Final Exam
MET 330 Fluid Mechanics
Summer Semester
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Alexander Higgins
ahigg013@odu.edu

Project:

Design pipe system to empty a railcar tank into a storage tank.

Fluid:

- **Machining Coolant**
  - SG: 0.94
  - Freezing point: 0°F
  - Same corrosiveness as water
  - Viscosity and Vapor Pressure: 1.5x that of water at a given temperature

Design Considerations:

- The positions of the railcar and the storage tank have already been determined
  - Railcar capacity: 15,000 gallons
  - Storage tank capacity: 20,000 gallons
- The system will be outdoor in an environment that is well below freezing for parts of the year and will require that the piping be buried beneath the frostline (36" below surface). Any exposed pipes will require insulation.
  - Minimum Temperature: -20°F
  - Maximum Temperature: 105°F
- The process must take **NOT LESS THAN 6 HOURS**
- Client requires that pipes be **NOT LESS THAN 1.5" IN DIAMETER**

Pump Type:

For this project, a radial kinetic pump is the best choice. The coolant being moved is not very viscous meaning a kinetic pump will have no issues with it. A kinetic radial pump is cheap and efficient, easy to repair, and simple enough to last a long time before parts need to be replaced. Other more complicated kinetic pumps would cost more initially and over time with higher repair costs. Positive displacement pumps have much higher initial cost and are better suited to more viscous or varying fluid types than will ever need to be pumped for this application.

Preliminary Pump Choice:

- An initial pump choice must be made using a critical velocity for the system and determining a pipe size that will be appropriate
- 3 m/s (9.852 ft/s) will be used as the critical velocity value

<u>Pipe Diameter:</u>

$$Q = A \cdot V \therefore A = \frac{Q}{V}$$

- *Q* must be calculated using the minimum time (6 hours) required to empty the railway tank:

$$Q > 15,000\ {}^{gal}\!/_{6h} = 2500\,{}^{gal}\!/_{h}\left(\frac{1ft^3 \cdot 1h}{7.481gal \cdot 3600s}\right) = \boxed{0.0928\,{}^{ft^3}\!/_{s}}$$

$$A = \left(\frac{0.0928 ft^3/s}{9.852 ft/s} \right) = 0.009419\, ft^2 = \boxed{1\,1/4\text{" diameter pipe}}$$

- The diameter calculated for the critical velocity is below the size specified by the client of 1.5”, meaning 1.5” diameter pipe is sufficient to remain below the critical velocity.

Pipe Choice:

1.5” Schedule 40 Steel Pipe

ID:	0.1342”
OD:	1.9”
Flow Area:	0.01414 ft^2
Wall Thickness:	0.145”
Roughness (ε):	1.5*10^{-4} ft

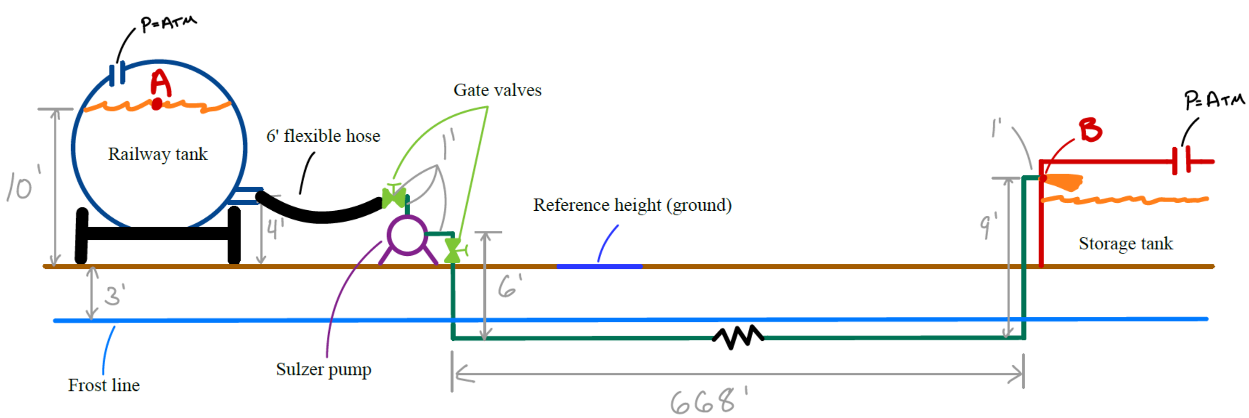
Actual Velocity of the System:

- Because the pipe diameter chosen is larger than the one calculated at the critical velocity, the critical velocity used in those calculations is higher than the actual velocity.
-

$$V = \frac{Q}{A} = \frac{0.0928 ft^3/s}{0.01414 ft^2} = \boxed{6.563\, ft/s}$$

Pipe Route Design:

- The railway tank stops approximately parallel to the storage tank for emptying, pipeline will be straight
- Pipe length between the pump and the storage tank must be buried 6” below the frost line, which is at a depth of 36”
    - All exposed pipeline to be insulated



Pipeline Components:

- 6' EPDM Host (ε=1.5*10^{-5} ft based on smooth PVC/rubber)
- 2x gate valves (K=8*ft)
- 5x elbows (K=30*ft)
- 687' 1.5" schedule 40 steel pipe (ε=1.5*10^{-4} ft)
- Entrance loss at railway tank exit (K=0.5)

Pump Head Calculations (h_A):

$$h_A = \frac{V_A^{\ 2}}{2g} + h_L + \left(z_B - z_A \right)$$

Energy Loss Calculations:

- Suction Side:
  - 6' hose
  - 2' steel pipe
  - 1x gate valve
  - 1x elbow

$$h_{L,\ pipe} = f \cdot \frac{L}{D} \cdot \frac{V^2}{2g} \qquad h_{L,minor} = K \cdot \frac{V^2}{2g}$$

  - Friction factor for the pipe, hose and for *K* values must be found using the relative roughness and Reynold's number to find friction factors on the Moody Chart

$$RR_{pipe} = \frac{D}{\varepsilon} = \frac{0.1342'}{1.5 \cdot 10^{-4} ft} = \boxed{895}$$

$$RR_{hose} = \frac{0.125'}{1.5 \cdot 10^{-5} ft} = \boxed{8333}$$

  - Due to large temperature variation at the site, the Reynolds number will be calculated for both the high and low extremes; the value with lowest energy loss will be chosen so that the flow rate will not exceed the minimum empty time of 6 hours.
  - Due to insulation and pipe depth, the low extreme will be 32°F instead of -20°F

$$v_{coolant\ @\ 32°F} = v_{water @ 32°F} \cdot 1.5 = \left(1.89 \cdot 10^{-5} \right) (1.5) = 2.8 \cdot 10^{-5}$$

$$v_{coolant @ 110°F} = v_{water\ @ 110°F} \cdot 1.5 = \left(6.55 \cdot 10^{-6} \right) (1.5) = 1.0 \cdot 10^{-5}$$

$$N_{R\ hose\ @32°F} = \frac{VD}{v} = \frac{\left(6.536 ft/s \right) (0.125')}{\left(2.8 \cdot 10^{-5} ft^2/s \right)} = \boxed{2.92 \cdot 10^4}$$

$$N_{R\ pipe\ @32°F} = \frac{\left(6.536 ft/s \right) (0.1342')}{\left(2.8 \cdot 10^{-5} ft^2/s \right)} = \boxed{3.14 \cdot 10^4}$$

$$\boxed{\begin{aligned} N_{R\ hose\ @110°F} &= \frac{\left(6.536 ft/s \right) (0.125')}{\left(1.0 \cdot 10^{-5} \right)} = \boxed{8.2 \cdot 10^4} \\ N_{R\ pipe\ @110°F} &= \frac{\left(6.536 ft/s \right) (0.1342')}{\left(1.0 \cdot 10^{-5} \right)} = \boxed{8.8 \cdot 10^4} \end{aligned}}$$

- Lowest energy loss occurs at the highest temperature due to reduced viscosity; pump will be selected using this Reynold's value as the flow rate will decrease in colder temperatures, maintaining the minimum 6-hour empty time restraint.
- Friction factors are determined with the Moody Chart:

$$f_{hose} = 0.019 \qquad f_{pipe} = 0.023 \qquad f_{T,\ pipe} = 0.02$$

$$h_{L,\ hose} = (0.019) \cdot \frac{(6')}{(0.125')} \cdot \frac{(7.545\,{ft}/{s})^2}{2 \cdot (32.2\,{ft}/{s^2})} = \boxed{0.806\,ft}$$

$$h_{L,\ pipe} = (0.023) \cdot \frac{(2')}{(0.1342')} \cdot \frac{(6.563\,{ft}/{s})^2}{2 \cdot (32.2\,{ft}/{s^2})} = \boxed{0.259\,ft}$$

$$h_{L,\,minor\ hose} = (0.5) \cdot \frac{(7.545\,{ft}/{s})^2}{2 \cdot (32.2\,{ft}/{s^2})} = \boxed{0.442\,ft}$$

$$h_{L,\ minor\ pipe} = (30 \cdot 0.02 + 8 \cdot 0.02) \cdot \frac{(6.563\,{ft}/{s})^2}{2 \cdot (32.2\,{ft}/{s^2})} = \boxed{0.508\,ft}$$

$$h_{L,\ suction} = h_{L,\ hose} + h_{L,\ pipe} + h_{L,\,minor\ hose} + h_{L,\ minor\ pipe}$$
$$= \boxed{2.015\,ft}$$

**Velocity for the hose is slightly higher than the pipe as the hose has a slightly smaller internal diameter*

- Discharge Side:
  - 685' steel pipe
  - 1x gate valve
  - 4x elbow

$$h_{L,\ pipe} = (0.023) \cdot \frac{(685')}{(0.1342')} \cdot \frac{(6.563\,{ft}/{s})^2}{2 \cdot (32.2\,{ft}/{s^2})} = \boxed{78.52\,ft}$$

$$h_{L,\ minor} = (4(30 \cdot 0.02) + 8(0.02)) \cdot \frac{(6.563\,{ft}/{s})^2}{2 \cdot (32.2\,{ft}/{s^2})} = \boxed{1.712\,ft}$$

$$h_{L,\ discharge} = h_{l,\ pipe} + h_{L,\ minor} = \boxed{80.233\,ft}$$

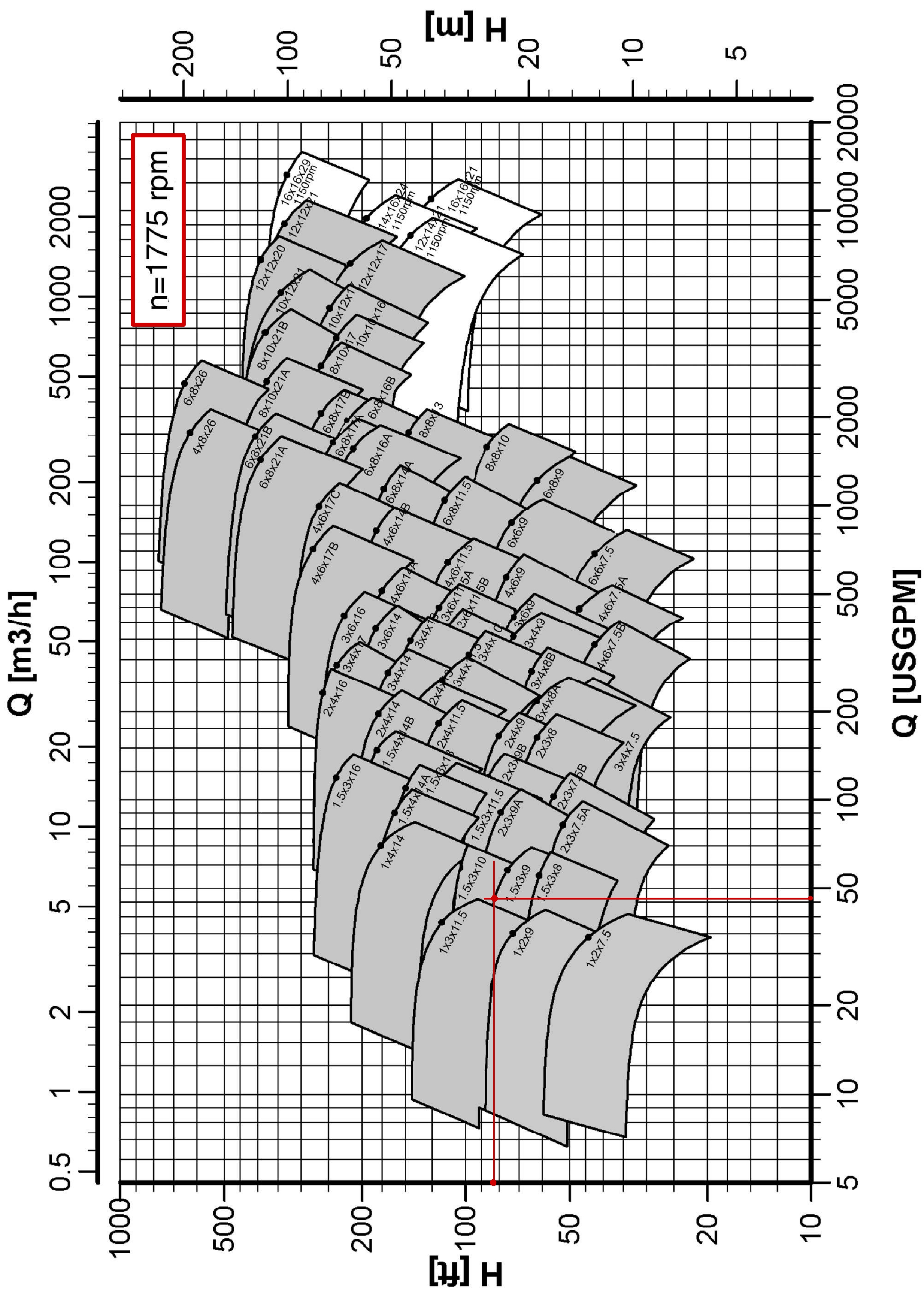
$$h_{L,\ total} = h_{L,\ suction} + h_{L,\ discharge} = \boxed{82.25\,ft}$$

$$h_A = \frac{(6.563\,{ft}/{s})^2}{2 \cdot (32.2\,{ft}/{s^2})} + 82.25\,ft + (9' - 10') = \boxed{81.92\,ft}$$

<u>Pump Selection</u>

- Using the calculated pump head (h_A) and flow rate (Q), select a pump from the Sulzer catalog that will meet the needs of the project
- See pump diagram page below for selection.

SULZER
CURVES - TYPE OHH
Range of Performances - 60 Hertz



The pump used for this project will be:

Sulzer 1.5x3x10 @ 1775 RPM

Impeller Selection:

- To select the impeller size, affinity laws must be used to adjust the RPM from 3520RPM to 1775 RPM to use the manufacturer's performance curves, where *Q* is the flow rate in gallons per minute and *h* is the pump head in feet:

$$\frac{Q_1}{Q_2}=\frac{N_1}{N_2} \qquad \frac{h_1}{h_2}=\left(\frac{N_1}{N_2}\right)$$

- Perform calibration of performance curves from 3520 RPM to 1775 RPM

10.1" impeller:

$$Q_1=40,\ 80,\ 120,\ 160 \qquad h_1=440,\ 435,\ 430,\ 405,\ 360$$

$$Q_{2,1}=Q_1\left(\frac{N_2}{N_1}\right)=40\left(\frac{1775}{3520}\right)=\boxed{20} \qquad h_{2,0}=\frac{h}{\left(\frac{N_1}{N_2}\right)^2}=\frac{440}{\left(\frac{3520}{1775}\right)^2}=\boxed{112}$$

$$Q_2=20,\ 40,\ 60,\ 80 \qquad h_2=112,\ 111,\ 103,\ 109,\ 92$$

9.69" impeller:

$$Q_1=40,\ 80,\ 120,\ 160 \qquad h_1=390,\ 385,\ 375,\ 355,\ 305$$

$$Q_2=20,\ 40,\ 60,\ 80 \qquad h_2=100,\ 98,\ 95,\ 90,\ 78$$

9.19" impeller:

$$Q_1=40,\ 80,\ 120,\ 160 \qquad h_1=340,\ 335,\ 330,\ 305$$

$$Q_2=20,\ 40,\ 60,\ 80 \qquad h_2=86,\ 85,\ 84,\ 77$$

8.69" impeller:

$$Q_1=40,\ 80,\ 120,\ 160 \qquad h_1=300,\ 295,\ 285,\ 260$$

$$Q_2=20,\ 40,\ 60,\ 80 \qquad h_2=76,\ 75,\ 72,\ 66$$

- The system resistance curve will also need to be drawn to select the impeller:
  - To calculate the system curve, the initial pump head calculation will be used, varying the flow rate to adjust the operating point of the pump. Two other points of operation will be found to draw the system resistance curve.
  - The pump head equation must be re-written in terms of *Q*:

$$h_A = \Delta z + \left(\frac{f_{pipe} \cdot L_{pipe}}{D_{pipe}} + 5(K_{elbow}) + 2(K_{valve}) + 1 \right) \cdot \frac{Q^2}{2gA_{pipe}^2}$$
$$+ \left(\frac{f_{hose} \cdot L_{hose}}{D_{hose}} + K_{entrance} \right) \cdot \frac{Q^2}{2gA_{hose}^2}$$

Pipe section:

$$h_{L,\ pipe} + \frac{V^2}{2g} = \left(\frac{0.023 \cdot 687'}{0.1342'} + 5(30 \cdot 0.02) + 2(8 \cdot 0.02) + 1 \right) \cdot \frac{Q^2}{2\left(32.2 ft/_{s^2}\right)\left(0.01414 ft^2\right)^2}$$
$$= 10272 Q^2$$

Hose section:

$$h_{L,\ hose} = \left(\frac{0.019 \cdot 6'}{0.125'} + 0.5 \right) \cdot \frac{Q^2}{2\left(32.2 ft/_{s^2}\right)\left(0.0123 ft^2\right)^2}$$
$$= 145 Q^2$$

Resistance curve equation:

$$\boxed{h_A = -1 + 10420 Q^2}$$

  - The pump head will be calculated at 20 gallons per minute and 60 gallons per minute to get points with which to plot the resistance curve

$$h_{A@20gpm} = -1 + 10420\left(0.04456 ft^3/_s\right) = \boxed{19.69 ft}$$
$$h_{A@60gpm} = \boxed{185 ft}$$

- See performance curve page below for calculated resistance curve and impeller selection

Final Impeller Selection:

8.69" Impeller

- This impeller was chosen as it allows for a slower flow rate while also falling closer to the peak efficiency for the pump according to the manufacturer's performance curve. If an in crease in flow rate is desired later, the client can put a larger impeller in the same pump casing without replacing the entire pump

Cavitation Check Using NPSH

- The Net Positive Suction Head (NPSH) curve must have a value lower than the actual NPSH for the pipe system to avoid cavitation in front of the pump inlet, leading to corrosion
- The $NPSH_R$ on the chart is:

$$NPSH_R = 4.1$$

- The actual NPSH ($NPSH_A$) can be calculated using:

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

- Most of these values must be calculated

$$h_{sp} = \frac{P_{abs}}{\gamma}$$

$$\gamma_{coolant} = \rho_{coolant} \cdot g$$

$$\rho_{coolant} = \rho_{water} \cdot SG_{coolant} = \left(1.92 slugs/ft^3\right) \cdot (0.94) = 1.805 slugs/ft^3$$

$$\gamma_{coolant} = \left(1.805 slugs/ft^3\right) \cdot \left(32.2 ft/s^2\right) = 58.121 lbf/ft^3$$

$$h_{sp} = \frac{P_{atm}}{\gamma_{coolant}} = \frac{2117 lbf/ft^2}{58.121 lbf/ft^3} = \boxed{36.4'}$$

$$h_s = \boxed{+6'}$$

$$h_f = \boxed{2.015'}$$

$$h_{vp,\ coolant} = h_{vp,\ water} \cdot 1.5 = (2.205') \cdot 1.5 = \boxed{3.31'}$$

$$NPSH_A = 36.4' + 6'' - 2.015' - 3.31' = \boxed{37.1'}$$

- The $NPSH_A$ is deemed acceptable if it is greater than 1.1 times the $NPSH_R$:

$$NPSH_A > 1.1 \cdot NPSH_R \quad \therefore \quad 37.1' > 1.1 \cdot 4.1' = 4.51'$$

This system has a greater $NPSH_A$ than required and will not suffer from cavitation.

Necessary Power Draw for the Selected Pump:

- The power curve supplied by the manufacturer for the selected pump and impeller at 1775 RPM must be adjusted using affinity laws to find the required power for this system
- The flow rate, *Q*, is represented in gpm and the power, *P*, is in break horsepower (BHP)

$$\frac{P_1}{P_2} = \left(\frac{N_1}{N_2}\right)^3$$

$$Q_1 = 40,\ 80,\ 120,\ 160 \qquad P_1 = 10,\ 13,\ 18$$

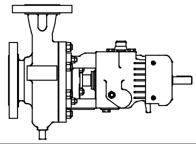
$$Q_2 = 20,\ 40,\ 60,\ 80 \qquad P_2 = \frac{P_1}{\left(\frac{N_1}{N_2}\right)^3} = 1.3,\ 1.7,\ 2.3$$

- The power specified by the curve is 1.8 BHP, but the power requested for the motor will be 1.1 times the manufacturer suggestion so:

$$P_{suggested} = 1.1 \cdot P_{man.\ spec} = 1.1 \cdot 1.8 = \boxed{1.98\ BHP}$$

- The requested power for this pump will be:
  2HP

**See attached page for System Resistance Curve and all manufacturer curves that have been adjusted using affinity laws*

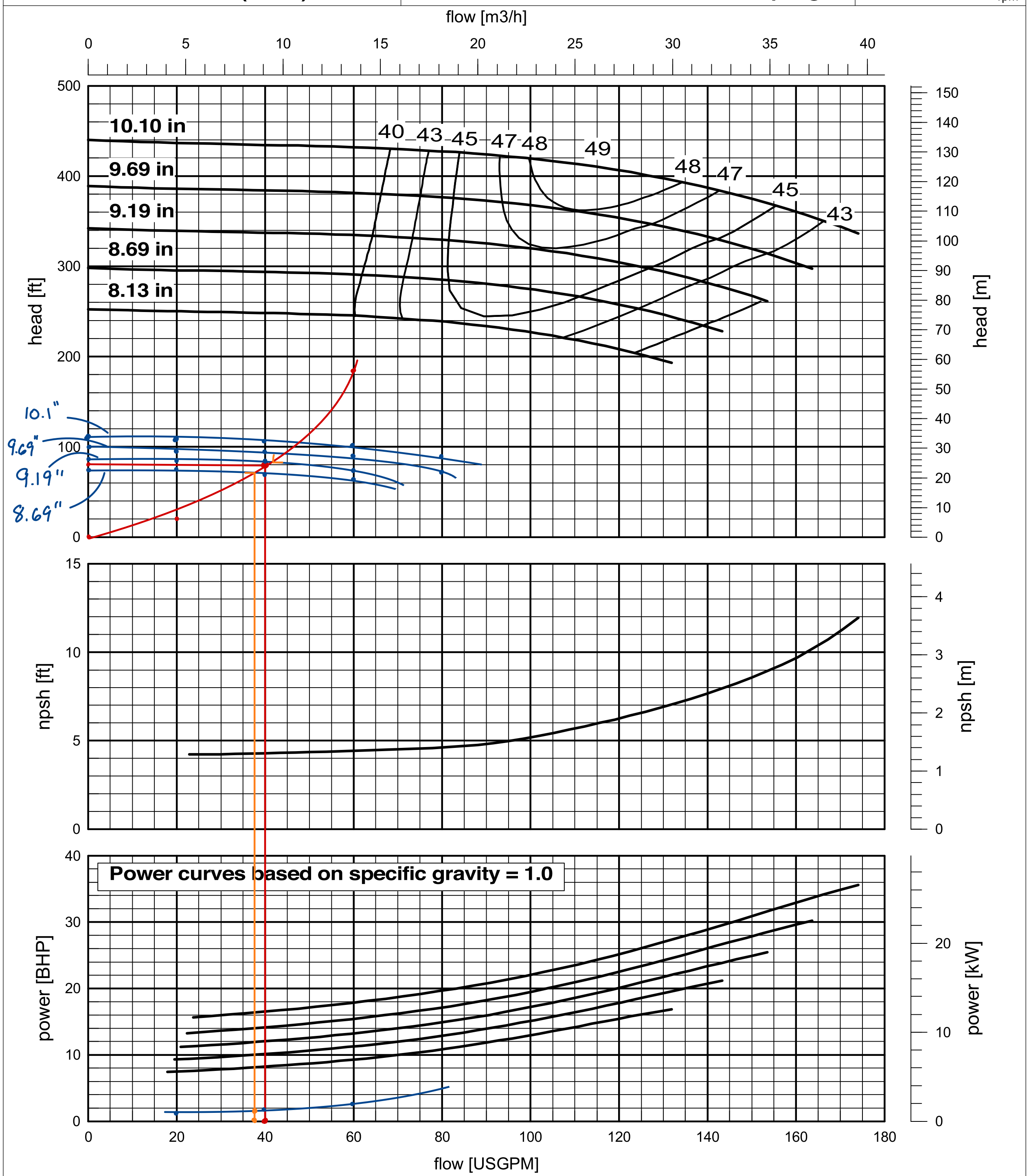


1.5 x 3 x 10 -1 OHH

SULZER

series 2.00 / 60Hz E030

Curve No	**OHH 60-1-1-01**	**NSS**	**9890 (192)**	Speed
Efficiency Basis	**API Std. clearances**	**NS**	**420 (8)**	**3520**
Max Solid	**.25 in (6 mm)**	**Rotation**	**CCW viewed from coupling**	rpm



Rated Conditions

Project	Item	
H =	Q =	P =
Calculated Efficiency =		$NPSH_{3\%}$ =

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