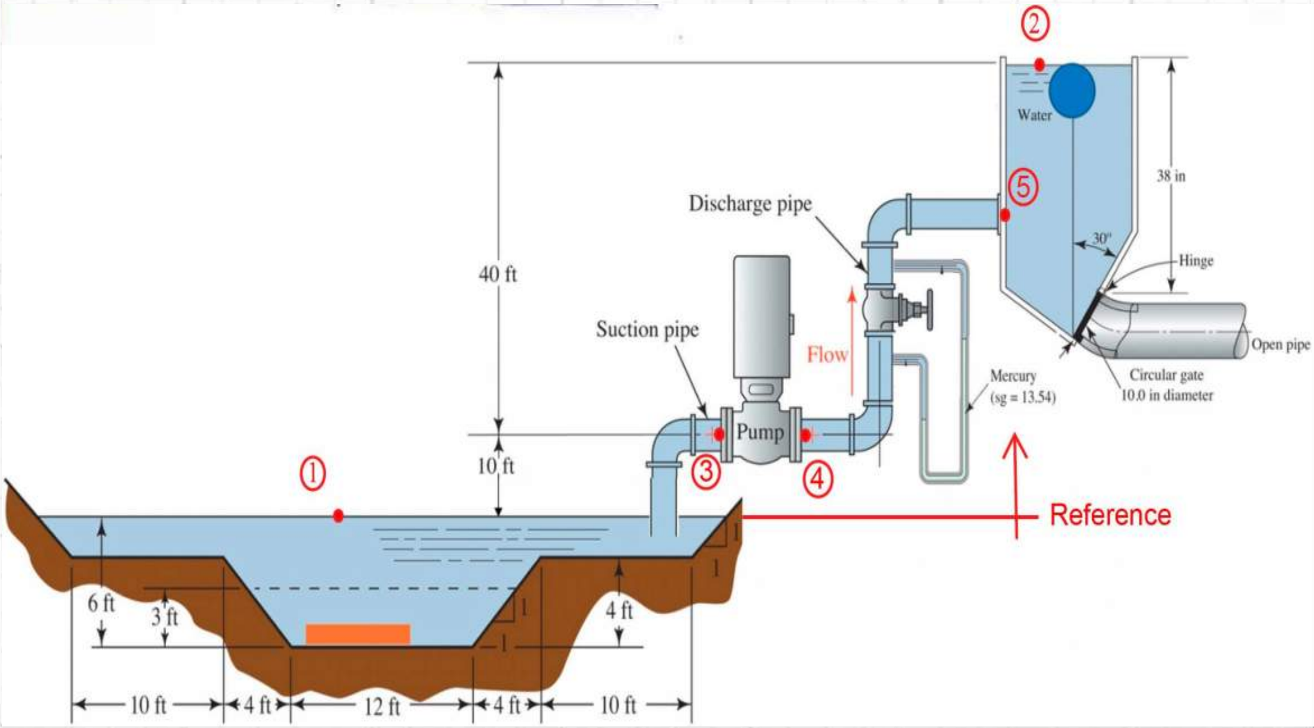
TEST 3

PROFESSORS SOLUTIONS



a1) Use Bernoulli's eq:

$$h_A + \frac{p_1}{\gamma} + \frac{V_1^2}{2g} + z_1 = \frac{p_2}{\gamma} + \frac{V_2^2}{2g} + z_2 + h_{L_{1-2}}$$

which leads to (see 2nd test):

$$h_A = (z_2 - z_1) + h_{L_{1-2}}$$

Now, for $h_{L_{1-2}}$, we need to include the minor losses

$$h_{L_{1-2}} = h_{pipe} + h_{elbows} + h_{valve} + h_{exit} + h_{entrance}$$

And the equations for each of those terms are:

$$h_{pipe} = f\frac{L}{D}\frac{V^2}{2g} \quad ; \quad f < \begin{cases} Re = \frac{VD}{\nu} \rightarrow V = \frac{Q}{A} \\ D/\varepsilon \end{cases}$$

$$h_{elbows} = 3K_{elbow}\frac{V^2}{2g} \quad ; \quad K_{elbow} = 20 f_T$$

$$h_{valve} = K_{valve}\frac{V^2}{2g} \quad ; \quad K_{valve} = 8 f_T$$

$$h_{exit} = K_{exit}\frac{V^2}{2g} \quad ; \quad K_{exit} = 1.0$$

$$h_{entrance} = K_{entrance}\frac{V^2}{2g} \quad ; \quad K_{entrance} = 0.78$$

$$f_T = \lim_{Re \to \infty} f$$

I used excel to compute all those values:

$V = 9.749\ ft/s$

$Re = 5.36 \times 10^5$

$D/\varepsilon = 4434.0$

$f = 0.01566$

$f_T = 0.01407$

$$\left.\begin{aligned} h_{suction} &= 1.949\ ft \\ h_{discharge} &= 89.338\ ft \end{aligned}\right\} h_{L_{1-2}} = 91.287\ ft$$

$$h_A = 141.287\ ft$$

$$P = \frac{\gamma Q h_A}{\eta} = \frac{62.4\ lb/ft^3 \times 3.387\ ft^3/s \times 141.287\ ft}{0.6}$$

Open Channel Info								
n=	0.05							
S=	0.00015							
L_lower trapezoid=	12	ft						
H_lower trapezoid=	4	ft						
L_upper trapezoid=	40	ft						
H_lower trapezoid=	6	ft						
Pipe Info								
Ldisch=	2500	ft						
Lsuct=	11	ft						
ε=	1.50E-04	ft						
z2=	50	ft						
z1=	0	ft						
z3=z4=	10	ft						
Kentrance=	0.78							
Kexit=	1							
Kelbow=	20	*fT						
Kvalve=	8	*fT						
Pump Info								
Qoriginal=	3.3870	ft3/s	Q increase percentage= 0%		Qincreased=	3.3870 ft/s	1520.20 gpm	
η=	0.6							
Fluid Info								
ν=	1.21E-05	ft2/s						
γ=	62.4	lb/ft3						
Flowmeter Info				SELECTING -> 8 in Schedule 40 Steel Pipe				
β=	0.5			7.943 in	D=	0.6651 ft		
					A=	0.3474 ft2		
	PIPE SELECTION							
	D=	0.662 ft						
	ENERGY LOSSES							
	v=	9.749 ft/s						
	Re=	5.36E+05						
	D/e=	4434.00						
	f=	0.01566						
	fT=	0.01407						
		h_suction=	1.949 ft					
		h_discharge=	89.338 ft					
		h_1-2=	91.287 ft					
	PUMP HEAD	hA=	141.287 ft					
	PUMP POWER	P=	49767.9065 lb x ft/s					
		P=	90.49 HP					

$$\mathcal{P} = 49{,}767.906 \ \frac{lb \times ft}{s}$$

or, $$\boxed{\mathcal{P} = 90.49\ HP}$$

I changed the order

Q3 We need to use the same Bernoulli's eq as before; that lead us to:

$$h_A = (z_2 - z_1) + h_{L_{1-2}}$$

Now, including all losses:

$$h_A = \Delta z + f\frac{L}{D}\frac{V^2}{2g} + 3K_{elbow}\frac{V^2}{2g} + K_{valve}\frac{V^2}{2g} + K_{ex}\frac{V^2}{2g} + K_{ent}\frac{V^2}{2g}$$

Given that the pump power remains unchanged, we can get h_A from $\mathcal{P}$:

$$\mathcal{P} = \frac{\gamma Q h_A}{\eta} \longrightarrow h_A = \frac{\mathcal{P}\eta}{\gamma Q}$$

Let us not forget to replace V with Q using:

$$Q = V \times A \Rightarrow V = \frac{4Q}{\pi D^2} \Rightarrow V^2 = \frac{16Q^2}{\pi^2 D^4}$$

All of the above leads to:

$$\frac{P\eta}{\gamma Q}=\Delta z+\left[f\frac{L}{D}+3K_{elb}+K_{valv}+K_{exit}+K_{ent}\right]\frac{1}{\cancel{2}g}\frac{\cancel{16}^{8}Q^2}{\pi^2 D^4}$$

Rearranging:

$$\underbrace{\frac{P\eta}{\gamma Q}-\Delta z}_{LHS}=\underbrace{\left[f\frac{L}{D}+3K_{elb}+K_{valv}+K_{exit}+K_{ent}\right]\frac{8Q^2}{g\pi^2 D^4}}_{RHS}$$

where I identified the unknown D and LHS and RHS of the equation. Nothe that LHS is a constant.

I proceed to solve this equation by iterations with excel, using this sequence:

1) Assume D
2) Compute $Re\left(=\frac{VD}{\nu}\right)$ & D/ε (Need $V=\frac{4Q}{\pi D^2}$)
3) Compute f & f_T
4) Compute RHS
5) Compute $\%diff=\frac{LHS-RHS}{LHS}\times 100$
6) If $\%diff<0.1\%\rightarrow$ STOP.
If not, go to 1)

With it I get that the diameter should be

$$\boxed{D=0.899\,ft}$$

Open Channel Info

n=	0.05	
S=	0.00015	
L_lower trapezoid=	12	ft
H_lower trapezoid=	4	ft
L_upper trapezoid=	40	ft
H_lower trapezoid=	6	ft

Pipe Info

Ldisch=	2500	ft
Lsuct=	11	ft
ε=	1.50E-04	ft
z2=	50	ft
z1=	0	ft
z3=z4=	10	ft
Kentrance=	0.78	
Kexit=	1	
Kelbow=	20	*fT
Kvalve=	8	*fT

Pump Info

Qoriginal= 3.3870 ft3/s | Q increase percentage= 50% | Qincreased= 5.0805 ft/s 2280.29 gpm

η= 0.6

Fluid Info

ν=	1.21E-05	ft2/s
γ=	62.4	lb/ft3

Flowmeter Info

β= 0.5

SELECTING -> 8 in Schedule 40 Steel Pipe

7.943 in D= 0.6651 ft

A= 0.3474 ft2

PIPE SELECTION

D= 0.662 ft

ENERGY LOSSES

v=	9.749	ft/s
Re=	5.36E+05	
D/e=	4434.00	
f=	0.01566	
fT=	0.01407	

h_suction=	1.949	ft
h_discharge=	89.338	ft
h_1-2=	91.287	ft

$$\underbrace{\frac{P\eta}{\gamma Q} - \Delta z}_{LHS} = \underbrace{\left[f\frac{L}{D} + 3K_{elb} + K_{valv} + K_{exit} + K_{ent}\right]\frac{8Q^2}{g\pi^2 D^4}}_{RHS}$$

PUMP HEAD hA= 141.287 ft

PUMP POWER P= 49767.9065 lb x ft/s

P= 90.49 HP

1) Assume D
2) Compute Re($=\frac{VD}{\nu}$) & D/ε (Need $V=\frac{4Q}{\pi D^2}$)
3) Compute f & f_T
4) Compute RHS
5) Compute $\%diff = \frac{LHS - RHS}{LHS} \times 100$
6) If %diff < 0.1% ⇒ STOP.
If not, go to 1)

LHS= 44.1910368

Iteration	D (ft)	V (ft/s)	Re	D/ε	f	fT	RHS	%diff
1	0.7	13.2014	7.64E+05	4.67E+03	0.01516	0.01392	154.5876	-249.817%
2	0.8	10.1073	6.68E+05	5.33E+03	0.01503	0.01355	79.1274	-79.057%
3	0.9	7.9860	5.94E+05	6.00E+03	0.01496	0.01323	43.9770	0.484%
4	0.89	8.1665	6.01E+05	5.93E+03	0.01496	0.01326	46.4906	-5.204%
5	0.899	8.0038	5.95E+05	5.99E+03	0.01496	0.01324	44.2208	-0.067%

I changed the order

a2) For this part, I again use same Bernoulli's eq and all energy losses in a1

$$h_A = \Delta z + h_{L_{1-2}}$$

$$h_{L_{1-2}} = h_{pipe} + h_{elbows} + h_{valve} + h_{exit} + h_{entrance}$$

$h_{pipe} = f \frac{L}{D}\frac{V^2}{2g}$; $f <$ $Re = \frac{VD}{\nu} \rightarrow V = Q/A$ This is going to get affected ; D/ε

$h_{elbows} = 3K_{elbow}\frac{V^2}{2g}$; $K_{elbow} = 20f_t$

$h_{valve} = K_{valve}\frac{V^2}{2g}$; $K_{valve} = 8f_t$

$h_{exit} = K_{exit}\frac{V^2}{2g}$; $K_{exit} = 1.0$

$h_{entran} = K_{entran}\frac{V^2}{2g}$; $K_{ent} = 0.78$

Using excel I get:

$V = 14.623\ ft/s$
$Re = 8.04\times10^5$
$D/\varepsilon = 4434.0$
$f = 0.01523$
$f_T = 0.01407$

$h_{suct} = 4.361\ ft$
$h_{dischar} = 195.632\ ft$

$h_{L_{1-2}} = 199.992\ ft$

$$\boxed{h_A = 249.992\ ft}$$

$P = 132,088.99\ \frac{lb\times ft}{s}$

$$\boxed{\cancel{P = 240.16\ HP}}$$

Open Channel Info								
n=	0.05							
S=	0.00015							
L_lower trapezoid=	12	ft						
H_lower trapezoid=	4	ft						
L_upper trapezoid=	40	ft						
H_lower trapezoid=	6	ft						
Pipe Info								
Ldisch=	2500	ft						
Lsuct=	11	ft						
ε=	1.50E-04	ft						
z2=	50	ft						
z1=	0	ft						
z3=z4=	10	ft						
Kentrance=	0.78							
Kexit=	1							
Kelbow=	20	*fT						
Kvalve=	8	*fT						
Pump Info								
Qoriginal=	3.3870	ft3/s	Q increase percentage=	50%	Qincreased=	5.0805 ft/s	2280.29	gpm
η=	0.6							
Fluid Info								
ν=	1.21E-05	ft2/s						
γ=	62.4	lb/ft3						
Flowmeter Info				SELECTING -> 8 in Schedule 40 Steel Pipe				
β=	0.5		7.943 in		D=	0.6651	ft	
					A=	0.3474	ft2	

PIPE SELECTION

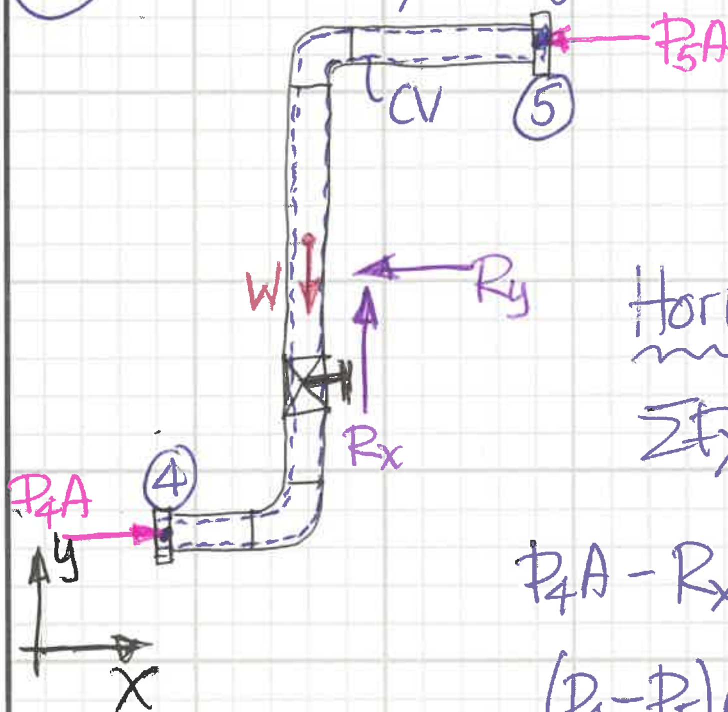
D=	0.662	ft

ENERGY LOSSES

v=	14.623	ft/s
Re=	8.04E+05	
D/e=	4434.00	
f=	0.01523	
fT=	0.01407	
h_suction=	4.361	ft
h_discharge=	195.632	ft
h_1-2=	199.992	ft

PUMP HEAD	hA=	249.992	ft
PUMP POWER	P=	132088.997	lb x ft/s
	P=	240.16	HP

b) Free body diagram



Horizontal

$$\sum F_x = \rho Q(\cancel{V_{2x} - V_{1x}})$$ same velocity

$$P_4A - R_x - P_5A = 0$$

$$(P_4 - P_5)A = R_x$$

Now, using Bernoulli's eq; from 4 to 5

$$\frac{P_4}{\gamma} + \cancel{\frac{V_4^2}{2g}} + z_4 = \frac{P_5}{\gamma} + \cancel{\frac{V_5^2}{2g}} + z_5 + h_{L_{4-5}}$$

$$\frac{P_4 - P_5}{\gamma} = (z_5 - z_4) + h_{L_{4-5}}$$ $h_{L_{discharge}}$

So,

$$R_x = \gamma A(\Delta z_{45} + h_{L_{discharge}})$$

from (a1): $h_{L_{discharg}} = 89.34\,ft$

I will assume

$$\Delta z_{45} \sim 40\,ft - \left(\frac{36}{12}\right)\left(\frac{2}{3}\right)ft$$

$$\Delta z_{4-5} \sim 38\,ft$$

$$R_x = 62.4\frac{lb}{ft^3} \times 0.3472\,ft^2 \times (38\,ft + 89.338\,ft)$$

$$\boxed{R_x = 2{,}758.81\ lb}$$

Vertical

$$\sum F_y = \rho Q(\cancel{V_{2y}}^{0} - \cancel{V_{1y}}^{0})$$

$$R_y = W$$

$$W = \gamma V$$
$$= \gamma \times A \times L$$
$$= 62.4\frac{lb}{ft^3} \times 0.3472\,ft^2 \times 2500\,ft$$

$$\boxed{R_y = 54{,}163.20\ lb}$$

c) The pump must be the kinetic type because we are not dealing with multiphase flows, nor very viscous fluid, neither we need a constant flow rate.

To determine the type of kinetic pump (radial, mixed, or axial), we compute the specific speed

$$N_s = \frac{N Q^{1/2}}{h_A^{3/4}}$$

$N \rightarrow rpm$
$Q \rightarrow gpm$
$h_A \rightarrow ft$

$$N_s = \frac{3600 \times \sqrt{1520.20}}{(141.29)^{3/4}} = 3,425.07$$

This is less than 4,000, so we need a radial pump (refer to figure in lecture notes)

C2 * See attached pump map, with which I preselect the 6×6×7.5-1 pump.

* Then I go to the actual pump performance curves (see attached) to verify that the operating point indeed lands within the region of operation. Based on that, I see that we will need an impeller of approximately 7.305 in diameter. I also see that the actual efficiency is $\eta \sim 77.7\%$. From these curves, I can also see that the pump suction size, discharg size, and max impelle size are 6in, 6in, and 7.5 in respectively. Also, from the pump curves we can see that the actual required power is 70 HP.

Regarding the size and weight, we need to find the specific chart in the catalog. (see attached) I highlighted the relevant information.

So, in summary these are the pump characteristics:

6×6×7.5-1 pump

$D_{impeller} \sim 7.305\ in$

$D_{suction} = 6\ in$

$D_{discharge} = 6\ in$

$D_{max\ impeller} = 7.5\ in$

$\eta = 77.7\%$

$P = 70\ HP$

$W_{base} = 930\ lb$

$W_{pump} = 522\ lb$

$B_{base} = 30.0\ in$

$L_{base} = 84.5\ in$

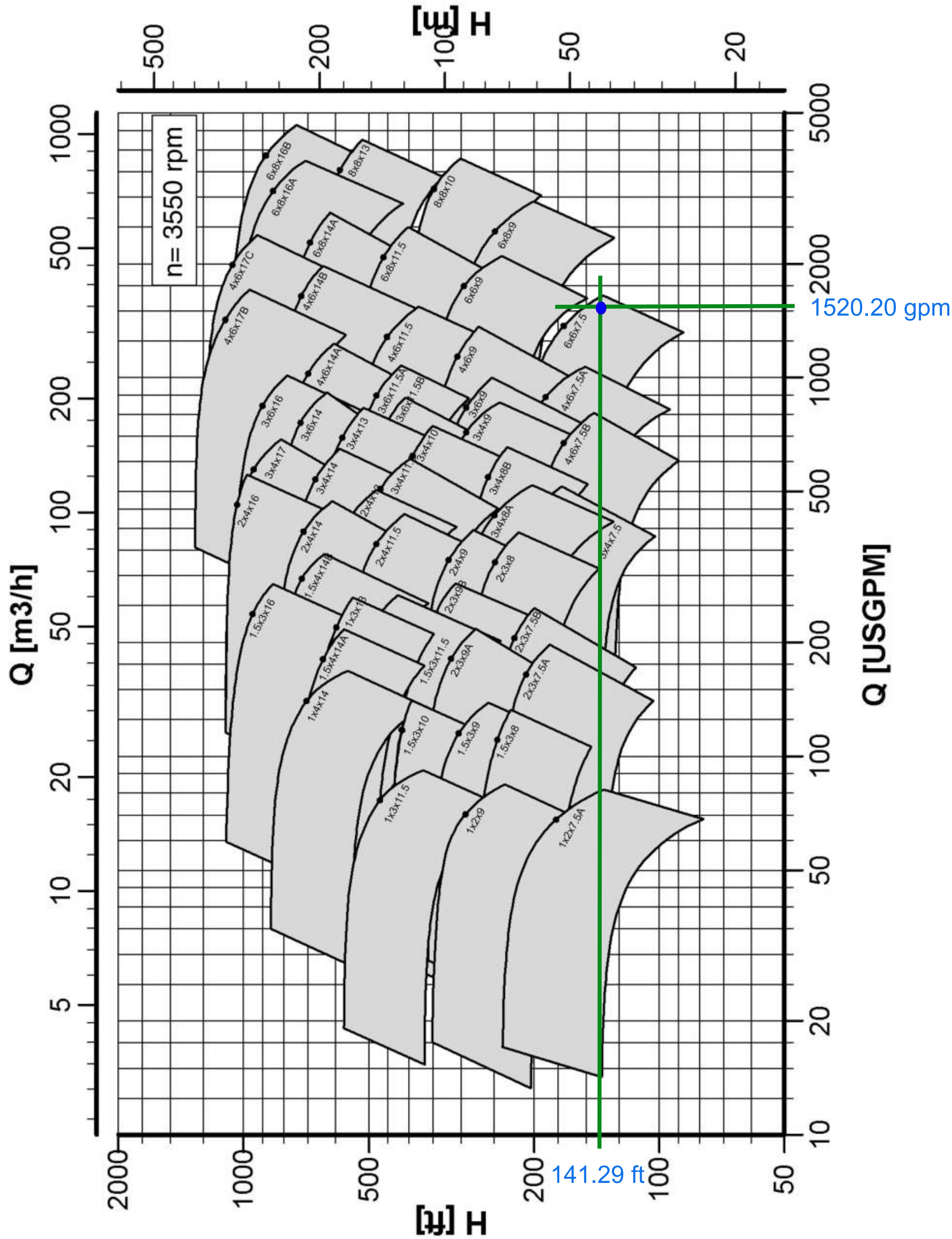
(*) As for the assumed 60% efficiency, it was underestimated. It should have been ~78%. But for rough estimates, it is fine.

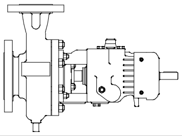
SULZER

CURVES - TYPE OHH

Range of Performances - 60 Hertz 3550 rpm

Series **2.00**	Page
CURVES	60hz
12 February 2002	**E0D**



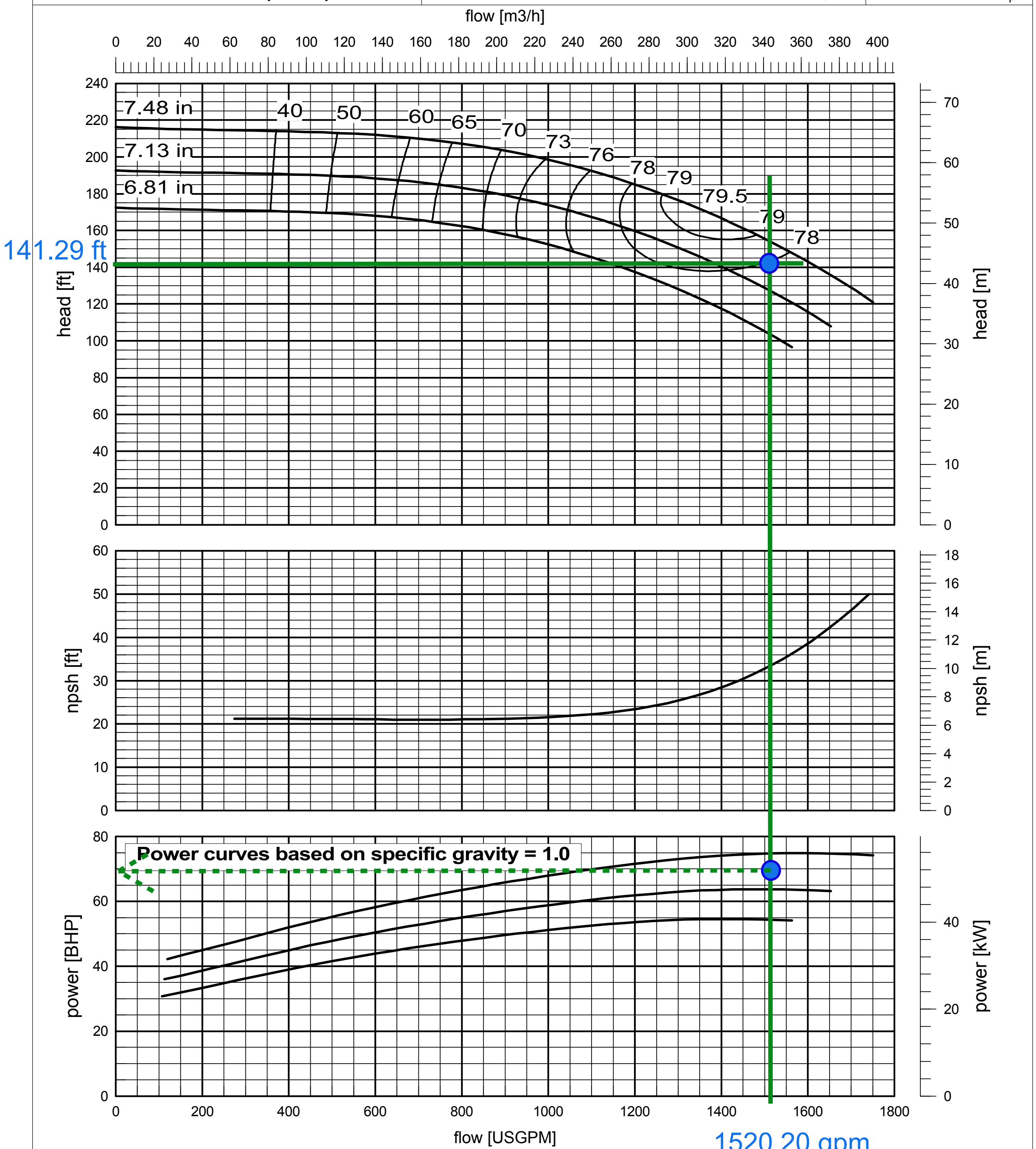


6 x 6 x 7.5 -1 OHH

SULZER

Series 2.00 / 60Hz E009

Curve No	**OHH 46-1-1-02**	**NSS**	**10970 (212)**	Speed
Efficiency Basis	**API Std. clearances**	**NS**	**2790 (54)**	**3550**
Max Solid	**.31 in (8 mm)**	**Rotation**	**CCW viewed from coupling**	rpm



Rated Conditions

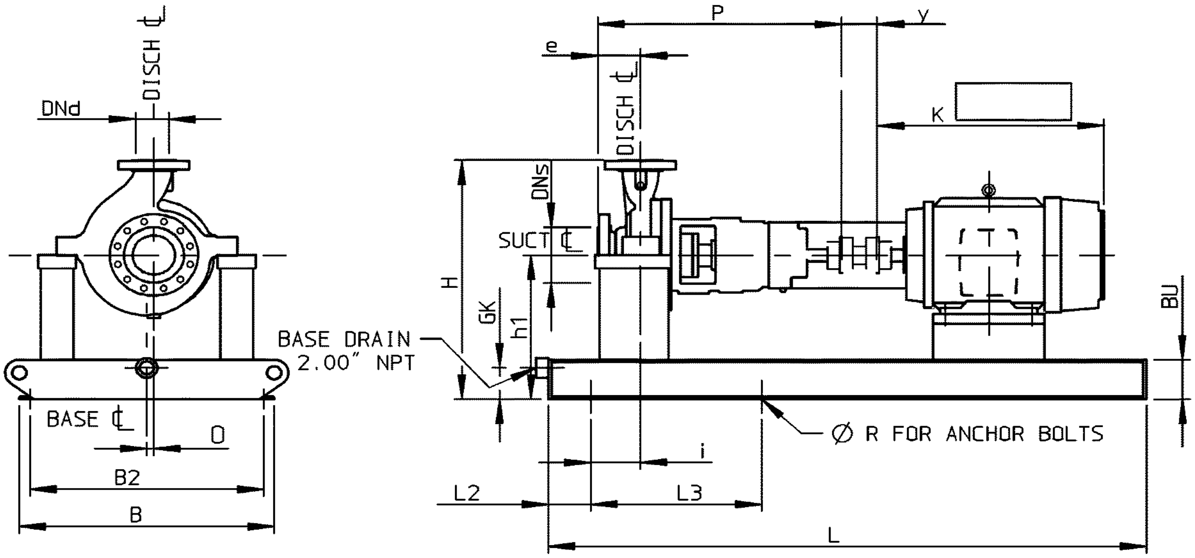
Project	Item	
H =	Q =	P =
Calculated Efficiency =		$NPSH_{3\%}$ =

Issued: **MSC / 05.13.2002**

SULZER

DIMENSIONAL DATA - TYPE OHH

General Arrangement Dimensions – End Suction – US Customary Units



Certified by :________________________
Date: _______________ Certified for Nozzle & Anchor Bolt locations only when signed above
Ref No. : ________________________________
Project Name : ______________________________
Project Item No.: _____________________________
HH -- Number of Base Hold Down Holes each side, equally spaced.
L3 -- Distance between holes.
GH -- # of Grout Holes

API No.	Base wt lbs	B	B2	BU	L	L2	L3	R	GK	HH	GH
1.5	800	30	27	6	72.5	6	30.25	1	4.75	3	4
2.0	930	30	27	6	84.5	6	24.16	1	4.75	4	4

Dimension K is derived from NEMA standards or motor supplier catalogue. The rotation is counterclockwise – H.I. looking from Drive End. All dimensions are in nominal inches and for guidance only. Certified Drawings will be issued for actual construction.

When Available 'TS" frame should be used to minimize coupling size, there is no price difference on drivers. **WP-XXX**

PUMP SIZE	PUMP wt lbs	DNs (in)	DNd (in)	O (in)	B (in)	e (in)	P (in)	h1 (in)	i (in)	H (in)	y (in)	BASE REFERENCE (Electric Driver - NEMA Frame)
1x2x7.5-1	311	2	1	0	30	4.92	31.06	18	**5.63**	27.06	5	1.5 (143T-286T) (284TS-286TS) 2.0 (324T-405T) (324TS-405TS)
2x3x7.5A-1	332	3	2	0	30	4.92	31.18	18	**5.38**	27.06	5	
2x3x7.5B-1	331	3	2	0	30	4.92	31.18	18	**5.38**	27.06	5	
3x4x7.5-1	352	4	3	0	30	4.92	31.26	18	**5.36**	27.06	5	
4x6x7.5B-1	398	6	4	0	30	5.51	32.20	18	**5**	28.04	5	
4x6x7.5A-1	399	6	4	0	30	5.51	32.20	18	**5**	28.04	5	
6x6x7.5-1	522	6	6	1	30	8.07	35.67	18	**5.63**	30.60	7	2.0 (284T-365T) (284TS-365TS)
1.5x3x8-1	335	3	1.5	0	30	5.51	32.01	18	**5.65**	27.06	5	1.5 (143T-286T) (284TS-286TS) 2.0 (324T-405T) (324TS-405TS)
2x3x8-1	336	3	2	0	30	5.91	32.56	18	**5.63**	27.06	5	
3x4x8A-1	360	4	3	0	30	6.30	32.83	18	**5.38**	27.45	5	
3x4x8B-1	370	4	3	0	30	6.30	33.03	18	**5.63**	27.45	5	
3x4x8B-2	370	4	3	0	30	6.30	33.03	18	**5.63**	27.45	5	
1x2x9-1	320	2	1	0	30	5.51	31.65	18	**5.63**	27.06	5	
1.5x3x9-1	334	3	1.5	0	30	5.51	31.69	18	**5.63**	27.06	5	
2x3x9A-1	338	3	2	0	30	5.51	31.73	18	**5.5**	27.45	5	
2x3x9B-1	334	3	2	0	30	5.51	31.81	18	**5.63**	27.45	5	
2x4x9-1	360	4	2	0	30	5.51	31.77	18	**5.38**	28.04	5	
3x4x9-1	374	4	3	0	30	5.51	31.85	20	**7.38**	30.43	5	
3x4x9-2	374	4	3	0	30	5.51	31.85	20	**7.38**	30.43	5	
3x6x9-1	406	6	3	0.5	30	5.91	32.32	20	**7.25**	31.02	5	
3x6x9-2	406	6	3	0.5	30	5.91	32.32	20	**7.25**	31.02	5	