Name: Dylan Arnold

UID: 01166349

MET 330 Fluid Mechanics
Dr. Orlando Ayala
Summer 2023
FINAL Test

DUE DATE: Saturday August 5th before midnight

READ FIRST

1. RELAX!!!! DO NOT OVERTHINK THE PROBLEM!!!! 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 ninety (90). The other 10 points will come from the HW assignments.

3. There is only one problem and I will divide the 90 points among the different tasks.

4. PLEASE READ CAREFULLY THE TASKS AND INFORMATION BEFORE THE TASKS. Take notes while you read. You will NOT need everything stated on the project description section.

5. The test is open book, open notes. You cannot use online sources (only ODU related ones).

6. What you turn in should be only your work. You cannot discuss the exam with anyone else, except me. For those off campus, call me if you need help (302-397-4981).

7. 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.

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, even if it is ODU related.

TASKS

After the previous engineer left the consulting company, you got hired to continue his work on a project described on the next pages. The previous engineer designed the tanks and decided their locations (sketched in figure 1). You are in charge now of designing the pipeline of the system taking the coolant from the railroad tank to the storage tank (PLEASE, note that you are in charge of only one system). **The transfer must occur in not less than 6 hours.** The specific tasks for this design you are in charge of are:

1. Specify the layout of the piping system (make a hand drawing of it). For the pipe layout consider the distances shown in figure 1 and some of the requirements (such as frost line) in the project description. Propose the material type of the pipe and its diameter. From the layout get the pipe length required. Please remember that for a pumped system, the pipe size is chosen with the critical velocity criteria and the desired flow rate. Remember the pipe size requirement by the company.

2. Specify the number, type, material, and size of all valves, elbows, and fittings. Please remember that for a pumped system, the pipe size (and therefore fitting sizes) is chosen with the critical velocity criteria and the desired flow rate.

3. Develop the hydraulic analysis of all parts of the system; this is to compute the energy losses due to pipe friction and minor losses. You should list the energy losses of the suction pipe, the discharge pipe, and the total.

4. What are the preliminary requirements of the pump (i.e. pump head and flow rate)?

5. Argue why you need a kinetic pump (instead of a positive displacement) and prove that the radial pump is the type of kinetic pump you need.

6. Select the appropriate SULZER pump (use affinity laws when required). Specify the exact point of operation of the pump. Include pump curves with the system curve and point of operation. Keep in mind that if you are required to use affinity laws to get the curves at another rpm, you can just scale the y- and x- axis appropriately of the pump H-Q curve. YOU MUST INCLUDE THE PUMP CURVE WITH THE SYSTEM CURVE DRAWN ON TOP OF IT!

7. Specify electrical motor requirement for our pump for our electrical engineering colleagues. Recall that we specify the power of the electrical motor as about 1.10 times the power required by the pump.

8. Evaluate the NPSH available for your design and demonstrate that your pump will not suffer cavitation.

9. Prepare a list of materials. Include everything you designed/selected. The list should contain the materials of the system as well as all the equipment (pump).

PROJECT DESCRIPTION

Continental AG is planning for a new manufacturing facility. As part of the new plant, there will be an automated machining line in which five machines will be supplied with coolant from the same reservoir.

The layout of the planned facility is shown in figure 1. The following data, design requirements, and limitations are given.

1. New coolant is delivered to the plant by railroad tank cars carrying 15,000 gal each. A storage tank for new coolant must be specified.

2. The reservoir for the automated machining system must have a capacity of 1000 gal.

3. The 1000-gal tank is normally emptied once per week. Emergency dumps are possible if the coolant becomes overly contaminated prior to the scheduled emptying.

4. The dirty fluid is picked up by truck only once per month.

5. A holding tank for the dirty fluid must be specified.

6. The plant is being designed to operate two shifts per day, 7 days a week.

7. Maintenance is normally performed during the third shift.

8. The building is one-story high with a concrete floor.

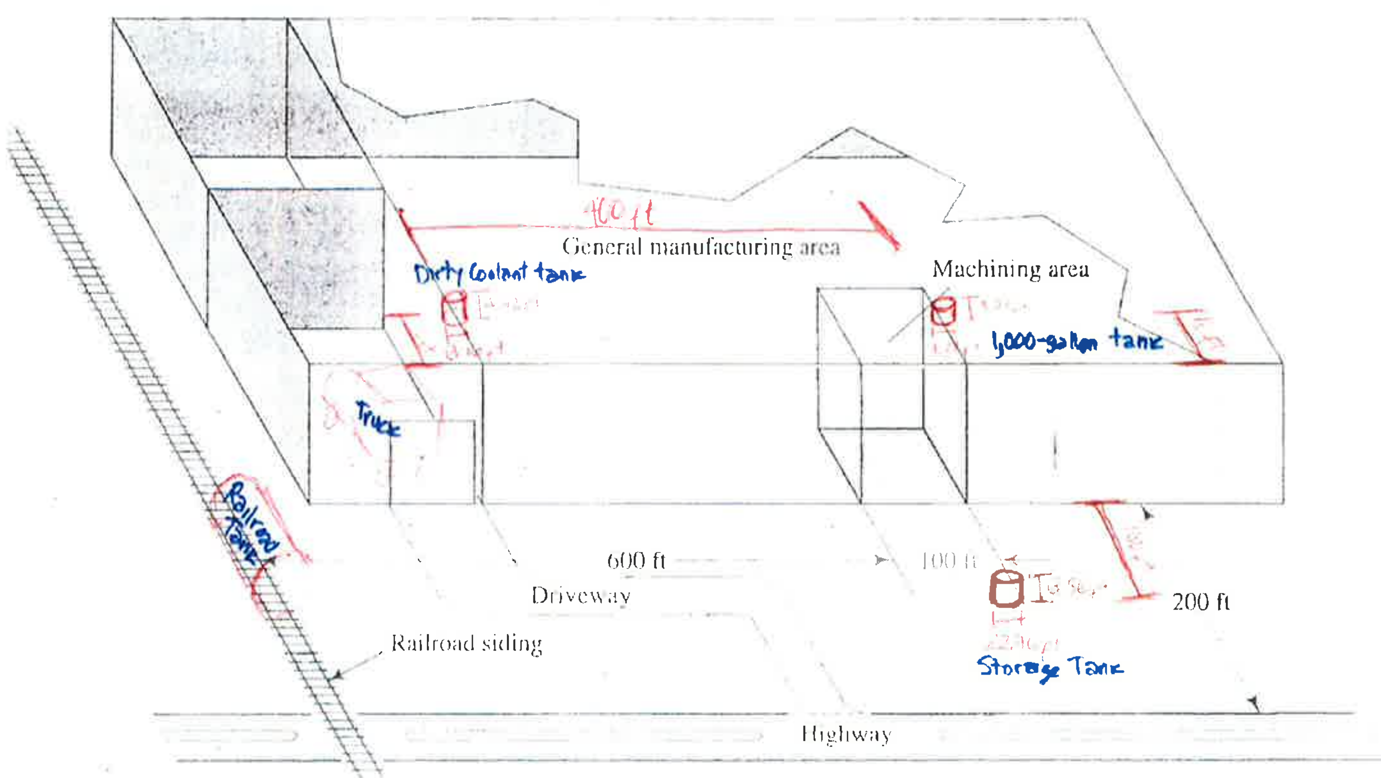

FIGURE 1. Plot plan of a hypothetical factory building for the design problem.

9. The floor level is at the same elevation as the railroad track.

10. No storage tank can be inside the plant or under the floor except the 1000-gal reservoir that supplies the machining system.

11. The roof top is 32 ft from the floor level and the roof can be designed to support a storage tank.

12. The building is to be located in Dayton, Ohio, where the outside temperature may range from -20°F to +105 °F.

13. The frost line is 30 in below the surface. Therefore most of any pipeline outside the building must be below this frost line.

14. The coolant is a solution of water and soluble oil with a specific gravity of 0.94 and a freezing point of 0 °F. Its corrosiveness is approximately the same as that of water.

15. Assume that the viscosity and vapor pressure of the coolant are 1.50 times that of water at any temperature.

17. The basic coolant storage and delivery system is to have the functional design sketched in the block diagram in Figure 2.

18. The company would like ALL of their pipes to be not smaller than 1.5 inches in diameter (nominal). You can select any pipe size larger than that but nothing smaller than that.

19. The required pumps can only SULZER pumps. **YOU ARE ALLOWED TO USE ONLY SULZER PUMP CATALOG PROVIDED IN CLASS! Which you should have access to for the test.**

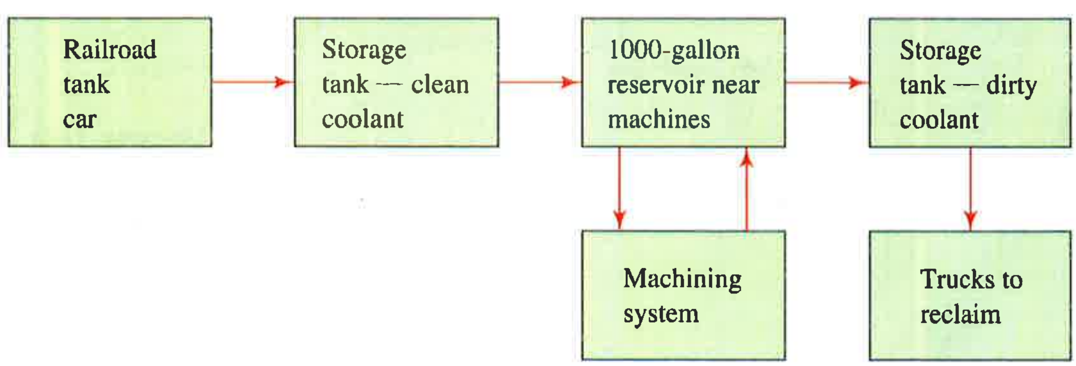

FIGURE 2. Block diagram of coolant system.

HONOR CODE

I pledge to follow the Honor Code and to obey all rules for taking exams and performing homework assignments as specified by the course instructor.

I understand that when asked to follow the Honor Code on exams or homework assignments I must follow the rules below.

1. When following the Honor Code a student must work entirely alone on exams.

2. When following the Honor Code a student may not share information about any aspect of the exam with other members of the class, other faculty members, or other people who has not already taken the exam this year, or its equivalent in future years.

3. When following the Honor Code a student must direct all questions concerning the exam or homework assignment to the course instructor or teaching assistant.

4. When following the Honor Code it is the student's responsibility to obtain clarification from the instructor if there are questions concerning the requirements of the Honor Code.

5. When following the Honor Code a student can only access websites related to ODU (such as Blackboard, etc.) while taking the test.

6. When following the Honor Code a student cannot access, neither ask for help, from websites such as coursehero, chegg, and any other similar website, while taking the test.

I understand that failure to follow this Honor Code imply that the professor will immediately report my case for academic dishonesty to the ODU Office of Student Conduct & Academic Integrity.

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UIN: 01166349

Student Signature: [signature]

Date: 08/05/2023

Dylan Arnold Final Exam University ID: 01166349
MET 330 Professor Ayala August 5th, 2023

1. Purpose: To specify the layout of the piping system. Specify the number, type, and material of all valves, elbows, and fittings. Develop hydraulic analysis of all parts of the system to compute energy losses due to friction and minor losses. Preselect pump. Discuss why kinetic pump should be chosen over a positive displacement pump and prove why radial pump is the best choice. Select appropriate SULZER pump. Specify electrical motor requirements for the pump chosen (1.10X power required). Evaluate NPSH available in our design and demonstrate cavitation will not happen. Finalize and prepare list of materials for the design.

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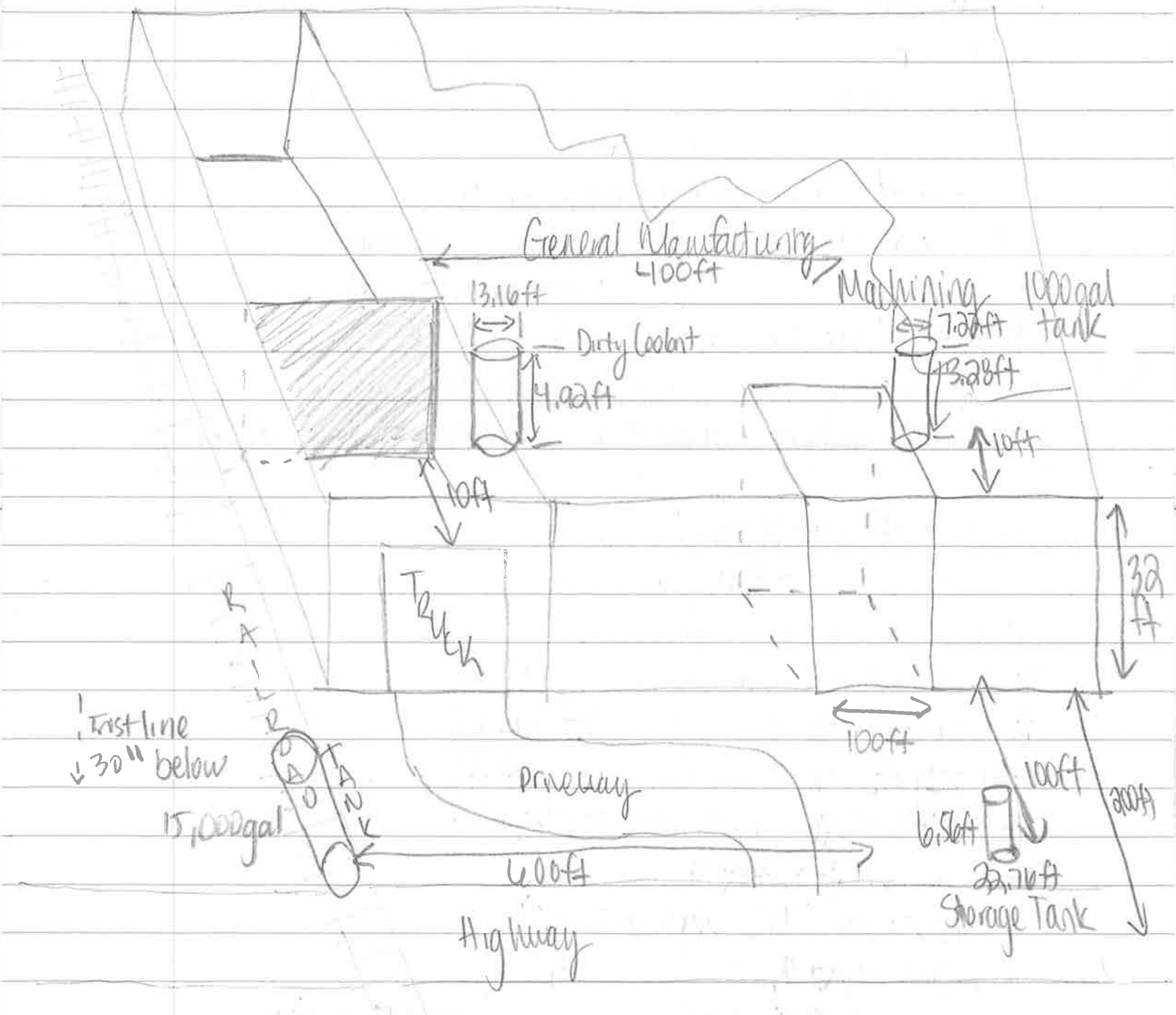
Drawing:

coolant ∪ water + soluble oil sg = 0.94
-20° ↔ 105°F temperature range

All pipes no smaller than 1.5" nominal



Railroad → Storage Tank → 1000 gal tank → Dirty Tank → Trucks
↓ Machines ↑

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Sources: Mott and Untener, Applied Fluid Mechanics, 7th Edition, 2015. Pearson Education.

Design Considerations:

1) Incompressible Fluid
2) Isothermal Process
3) Steady State
4) Transfer in no less than 6 hours
5) No smaller than 1.5" nominal piping
6) Coolant corrosion similar to water
7) Frost line 30" below surface, so all outside piping must be below this.
8) Viscosity and vapor pressure are 1.5x of water

Data and Variables:

1) SG = 0.94 = 58.66 lb/ft³
2) Freezing point 0°F
3) Railroad tank capacity 15,000 gallons
4) Storage tank 22.76' OD, 6.56 ft H
5) Machine reservoir tank 7.22' OD, 3.28 ft H
6) Dirty tank 13.16' OD, 4.92 ft H
7) Plant roof 32 ft
8) Frost line 30" below surface
9) Temp range = -20°F ⟺ 105°F
10) Viscosity and vapor pressure 1.5X of water
11) Corrosiveness same as water

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Procedure and Calculations:

$0.0928\ ft^3/s = 9.84\ ft/s\ A$
$0.0094 = A$ ↓ $3\ m/s$
$A = \frac{\pi D^2}{4}$
$D = 1.31''$ needs to be $> 1.5''$

Flow rate = $Q = VA$
360 mins = 6 hours
$\frac{15{,}000\ \text{gallons}}{360\ \text{mins}} = 41.67\ \text{gpm} = 0.0928\ ft^3/s$

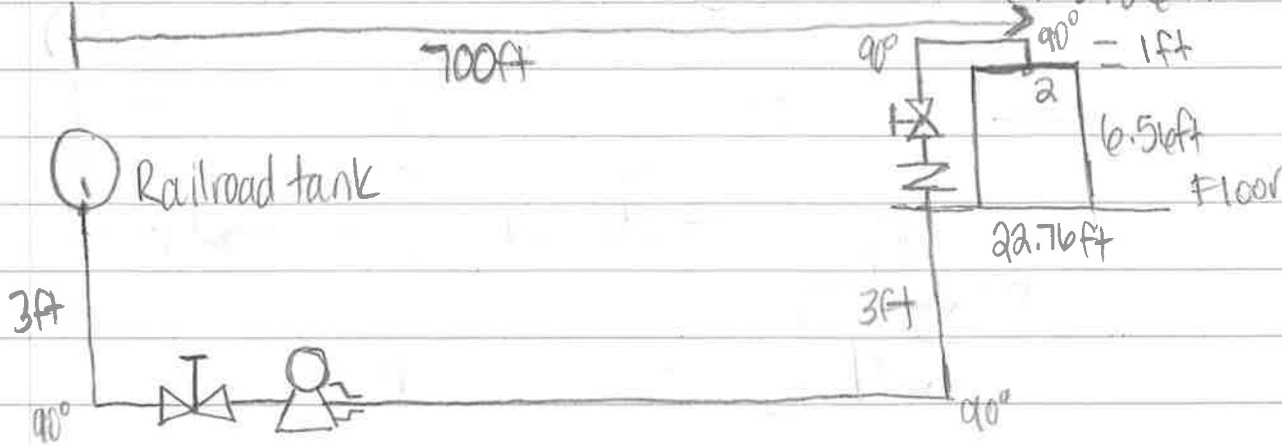
Closest to 1.31" that's $\geq 1.5''$ nominal is SCH40 1.5"
with $D = 1.61''$ or $0.1342\ ft$ $A = 0.01414\ ft^2$

$V = \frac{Q}{A}$ $V = \frac{0.0928\ ft^3/s}{0.01414\ ft^2}$ $V = 6.56\ ft/s$ or $2\ m/s$ ✓

No storage tank below floor * besides machine reservoir tank

Appendix F Table F.1 SCH40
1 1/2 NPS ID = 1.610" ✓ meets criteria

Part 1 Total pipe length = 3 + 700 + 3 + 6.56 + 1
= 713.56 ft



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Kinematic viscosity of water at 32°F (lowest value in table) = 1.89×10^{-5} ft²/s
multiplied by 1.5 = 2.84×10^{-5}

$$N_R = \frac{(6.56\,ft/s)(0.1342\,ft)}{2.84 \times 10^{-5}\,ft^2/s} = 30998$$

ε steel pipe (commercial) = 1.5×10^{-4} ft

$$\frac{D}{\varepsilon} = \frac{0.1342\,ft}{1.5 \times 10^{-4}\,ft} = 894.67$$

$$f = \frac{0.25}{\left[\log\left(\frac{1}{3.7(894.67)} + \frac{5.74}{(30998)^{0.9}}\right)\right]^2}$$

$$[\log(0.000302 + (0.000521))]^2$$

$f = 0.026$

f_T of 1.5 NPS = 0.020 but use above value from equation 8-7

$$H_L \text{ of pipe} = f_T\left(\frac{L}{D}\right) = 0.026\left(\frac{713.56\,ft}{0.1342\,ft}\right) = 138.25\,ft$$

gate value = $8f_T$ = $8(0.026)$ = 0.208
QTY 2 = 0.208 x 2 = 0.416

elbows = $30f_T$ = $30(0.026)$ = 0.78
QTY 4 = 0.78 x 4 = 3.12

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Swing check valve = 100 ft = 100(0.026) = 2.6

entrance loss
assuming inward-projecting pipe K = 0.78

reducer
= 0.37(0.668) = 0.25

$H_L = K\left(\frac{v_2^2}{2g}\right)$ $0.78\left(\frac{6.56^2}{2 \cdot 32.2}\right) = 0.52$

exit loss $H_L = K\left(\frac{v_2^2}{2g}\right)$ where K = 1.0

$1.0\left(\frac{6.56^2}{2 \cdot 32.2}\right) = 0.668$

$H_L = 138.25 + 0.416 + 3.12 + 2.6 + 0.52 + 0.668$
$H_L = 145.824$ ft

$H_a = H_L + \Delta z + \left(\frac{v_2^2}{2g}\right)$ $H_a = 145.824 + 6.56 + \left(\frac{6.56^2}{2 \cdot 32.2}\right)$
$H_a = 153.05 \sim 153$ ft Q = 41.67 gpm ~ 42 gpm

Pumps at rpm 2900 available for above values. However, optimal selection is 1" pump suction line and that does not not meet customer requirements. Therefore, must use one "behind" optimal

Pump preselection = 1.5 x 3 x 8 - 10HH

See Sulzer table*

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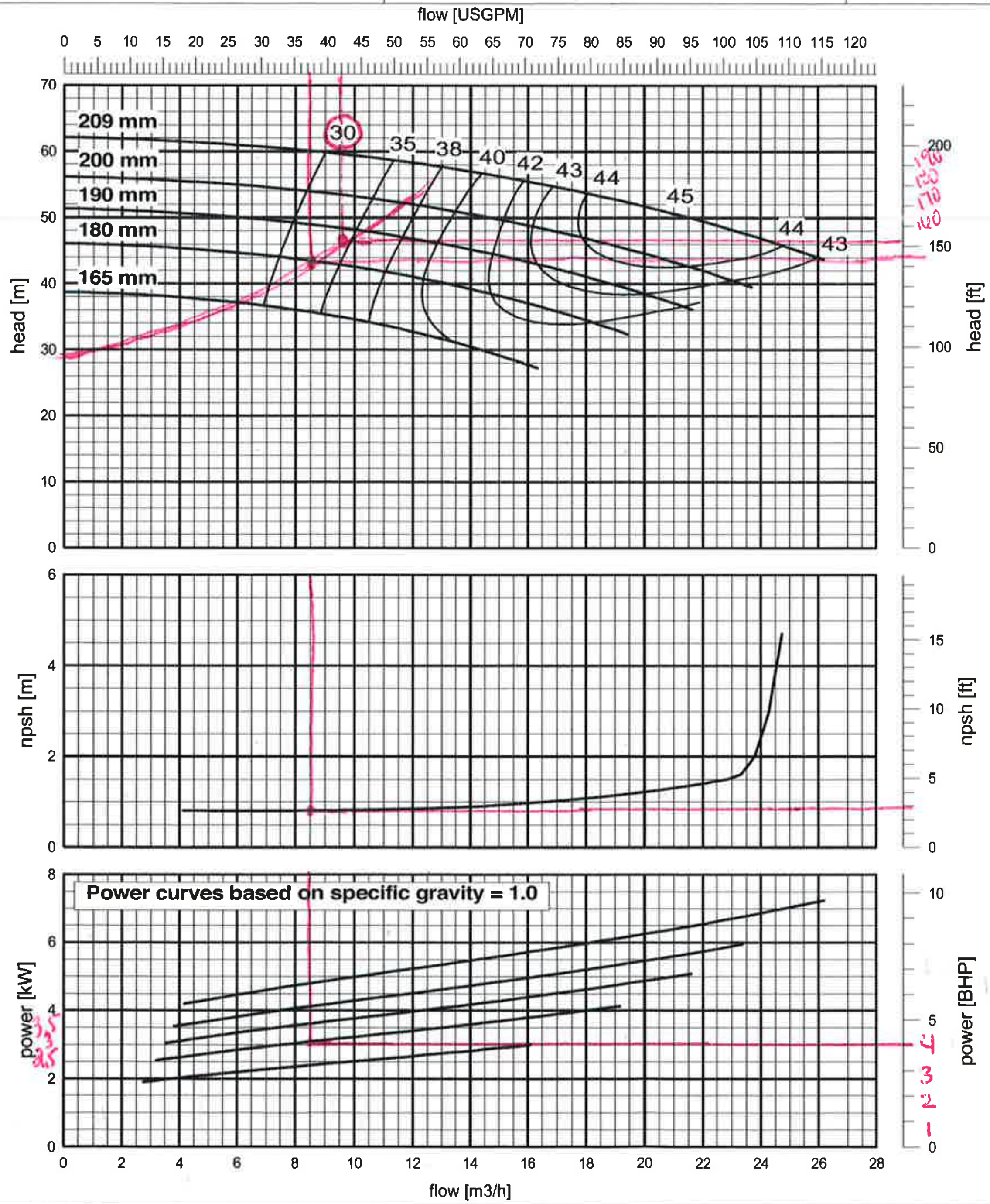
1.5 x 3 x 8 -1 OHH

SULZER

Series 2.00 / 50Hz E011

Curve No	**OHH 70-1-2-03**	**NSS**	**181 (9330)**	Speed
Efficiency Basis	**API Std. clearances**	**nq**	**12 (600)**	**2910**
Max Solid	**6 mm (.24 in)**	**Rotation**	**CCW viewed from coupling**	rpm



Rated Conditions		
Project	Item	
H =	Q =	P =
Calculated Efficiency =		$NPSH_{3\%}$ =
		Issued: MSC / 07.24.2002

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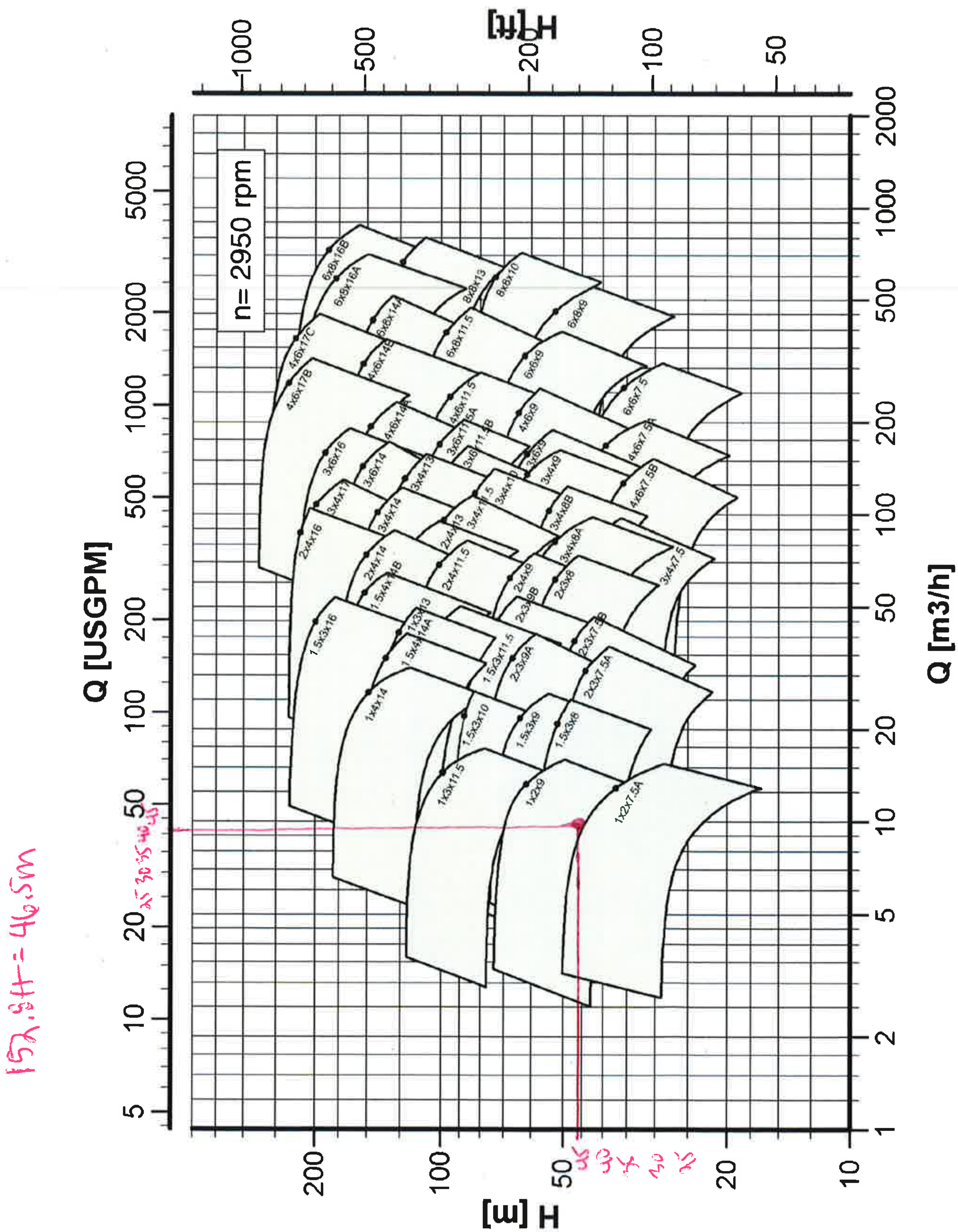
SULZER

CURVES - TYPE OHH

Range of Performances - 50 Hertz / 2950 rpm

Series **2.00**	Page
CURVES	50hz
12 February 2002	**E0F**



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Since we can not exceed 41.67gpm, we can't choose best choice along curve of impeller diameter of 190mm. Therefore, we will drop to impeller diameter of 180mm

impeller diameter 180mm or 7.087"
giving us new Ha value of 145ft and Q value of 37gpm which would then take 6.75 hours to transfer.

$Q_1 = 35$ gpm Ha ~ 147 ft
$Q_2 = 37$ gpm Ha ~ 145 ft
$Q_3 = 40$ gpm Ha ~ 141 ft

$$\frac{\frac{37}{449}}{0.01414} = 5.83 \text{ ft/s}$$

A kinetic pump is needed over a positive displacement pump because we can provide high pressure with our moderate flow rate. Also, there will be times that we will not be delivering fluid to the pump, (as positive displacement requires fixed quantity with every turn). We also need the high pressure from the kinetic pump to get it through the 700 ft of pipe. Lastly, a PD pump requires a relief valve which adds cost to the already expensive project.

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$P_A = h_a \gamma Q$

P_A = power delivered by pump

$= \sim 145 ft\ (0.94 \times 62.4\ lb/ft^3)\left(\frac{37}{449}\ \frac{ft^3}{s}\right)$

$= 700\ \frac{lb \cdot ft}{s} \cdot \frac{1\ hp}{550\ \frac{lb \cdot ft}{s}} = 1.274\ HP$

$1.274\ HP \cdot \frac{745.7\ W}{1\ hp} = 950\ W$

$P_I = \frac{P_A}{E_m}$ where E_m = **30%** per SULZER pump curve
↳ 0.3

$P_I = \frac{1.274\ HP}{0.3} = 4.25\ HP$ or $3,169\ W$

electrical power $= 1.1(P_I) = 1.1(4.25\ HP) = 4.675\ HP$
(3486 W)

$NPSH_A = 1.10\ NPSH_R$

$NPSH_A = h_{sp} \pm h_s - h_f - h_{vp}$

$h_{sp} = \frac{14.7\ psi\ (atm)}{0.0764\ \frac{lb}{ft^3}} \cdot \frac{1\ ft}{144\ in^2} = 1.34\ ft$

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$h_s = \pm 13ft$ $\qquad \frac{6.56^2}{2 \cdot 32.2} = 0.668$

3ft under + 10ft tank $\qquad h_L = 0.026\left(\frac{10ft}{0.1342}\right) = 1.94$

$h_f = 1.94(0.668) + 0.52(0.668) + 0.78(0.668) + 0.208(0.668)$

$h_f = 2.3\ ft$

h_{vp} = @ 59°F = Fig 13.37 $h_{vp} = 0.5ft \times 1.5 = 0.75$

$NPSH_A = 1.34 + 13 - 2.3 - 0.75 = 11.29ft$

$NPSH_R = \frac{NPSH_A}{1.10} = \frac{11.29ft}{1.10} = 10.26ft$

NPSH of 1.5X3x8 (180mm impeller) is roughly 3ft therefore no cavitation will occur

↳ see SULtER curve page 7.

Suction line

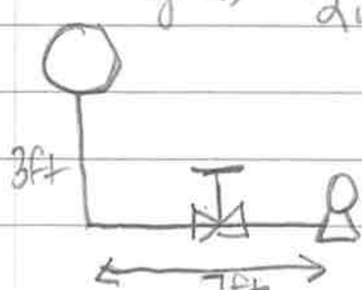
= 10ft of pipe = $0.026\left(\frac{10}{0.1342}\right)(0.668) = 1.29$

= entrance loss = $0.78(0.668) = 0.52$

= 1 elbow = $0.026(30)(0.668) = 0.52$

= 1 valve (gate) = $0.026(8)(0.668) = 0.13$

2.46ft minor loss in suction line



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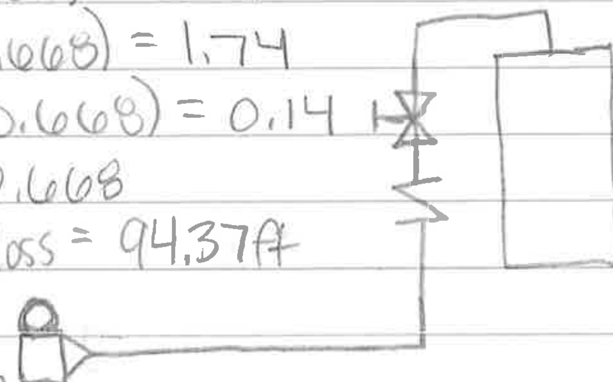
Discharge line
1 3x1.5 reducer = 0.37(0.668) = 0.25
703.56 ft of pipe = $0.026\left(\frac{703.56}{0.1342}\right)(0.668) = 91.05$
3 elbows = 30(0.026)(0.668) = 0.52
1 check value = 100(0.026)(0.668) = 1.74
1 gate value = 8(0.026)(0.668) = 0.14
exit loss = 1.0(0.668) = 0.668
discharge line minor loss = 94.37 ft



See page 6 for total system

Materials:
Railroad tank approx 10ft diameter
1.5NPS (in) nominal SCH40 steel pipe 714ft in length
inward-projecting pipe into railroad tank
4 elbows 90° standard 1 3x1.5 reducer
2 gate valves
1 swing check value
exit loss into storage tank (straight-edged)
1.5 x 3 x 8 (180mm impeller diameter)
Q = 37 gpm
V = 5.83 ft/s

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Summary:
Piping system designed will contain 714ft of 1.5" SCH40 steel pipe, 4 90° standard elbows, 2 gate valves, 1 swing check valve, and a SULZER 1.5 x 3 x 8 with 180mm impeller with a 3x1.5" reducer to go back to 1.5" nominal steel SCH40. Transfer will complete in 6.75 hours which meets criteria from customer.

Analysis: Design of plant could be more thought out (to minimize length in between) tanks, but we were brought on after initial design already implemented. Pipe options are limited with flow rate criteria but it's doable as shown!