PUMP SELECTION FOR A RESERVOIR SYSTEM

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Introduction:

This project deals with a typical system in the area of hydraulic engineering. Delivering water between two points of an existed hydraulic reservoir system requires attention and careful consideration. First of all, it is necessary to know whether the system selected for the project is in compliance with engineering standards. Second, considering all the potential cases concerning safety, it is important also to determine how much the planned project or system is functional. Moreover, regardless of what is being dealt with the current plan under question, it is also essential to account for any other possible alternatives that may replace the current option on hand.

Design Procedure:

This project comprises of two reservoirs which are apart from each other by a certain distance and elevation. One reservoir supplies water to the second one through a line of pipe system and fittings. Two pumps are available from a manufacture company that is supposed to be the provider of the pumps for the project. Only one pump is needed to be fixed on the delivery system. It is required to choose between the two pumps. In addition, the manufacture company supplied the project superintendent with the characteristic data belonging to the pumps.

In this case, the design procedure for the selection process would be the following;

1. Taking advantage of discharge, head, and efficiency that are provided for both pumps, the characteristic curves for the two pumps can be drawn.
2. Considering the static head between the two reservoirs as well as the head loss through the delivery pipe, the system head can be determined and its curve can be drawn along with the characteristic curves for both the pumps.

3. The point where the system head crosses the pump head is operating point (OP). The extension of OP up to the point where intersects with the efficiency curve determines the OP efficiency.
4. The same procedure is followed for both the pumps.
5. The pump that gives the lease (BEP-OP) is considered to be the right pump for the project; as this indicates that the pump will operate with least power consumption while providing the required head that is needed for delivering water from one reservoir into the other.

Theory:

$\underline{A. Pump\ System}$:

$$1. P = \frac{\gamma Q h_p}{\eta}$$

$2. Develop\ characteristic\ curves$

$$3. Z = \frac{P_{atm}}{\gamma} - h_{L_s} - \frac{P_v}{\gamma} - \sigma h_p$$

$$4.\ h_{p2} = h_{p1} \frac{{N_2}^2 {d_2}^2}{{N_1}^2 {d_1}^2} = h_{p1} \frac{{N_2}^2}{{N_1}^2}$$

$$P_2 = P_1 \frac{{N_2}^3 {d_2}^5}{{N_1}^3 {d_1}^5} = P_1 \frac{{N_2}^3}{{N_1}^3}$$

$\underline{B. Delivery\ Pipe\ System}$:

$1. Develop\ H_{syst}\ Curve$

$$2.\ H_{syst} = H_{stat} + \sum h_L$$

$$3.\ \sum h_L = h_{L_f} + h_{L_m}$$

$$4.\ h_{L_f} = f \frac{L}{d^5} \frac{16}{\pi^2} \frac{Q^2}{2g}$$

$$5.\ h_{L_m} = k \frac{Q^2}{A^2} \frac{1}{2g} = (K_v + 3K_b) \frac{Q^2}{A^2} \frac{1}{2g}$$

$$6.\ Q = AV = \frac{\pi d^2}{4} V$$

$$7.\ V = \frac{R\mu}{\rho d}$$

$8. Go\ to\ Moody\ chart; find\ R$

$9.\ Assume\ f$

$$10.\ \frac{e}{d}$$

Problem Statement:

Water at $20°C$ is to be pumped from a lower reservoir to a higher reservoir through a $30m$ long, $150mm$ diameter delivery pipe made of PVC (roughness height, $e = 0.0015mm$) which is fitted with a fully open gate valve and three threaded $90°$ elbows. Head loss in the intake pipe can be neglected. The elevation difference between the water surfaces in the two reservoirs will be $10.0m$.

Two pumps with the following characteristic data at an operating speed of $800rpm$ are considered for the project.

	Pump 1		Pump 2	
Q (lit/s)	h_p (m)	η (%)	h_p (m)	η (%)
0	20.0	0	18.0	0
100	19.5	35	17.3	50
200	18.2	54	15.5	68
300	15.9	63	13.5	71
400	12.5	71	10.7	66
500	8.3	68	7.2	47
600	3.0	56	2.0	33

1. Select between the two pumps [show necessary plots]
2. Determine the power required to operate the selected pump
3. Determine the setting for the selected pump. Both pumps have the same cavitations characteristic (σ) equal to 0.6
4. Prepare the characteristic curves for the selected pump if it is operated at a speed of 1200rpm

Given:

$\underline{A. Pump\ System}$:

	Pump 1		Pump 2	
Q (lit/s)	h_p (m)	η (%)	h_p (m)	η (%)
0	20.0	0	18.0	0
100	19.5	35	17.3	50
200	18.2	54	15.5	68
300	15.9	63	13.5	71
400	12.5	71	10.7	66
500	8.3	68	7.2	47
600	3.0	56	2.0	33

$N_1 = 800\ rpm$

$N_2 = 1200\ rpm$

$\sigma = 0.6\ \ for\ both\ the\ pumps$

$\underline{B.\ Reservoirs\ and\ delivery\ pipe\ system}$:

$H_{stat} = 10m$

$T_{water} = 20°C$

$L_{pipe} = 30m$

$d_{pipe} = 150mm$

$PVC\ pipe$

$e = 0.0015mm$

$Fitted\ with\ a\ Fully\ open\ gate\ valve$

$Fitted\ with\ 3\ threaded\ 90°\ elbow$

h_{L_i}=0

<u>To Find:</u>

1. $Pump\ 1\ or\ Pump2$
2. $P\ \ selected\ pump$
3. $Z\ \ selected\ pump$
4. $Ch^{C}\ selected\ pump$

Constants:

$T_{water} = 20°C\ (given);$

$\gamma_w = 9789\ \frac{N}{m^3}$

$\rho_w = 998.2\ \frac{kg}{m^3}$

$\mu = 1x10^{-3}\ Pa.s$

$P_v = 2.34x10^3\ \frac{N}{m^2}$

$K_v = 0.2$

$K_b = 0.9$

$g = 9.80m/s^2$

$Assume\ sea\ level;$

$P_{atm} = 1.013x10^5 - 3.5x10^3 = 97800\ N/m^2$

Conversions:

$1m^3 = 10^3\ lit.$

$1mm = 10^{-3}m$

$1kw = 1000w$

Calculations:

A. Pump System:

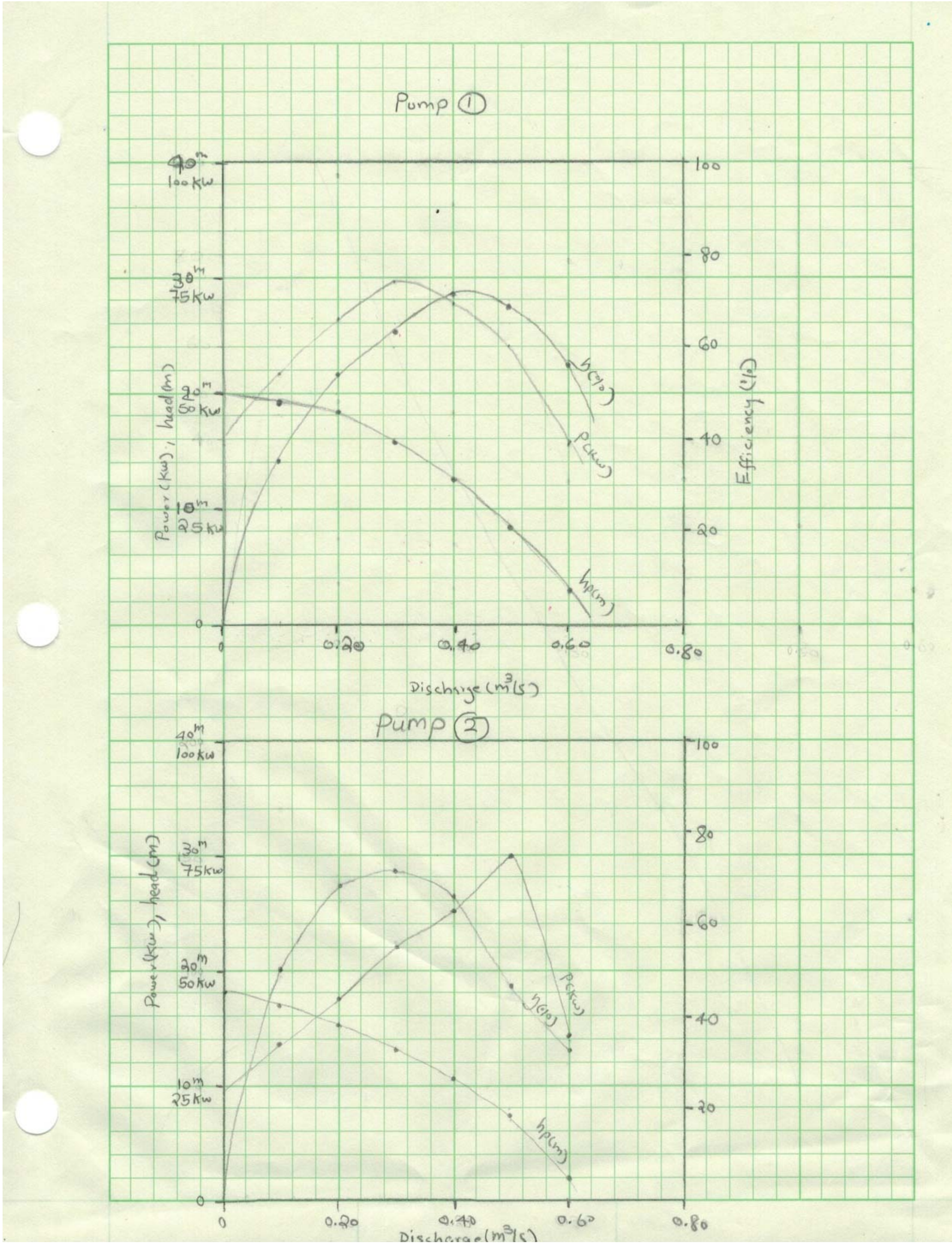
$for\ pump\ 1: as\ an\ example; if\ Q = 0.10\frac{m^3}{s}, h_p = 19.5m,\ \eta = 35\%; then$

$$1.\ P = \frac{(9789)(0.10)(19.5)}{(0.35)} x \frac{1}{1000} = 54.5kw$$

$The\ following\ table\ is\ the\ list\ of\ other\ values\ of\ P\ for\ both\ pumps$

	Pump 1			Pump 2		
Q (m^3/s)	h_p (m)	η (%)	P(kw)	h_p (m)	η (%)	P(kw)
0	20.0	0	0	18.0	0	0
0.1	19.5	35	54.5	17.3	50	34
0.2	18.2	54	66	15.5	68	44.5
0.3	15.9	63	74	13.5	71	56
0.4	12.5	71	69	10.7	66	63.5
0.5	8.3	68	60	7.2	47	75
0.6	3.0	56	31.5	2.0	33	35.5

2. $Characteristic\ curves\ (N = 800\ rpm)(Chart\ \#1)$



$\underline{B. Delivery\ Pipe\ System:}$

10. $\frac{e}{d} = \frac{0.0015}{150} = 1.0x10^{-5}$

9. $Assume\ f = 0.012$

8. $Go\ to\ Moody\ chart; find\ R = 9.5x10^{5}$

7. $V = \frac{(9.5x10^{5})(1x10^{-3})}{(998.2)(150x10^{-3})} = 6.34m/s$

6. $Q = \frac{\pi(150x10^{-3})^{2}}{4}(6.34) = 0.11m^{3}/s$

5. $h_{L_m} = (0.2 + 3x0.9)\frac{(0.11)^{2}}{\pi(150x10^{-3})^{2}/_{4}}\frac{1}{2(9.80)} = 0.10m$

4. $h_{L_f} = (0.012)\frac{(30)}{(150x10^{-3})^{5}}\frac{16}{\pi^{2}}\frac{(0.11)^{2}}{2(9.80)} = 4.74m$

3. $\sum h_L = 4.74 + 0.10 = 4.84m$

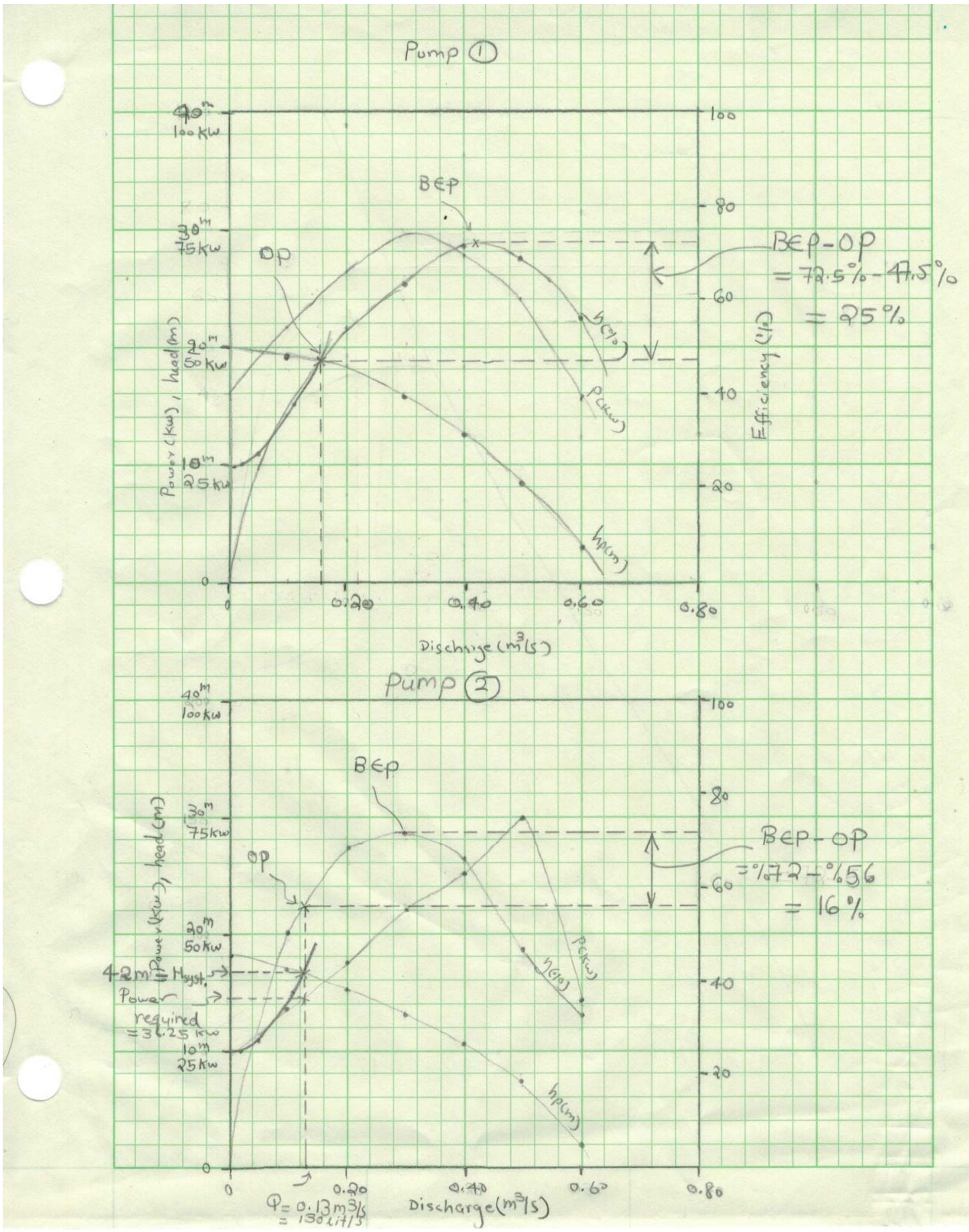
2. $H_{syst} = 10 + 4.84 = 14.84m$

1. $Develop\ H_{syst}\ Curve: The\ following\ is\ a\ table\ of\ listed\ value\ of\ assumed\ f\ and$

$obtained\ value\ of\ Q\ and\ H_{syst}$

f	R	V(m/s)	Q(m^3/s)	h_{Lm}(m)	h_{Lf}(m)	$\sum h_L$(m)	H_{stat}(m)	H_{syst}(m)
0.012	$9.5x10^5$	6.34	0.11	0.1	4.74	4.84	10	14.84
0.014	$4x10^5$	2.670	0.047	0.018	1.010	1.028	10	11.028
0.016	$2x10^5$	1.340	0.024	0.005	0.300	0.305	10	10.305
0.018	$1x10^5$	0.670	0.012	0.001	0.085	0.086	10	10.086
0.020	$6x10^4$	0.400	0.0071	0.000	0.033	0.033	10	10.033
0.022	$4x10^4$	0.270	0.0048	0.000	0.017	0.017	10	10.017

$1. H_{syst}$ *Curve plotted on the characteristic curves for both pumps (Chart #2)*



1. $For\ Pump\ 1: From\ Chart\ \#2$
   $BEP = 72.5\%$
   $OP = 47.5\%$
   $BEP - OP = 72.5\% - 47.5\% = 25\%$

   $For\ Pump\ 2: From\ Chart\ \#2$
   $BEP = 72\%$
   $OP = 56\%$
   $BEP - OP = 72\% - 56\% = 16\%$

   $16\% < 25\%$
   $Hence;$
   $Pump\ 2\ is\ selected$

2. $The\ power\ required\ to\ operate\ pump\ 2\ (from\ chart\ \#2);$
   $P = 36.25\ kw$

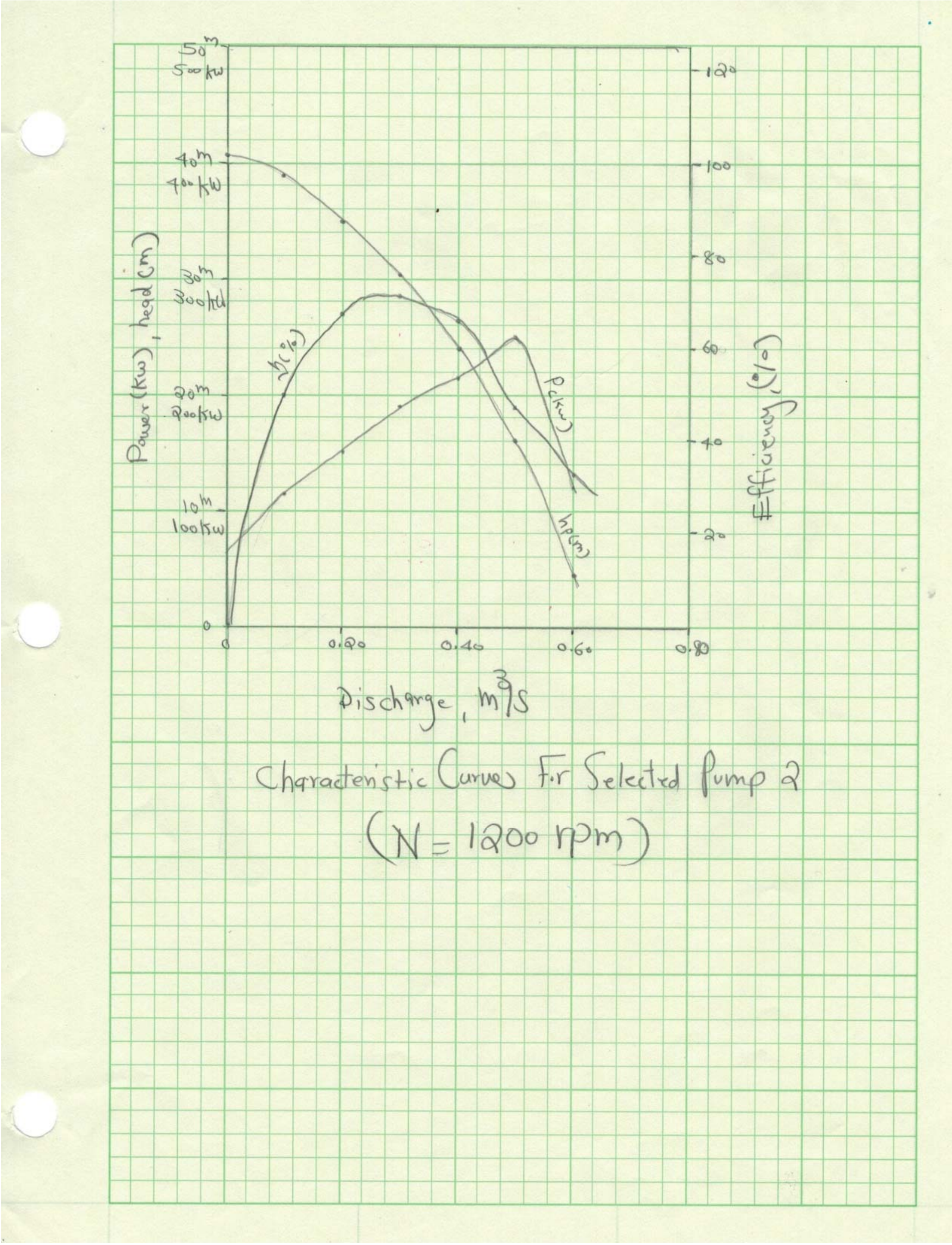
3. $From\ chart\ \#2;$
   $h_p\ at\ BEP = 13m$
   $$Z = \frac{97800}{9789} - 0 - \frac{2.34x10^3}{9789} - 0.6(13)$$
   $Z = 1.95m$

4. $h_{p2} = h_{p1}\frac{{N_2}^2}{{N_1}^2} = (18)\frac{(1200)^2}{(800)^2} = 40.5m$
   $$P_2 = P_1\frac{{N_2}^3}{{N_1}^3} = (34)\frac{(1200)^3}{(800)^3} = 114.75kw$$
   $The\ rest\ of\ the\ values\ are\ listed\ as\ below;$

Pump 2

Q (m^3/s)	h_{p1} (m)	h_{p2} (m)	P_1(kw)	P_2(kw)	η (%)
0	18.0	40.5	0	0	0
0.1	17.3	39.0	34	115	50
0.2	15.5	35.0	44.5	150	68
0.3	13.5	30.5	56	189	71
0.4	10.7	24.0	63.5	214	66
0.5	7.2	16.0	75	253	47
0.6	2.0	4.5	35.5	120	33

$Characteristic\ Curves\ for\ Pump\ 2\ (N = 1200\ rpm)$



Conclusion:

After completing the selection process, it has been determined that the second pump is more consistent to be used to be installed on the system. This is because it's eficiency is more optimum than the first pump, that is mean it is capable to get the head required with less operating power. It has been noted that due to the minor and friction head loss the system head is raised up with great amount from the static head (10m) up to about 42 meter.

Bibliography

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Miller, Rex, Mark R. Miller, and Harry L. Stewart. Pumps and Hydraulics*. 6th ed. Indianapolis, IN: Wiley Pub., 2004. Print.*

Properties of Water

♦ **Properties of Water[f] (SI Metric Units)**

Temperature (°C)	Specific Weight[a] γ (kN/m³)	Density[a] ρ (kg/m³)	Absolute Dynamic Viscosity[a] μ (Pa•s)	Kinematic Viscosity[a] υ (m²/s)	Vapor Pressure[e] P_v (kPa)
0	9.805	999.8	0.001781	0.000001785	0.61
5	9.807	1000.0	0.001518	0.000001518	0.87
10	9.804	999.7	0.001307	0.000001306	1.23
15	9.798	999.1	0.001139	0.000001139	1.70
20	9.789	998.2	0.001002	0.000001003	2.34
25	9.777	997.0	0.000890	0.000000893	3.17
30	9.764	995.7	0.000798	0.000000800	4.24
40	9.730	992.2	0.000653	0.000000658	7.38
50	9.689	988.0	0.000547	0.000000553	12.33
60	9.642	983.2	0.000466	0.000000474	19.92
70	9.589	977.8	0.000404	0.000000413	31.16
80	9.530	971.8	0.000354	0.000000364	47.34
90	9.466	965.3	0.000315	0.000000326	70.10
100	9.399	958.4	0.000282	0.000000294	101.33

♦ **Properties of Water (English Units)**

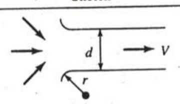
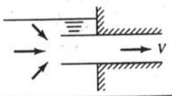
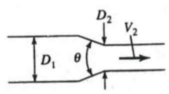
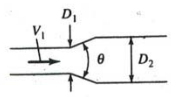
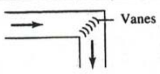
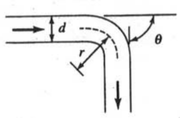
Temperature (°F)	Specific Weight γ (lbf/ft³)	Mass Density ρ (lbf-sec²/ft⁴)	Absolute Dynamic Viscosity μ (× 10^{-5} lbf-sec/ft²)	Kinematic Viscosity υ (× 10^{-5} ft²/sec)	Vapor Pressure P_v (psi)
32	62.42	1.940	3.746	1.931	0.09
40	62.43	1.940	3.229	1.664	0.12
50	62.41	1.940	2.735	1.410	0.18
60	62.37	1.938	2.359	1.217	0.26
70	62.30	1.936	2.050	1.059	0.36
80	62.22	1.934	1.799	0.930	0.51
90	62.11	1.931	1.595	0.826	0.70
100	62.00	1.927	1.424	0.739	0.95
110	61.86	1.923	1.284	0.667	1.24
120	61.71	1.918	1.168	0.609	1.69
130	61.55	1.913	1.069	0.558	2.22
140	61.38	1.908	0.981	0.514	2.89
150	61.20	1.902	0.905	0.476	3.72
160	61.00	1.896	0.838	0.442	4.74
170	60.80	1.890	0.780	0.413	5.99
180	60.58	1.883	0.726	0.385	7.51
190	60.36	1.876	0.678	0.362	9.34
200	60.12	1.868	0.637	0.341	11.52
212	59.83	1.860	0.593	0.319	14.70

♦ [a]From "Hydraulic Models," *ASCE Manual of Engineering Practice*, No. 25, ASCE, 1942.
[e]From J.H. Keenan and F.G. Keyes, *Thermodynamic Properties of Steam*, John Wiley & Sons, 1936.
[f]Compiled from many sources including those indicated: *Handbook of Chemistry and Physics*, 54th ed., The CRC Press, 1973, and *Handbook of Tables for Applied Engineering Science*, The Chemical Rubber Co., 1970.
Vennard, J.K. and Robert L. Street, *Elementary Fluid Mechanics*, 6th ed., 1982. Reproduced with permission of John Wiley & Sons.

Loss Coefficients for Transitions and Fittings

$$P = \frac{Q\gamma h_t}{550}$$
$$= 12 \cdot \left[\left(\pi \cdot \frac{10^2}{2}\right) + (20 \cdot 10)\right] \cdot 62.4 \cdot \frac{1948.5}{550}$$
$$= 947{,}000 \text{ hp}$$

Table 5-3 Representative Loss Coefficients for Various Transitions and Fittings

Description	Sketch	Additional Data	K	K	Source
Pipe entrance		r/d	K_e		(7)
		0.0	0.50		
		0.1	0.12		
		>0.2	0.03		
$h_L = K_e V^2/2g$			1.00		
Contraction		D_2/D_1	K_C $\theta = 60°$	K_C $\theta = 180°$	(7)
		0.0	0.08	0.50	
		0.20	0.08	0.49	
		0.40	0.07	0.42	
		0.60	0.06	0.32	
		0.80	0.05	0.18	
$h_L = K_C V_2^2/2g$		0.90	0.04	0.10	
Expansion		D_1/D_2	K_E $\theta = 10°$	K_E $\theta = 180°$	(7)
		0.0		1.00	
		0.20	0.13	0.92	
		0.40	0.11	0.72	
		0.60	0.06	0.42	
$h_L = K_E V_1^2/2g$		0.80	0.03	0.16	
90° miter bend		Without vanes	$K_b = 1.1$		(42)
		With vanes	$K_b = 0.2$		(42)
Smooth bend		r/d	K_b $\theta = 45°$	K_b $\theta = 90°$	(14)
		1	0.10	0.35	(22) and (30)
		2	0.09	0.19	
		4	0.10	0.16	
		6	0.12	0.21	
Threaded pipe fittings	Globe valve - wide open		$K_v = 10.0$		
	Angle valve - wide open		$K_v = 5.0$		
	Gate valve - wide open		$K_v = 0.2$		
	Gate valve - half open		$K_v = 5.6$		
	Return bend		$K_b = 2.2$		
	Tee		$K_t = 1.8$		
	90° elbow		$K_b = 0.9$		
	45° elbow		$K_b = 0.4$		

Physical Properties of Water

Physical Properties of Water

English Units

TEMPERATURE, °F	SPECIFIC WEIGHT, γ, lb/ft³	DENSITY, ρ, slug/ft³	VAPOR PRESSURE, p_v, psia
32	62.42	1.940	0.09
40	62.43	1.940	0.12
50	62.41	1.940	0.18
60	62.37	1.938	0.26
70	62.30	1.936	0.36
80	62.22	1.934	0.51
90	62.11	1.931	0.70
100	62.00	1.927	0.95
110	61.86	1.923	1.27
120	61.71	1.918	1.69
130	61.55	1.913	2.22
140	61.38	1.908	2.89
150	61.20	1.902	3.72
160	61.00	1.896	4.74
170	60.80	1.890	5.99
180	60.58	1.883	7.51
190	60.36	1.876	9.34
200	60.12	1.868	11.52
212	59.83	1.860	14.70

S.I. Units

TEMPERATURE, °C	SPECIFIC WEIGHT, γ, kN/m³	DENSITY, ρ, kg/m³	VAPOR PRESSURE, p_v, kN/m²
0	9.805	999.8	0.61
5	9.807	1000.0	0.87
10	9.804	999.7	1.23
15	9.798	999.1	1.70
20	9.789	998.2	2.34
25	9.777	997.0	3.17
30	9.764	995.7	4.24
40	9.730	992.2	7.38
50	9.689	988.0	12.33
60	9.642	983.2	19.92
70	9.589	977.8	31.16
80	9.530	971.8	47.34
90	9.466	965.3	70.10
100	9.399	958.4	101.33

Properties of the U.S. Standard Atmosphere

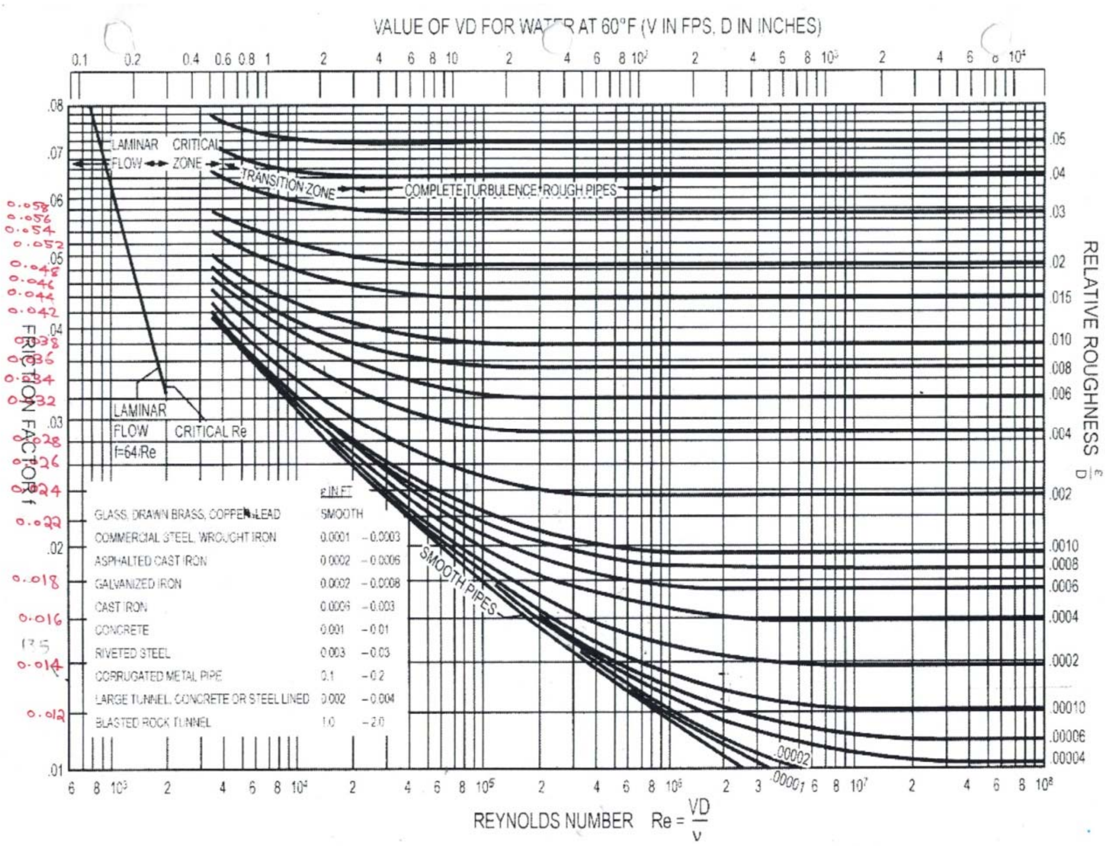
Altitude (ft)	Temperature (°F)	Pressure, p [lb/in.²(abs)]
−5,000	76.84	17.554
0	59.00	14.696
5,000	41.17	12.228
10,000	23.36	10.108
15,000	5.55	8.297
20,000	−12.26	6.759
25,000	−30.05	5.461
30,000	−47.83	4.373
35,000	−65.61	3.468
40,000	−69.70	2.730
45,000	−69.70	2.149
50,000	−69.70	1.692
60,000	−69.70	1.049
70,000	−67.42	0.651
80,000	−61.98	0.406
90,000	−56.54	0.255
100,000	−51.10	0.162
150,000	19.40	0.020
200,000	−19.78	0.003
250,000	−88.77	0.000

Properties of the U.S. Standard Atmosphere

Altitude (m)	Temperature (°C)	Pressure, p [N/m²(abs)]
−1,000	21.50	1.139 E + 5
0	15.00	1.013 E + 5
1,000	8.50	8.988 E + 4
2,000	2.00	7.950 E + 4
3,000	−4.49	7.012 E + 4
4,000	−10.98	6.166 E + 4
5,000	−17.47	5.405 E + 4
6,000	−23.96	4.722 E + 4
7,000	−30.45	4.111 E + 4
8,000	−36.94	3.565 E + 4
9,000	−43.42	3.080 E + 4
10,000	−49.90	2.650 E + 4
15,000	−56.50	1.211 E + 4
20,000	−56.50	5.529 E + 3
25,000	−51.60	2.549 E + 3
30,000	−46.64	1.197 E + 3
40,000	−22.80	2.871 E + 2
50,000	−2.50	7.978 E + 1
60,000	−26.13	2.196 E + 1
70,000	−53.57	5.221 E + 0
80,000	−74.51	1.052 E + 0

For pump calculations, values of p are reduced by 0.57 psi (3.5 kPa) to account for storm activity.

Moody Chart


VALUE OF VD FOR WATER AT 60°F (V IN FPS, D IN INCHES)
LAMINAR FLOW
CRITICAL ZONE
TRANSITION ZONE
COMPLETE TURBULENCE, ROUGH PIPES
LAMINAR FLOW f=64/Re
CRITICAL Re
FRICTION FACTOR f
RELATIVE ROUGHNESS ε/D
SMOOTH PIPES
ε IN FT
GLASS, DRAWN BRASS, COPPER, LEAD SMOOTH
COMMERCIAL STEEL, WROUGHT IRON 0.0001 – 0.0003
ASPHALTED CAST IRON 0.0002 – 0.0006
GALVANIZED IRON 0.0002 – 0.0008
CAST IRON 0.0006 – 0.003
CONCRETE 0.001 – 0.01
RIVETED STEEL 0.003 – 0.03
CORRUGATED METAL PIPE 0.1 – 0.2
LARGE TUNNEL, CONCRETE OR STEEL LINED 0.002 – 0.004
BLASTED ROCK TUNNEL 1.0 – 2.0
REYNOLDS NUMBER Re = VD/ν