

$Sg = 0.92$

$K_f = 1.85$

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

$L_s = 10$ FT

$L_D = 20$ FT

$\gamma_{COOLANT} = 0.92(62.4 \frac{lb}{ft^3}) = 57.408 \frac{lb}{ft^3}$

$h_D = 18$ FT $+ 4$ FT $= 22$ FT

MATERIALS: COOLANT

SCH. 40 STEEL PIPE

GATE VALVE (FULL OPEN)

FILTER

SWING CHECK

PROCEDURE AND CALCULATIONS:

BASED ON THE INFORMATION GIVEN, THE FLOW RATE REQUIRED TOTAL IS DOUBLED FROM 30 GPM TO 60 GPM. KNOWING THIS, I WILL NEED TO DETERMINE A NEW PIPE SIZE FOR 60 GPM AND 3 M/S FLOW VELOCITY.

$$Q = 60\frac{GAL}{MIN} \cdot \frac{1\,FT^3}{7.48\,GAL} \cdot \frac{1\,MIN}{60\,SEC} = 0.13369\,\frac{FT^3}{SEC}$$

$$V = 3\frac{M}{S} \cdot \frac{3.28\,FT}{1\,M} = 9.84\,\frac{FT}{S}$$

$$A = Q/V = \frac{0.13369\,\frac{FT^3}{SEC}}{9.84\,\frac{FT}{SEC}} = 0.013586\,FT^2$$

WITH THE AREA NEEDED, I WILL REFER TO APPENDIX F, TABLE F.1, SOURCE 1 AND DETERMINE A SCHEDULE 40 PIPE WITH A FLOW AREA CLOSE TO THE CALCULATED NUMBER (AS CLOSE AS POSSIBLE).

$1\frac{1}{2}''$ SCHEDULE 40 HAS A FLOW AREA OF $0.01414\,FT^2$

I WILL THEN CHECK MY MATH TO ENSURE THIS PIPE SIZE WILL WORK.

$$V_{REQUIRED} \approx 9.84\frac{FT}{S} \longrightarrow V = \frac{Q}{A} = \frac{0.13369\,\frac{FT^3}{SEC}}{0.01414\,\cancel{FT^2}} = 9.45474\,\frac{FT}{S}$$

NOW THAT I HAVE SELECTED MY PIPE SIZE, I WILL COMPUTE THE PUMP HEAD, POWER DELIVERED BY PUMP, AND INLET PRESSURE.

KNOWN: POWER ADDED, $P_A = h_A \gamma Q$ (REFER TO DIAGRAM FOR BERNOULLI'S EQ.)

$$\cancel{\frac{P_1}{\gamma}}^{0\,psig} + z_1 + \cancel{\frac{V_1^2}{2g}}^{0} + h_A - h_L = \cancel{\frac{P_3}{\gamma}}^{0\,psig} + z_3 + \frac{V_3^2}{2g} \rightarrow h_A = z_3 - z_1 + \frac{V_3^2}{2g} + h_L$$

NOW THAT I HAVE AN EQUATION FOR ENERGY ADDED TO THE SYSTEM, I NEED TO DETERMINE VALUES.

$$z_3 = \cancel{18}\,22\,FT, \quad z_1 = 0\,FT, \quad \frac{V_3^2}{2g} = \frac{(9.45474\,\frac{FT}{S})^2}{2(32.2\,\frac{FT}{S^2})} = 1.38808\,FT$$

ENERGY LOSSES (h_L) ARE MORE COMPLICATED, I WILL ADD EACH FROM THE SUCTION LEG AND THE DISCHARGE LEG. TO DO THIS, I FOUND THE REYNOLDS NUMBER AND THEN THE f VALUES. PIPE DIAMETER IN APP. F, TABLE F.1.

$$N_R = \frac{VD\rho}{\eta} \longrightarrow \frac{(9.45474\,\frac{FT}{S})(0.1342\,FT^2)\left(\frac{57.408\,\frac{lb}{FT^3}}{32.2\,\frac{FT}{S^2}}\right)}{3.6 \times 10^{-5}\,\frac{lb \cdot s}{FT^2}} = 62837.2 \text{ (TURBULENT)}$$

FROM TABLE 8.2 (STEEL)

$$\rightarrow \frac{D}{\epsilon} = \frac{0.1342\,FT^2}{(1.5\times10^{-4}\,FT)} = 894.667\,FT \longrightarrow \text{LOOK IN MOODY'S CHART, } N_R = 62{,}837.2,\ \frac{D}{\epsilon} = 894.667\,FT$$

FROM MOODY'S CHART, $f = 0.02$

NOW I CAN CALCULATE ENERGY LOSSES,

$$h_L = h_{L_S} + h_{L_{FILTER}} + h_{L_{GATE\ VALVE}} + h_{L_{CHECK\ VALVE}} + h_{L_D}$$

FOR GATE AND CHECK VALVE

NOTE, f_T IS FRICTION FACTOR IN ZONE OF COMPLETE TURBULENCE. (USE TABLES 10.4 AND 10.5)

FULLY OPEN GATE $\rightarrow \frac{L_e}{D} = 8$

SWING CHECK $\rightarrow \frac{L_e}{D} = 100$

f_T FOR $1\frac{1}{2}$ SCH. 40 = 0.020

$$h_{L_S} = f\left(\frac{L}{D}\cdot\frac{V^2}{2g}\right) = 0.02\left(\frac{10\ FT}{0.1342\ FT}\cdot\frac{9.45474^2\ \frac{FT}{S}}{2(32.2\ \frac{FT}{S^2})}\right) = 2.06867\ FT$$

$$h_{L_F} = K\left(\frac{V^2}{2g}\right) = 1.85\left(\frac{9.45474^2\ \frac{FT}{S}}{2(32.2\ \frac{FT}{S^2})}\right) = 2.56795\ FT$$

$$\left(\frac{V^2}{2g} = 1.38808\ FT\right)$$

$$h_{L_{GV}} = f_T\left(\frac{L_e}{D}\cdot\frac{V^2}{2g}\right) = 0.02\left(8\times 1.38808\ FT\right) = 0.222093\ FT$$

$$h_{L_{CV}} = K\left(\frac{V^2}{2g}\right) = \cancel{200}\ 2(1.38808\ FT) = 2.77616\ FT$$

$K = 100(0.02) = 2$

$$h_{L_D} = f\left(\frac{L}{D}\cdot\frac{V^2}{2g}\right) = 0.02\left(\frac{20\ FT}{0.1342\ FT}\cdot(1.38808\ FT)\right) = 4.13735\ FT$$

$$h_L = (2.06867\ FT) + (2.56795\ FT) + (0.222093\ FT) + (2.77616\ FT) + (4.13735\ FT)$$

$$h_L = 11.7722\ FT$$

NOW I CAN PLUG IN ALL VALUES FOR ENERGY ADDED,

$$h_A = z_3 - z_1 + \frac{V_3^2}{2g} + h_L = 22\ FT - 0\ FT + 1.38808\ FT + 11.7722\ FT$$

$$h_A = 35.1603\ FT$$

TO FIND POWER DELIVERED TO THE COOLANT BY PUMP,

$$P_A = h_A \gamma Q \rightarrow (35.1603\ FT)(57.408\ \frac{lb}{FT^3})(0.13369\ \frac{FT^3}{SEC}) \quad \left(\frac{FT\cdot lb}{SEC}\right)$$

$$P_A = 269.851\ \frac{FT\,lb}{SEC}\cdot\frac{1\ HP}{550\ \frac{FT\,lb}{SEC}} = 0.4906\ HP$$

$$\boxed{P_A = 0.4906\ HP}$$

THE TOTAL PUMP HEAD IS $z_3 - z_1 + h_L = h_A$,

$$h_A = 22\ FT + 11.7722\ FT = 33.7722\ FT$$

$$\boxed{\text{PUMP HEAD} = 33.7722\ FT}$$

TO FIND THE PRESSURE AT THE PUMP INLET, USE BERNOULLI'S

$$\frac{\cancel{P_1}^{0}}{\gamma_c} + \cancel{z_1}^{SAME} + \frac{\cancel{V_1^2}^{0}}{2g} = \frac{P_2}{\gamma_c} + \cancel{z_2}^{SAME} + \frac{V_2^2}{2g} + h_{L_S} \rightarrow P_2 = \left(-\frac{V_2^2}{2g} - h_{L_S}\right)(\gamma_c)$$

$$P_2 = \left(-\frac{V_2^2}{2g} - (h_{L_S} + h_{L_F} + h_{L_{GV}})\right)(\gamma_c)$$

$$= \left(-1.38808\ FT - (2.06867\ FT + 2.56795\ FT + 0.222093\ FT)\right)(57.408\ \frac{lb}{FT^3})$$

$$P_2 = -358.616\ \frac{lb}{FT^2}\cdot\frac{1\ FT^2}{144\ in^2} = -2.4904\ psi$$

$$\boxed{P_2 = 2.4904\ psig}$$

FOR QUESTIONS 2. f, g, SEE TEST 1 CALCULATIONS EXCEL SPREADSHEET. OPERATIONAL COSTS AND TOTAL COSTS CALCULATIONS AND FIGURES ARE SHOWN THERE.

Summary: THE SYSTEM IN FIGURE PROVIDED REQUIRED A FLOW RATE HIGHER THAN ORIGINALLY PLANNED. THE REQUIRED FLOW RATE WAS DOUBLED FROM ORIGINAL CALCULATIONS. (FROM 30 GPM FOR BOTH MACHINES TO 30 GPM EACH). SINCE THE SECOND HALF OF SYSTEM IS GRAVITY FED, I FOCUSED ON THE PUMPED SYSTEM IN ORDER TO PROVIDE A HIGHER FLOW RATE TO THE HEAD TANK SUPPLYING COOLANT TO THE MACHINES. FIRST, I DETERMINED THE REQUIRED FLOW AREA FOR THE NEW VOLUME FLOW RATE USING $A = Q/V$. THEN, I FOUND AN AREA IN THE APPENDIX F.1 TABLE THAT WAS AS CLOSE AS POSSIBLE, $1\frac{1}{2}$" SCH. 40 STEEL PIPE. I USED THIS PIPE SIZE FOR MY CALCULATIONS FOR THE POWER DELIVERED BY THE PUMP, THE PUMP HEAD, AND THE INLET PRESSURE OF THE PUMP BY SOLVING FOR THE VELOCITY AND USING IT ~~FO~~ FOR MY BERNOULLI'S AND REYNOLD'S EQUATIONS. TO DO THIS, I ALSO HAD TO CALCULATE ALL ENERGY LOSSES IN THE PUMPED SYSTEM, NEGLECTING LOSSES AT TANK INLETS AND OUTLETS DUE TO BEING NEGLIGIBLE. FOR ALL CALCULATIONS, I ALSO RAN THEM IN EXCEL. I THEN CHOSE FOUR OTHER PIPE SIZES AND RAN THE CALCULATIONS AGAIN BY USING EXCEL FUNCTIONS. I ALSO CALCULATED THE COSTS FOR INSTALLATION, 2 YEARS OF CONTINUOUS OPERATION, AND THE TOTAL OF BOTH. I THEN PLOTTED EACH IN A CHART FOR ANALYSIS.

ANALYSIS: AFTER RUNNING CALCULATIONS FOR THE VARIOUS PIPE SIZES, I NOTICED SEVERAL THINGS ABOUT THE RESULTS. THE SMALLEST PIPE SIZE THAT I SELECTED WAS 1". THIS PIPE HAD THE LOWEST INSTALLATION COST, BUT THE HIGHEST OPERATIONAL COST AS WELL AS THE HIGHEST TOTAL COST. THE LARGEST PIPE SIZE SELECTED WAS $2\frac{1}{2}$". THIS PIPE HAD THE HIGHEST INSTALLATION COST, THE LOWEST OPERATIONAL COST FOR 2 YEARS, AND THE THIRD LOWEST TOTAL COST. THE PIPE SIZE WITH THE LOWEST TOTAL COST WAS $1\frac{1}{2}$", HOWEVER, THIS PIPE SIZE DIDN'T HAVE THE LOWEST INSTALLATION OR 2-YEAR OPERATIONAL COSTS. IT APPEARS THAT MY RESULTS TREND LOGICALLY BASED ON THE SIZE OF THE PIPE VS. THE COSTS ASSOCIATED. THEREFORE, I BELIEVE THEY MAKE SENSE. FROM WHAT I CAN DEDUCE FROM ANALYSING MY RESULTS, THE LARGER THE DIAMETER OF THE PIPE, THE MORE EFFICIENT THE SYSTEM IS DUE TO LESS TURBULENT FLOW AND DRAG BEING PRODUCED IN THE FLUID/COOLANT BEING PUMPED. ALTHOUGH THE INSTALLATION COSTS FOR 1" SCHEDULE 40 PIPE WERE 1/3 THE COST OF $2\frac{1}{2}$" SCHEDULE 40 PIPES, THE OPERATIONAL COSTS ARE 5 TIMES HIGHER THAN THE OPERATIONAL COSTS FOR $2\frac{1}{2}$" AFTER A ~~5-YEAR~~ 2-YEAR PERIOD. THIS CAN BE ATTRIBUTED TO THE INEFFICIENCY OF THE 1" PIPE WHEN SUPPLYING THE REQUIRED FLOW RATE. OUT OF THE PIPE SIZES THAT I SELECTED, I WOULD PICK THE $2\frac{1}{2}$" SCHEDULE 40 PIPE FOR THIS APPLICATION. WHILE THE TOTAL COST ISN'T THE LOWEST, THE OPERATIONAL COSTS WILL SAVE THEM MONEY IN THE LONG RUN DUE TO THE LARGER PIPE SIZE REDUCING THE AMOUNT OF ENERGY LOSSES.