MEMORANDUM

To:	P. N Guin
From:	P. Olar Bear
Date:	04JAN2024
Subject:	CE 3372 – Water Systems Design, Exercise Set 5.

Problem 1

This memorandum presents an analysis of a water transfer system that lifts water from one elevation to another.

Discussion

The solution applies the energy equation and pumping concepts, computes a system curve, and uses that curve to find an operating point. The remainder of this section presents the various steps required, with intermediate calculations shown and references imbedded into the memorandum. The results for each problem are presented in the narrative below; the by-hand analysis is attached to this memorandum.

a) A sketch of the water supply system that draws from a river at an elevation of 800-feet and delivers the water to a storage reservoir at elevation 820-feet s shown in Figure 1. On the figure, the supply pipeline, which is a 1000-foot long, 10-inch diameter, cast iron pipe, is labeled. The single pump follows the performance curve shown below on Figure 6.

b) The inlet and outlet minor loss coefficients are 0.5 for the inlet (assumed flush, not re-entrant) and 1.0 for the outlet (small diameter into essentially infinite diameter pool). The values are obtained from directly Figure 2 below.

c) The roughness ratio for use in the Moody chart for cast-iron pipe is

$$\frac{k_s}{D} = \frac{0.00085}{10/12} = 0.00102 \tag{1}$$

The values are taken directly from Figure 3 below.

d) The energy equation for the system is

$$\frac{p_1}{\rho g} + \frac{V_1^2}{2g} + z_1 + h_p = \frac{p_2}{\rho g} + \frac{V_2^2}{2g} + z_2 + h_L \tag{2}$$

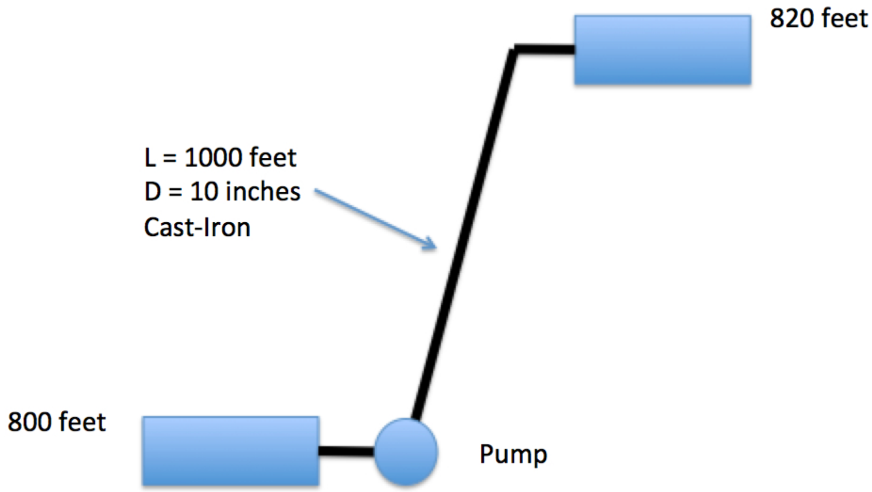


Figure 1: Sketch of the system

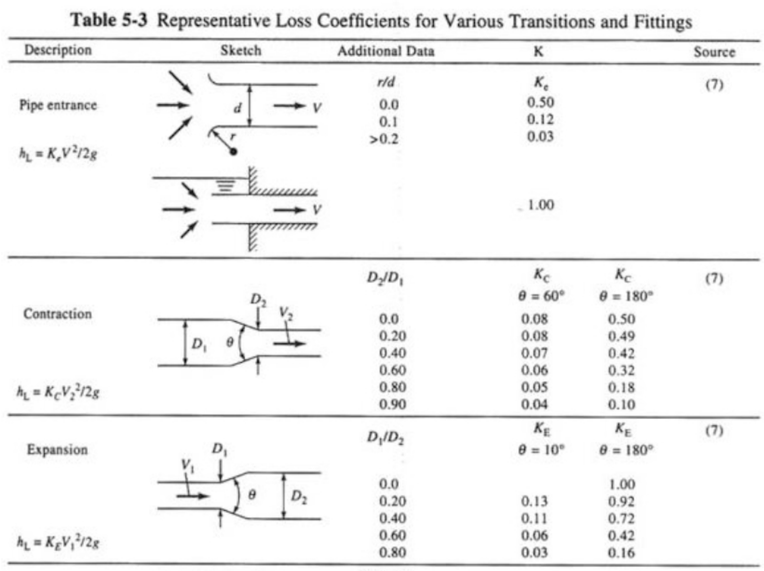


Table 5-3 Representative Loss Coefficients for Various Transitions and Fittings

Description	Sketch	Additional Data	K		Source
Pipe entrance		r/d	K_e		(7)
$h_L = K_e V^2/2g$		0.0	0.50		
		0.1	0.12		
		>0.2	0.03		
			1.00		
Contraction		D_2/D_1	K_C $\theta = 60°$	K_C $\theta = 180°$	(7)
$h_L = K_C V_2^2/2g$		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	
		0.90	0.04	0.10	
Expansion		D_1/D_2	K_E $\theta = 10°$	K_E $\theta = 180°$	(7)
$h_L = K_E V_1^2/2g$		0.0		1.00	
		0.20	0.13	0.92	
		0.40	0.11	0.72	
		0.60	0.06	0.42	
		0.80	0.03	0.16	

Figure 2: Loss Coefficients from Fluid Mechanics Textbook
(p 381 in DF Elger, BC Williams, Crowe, CT and JA Roberson, Engineering Fluid Mechanics 10th edition, John Wiley & Sons, Inc., 2013.)

After substitution of numerical values and the Darcy-Weisbach head loss model, cancel-

Material	e (ft)	e (mm)
Riveted steel	0.003–0.03	0.9–9.0
Concrete	0.001–0.01	0.3–3.0
Cast iron	0.00085	0.25
Galvanized iron	0.0005	0.15
Commercial steel or wrought iron	0.00015	0.046
Drawn tubing	0.000005	0.0015

Figure 3: Roughness heights for different materials from NCEES Supplied Reference (Moody-Stanton Chart)

lation of identical terms, and isolation of h_p, the energy equation is

$$h_p = 20 + \frac{V^2}{2g}(\frac{f\ 1000}{10/12} + 0.5 + 1.0) \tag{3}$$

e) The system loss for a discharge of 1200, 1600, 2000, 2400, and 2800 gallons-per-minute is shown below in Figure 4, which converts the discharges in GPM into CFS, then computes the Reynolds number (viscosity at 60 degrees F was used). These values were used to enter the Moody chart (Figure 5) . The friction factors are all about 0.02 (at our ability to read from the chart). Once these values are supplied the head loss in the pipeline are computed and used to complete the energy equation.

Discharge (gpm)	Discharge (cfs)	Velocity (ft/sec)	Viscosity	Reynolds Number	Friction Factor	VelocityHead	Head Loss	h_p (required)
1200	2.67	4.90	1.22E-05	3.35E+05	0.02	0.37	9.52	29.52
1600	3.57	6.54	1.22E-05	4.47E+05	0.02	0.66	16.92	36.92
2000	4.46	8.17	1.22E-05	5.58E+05	0.02	1.04	26.44	46.44
2400	5.35	9.81	1.22E-05	6.70E+05	0.02	1.49	38.07	58.07
2800	6.24	11.44	1.22E-05	7.81E+05	0.02	2.03	51.82	71.82

Figure 4: Tabulated values for different flow rates in the system.

f) The operating discharge for the system using the supplied pump curve is slightly under 2000 gallons-per-minute as shown on 6. The point is obtained by plotting the required pump head values from Figure 4 onto the pump performance curve that was supplied.

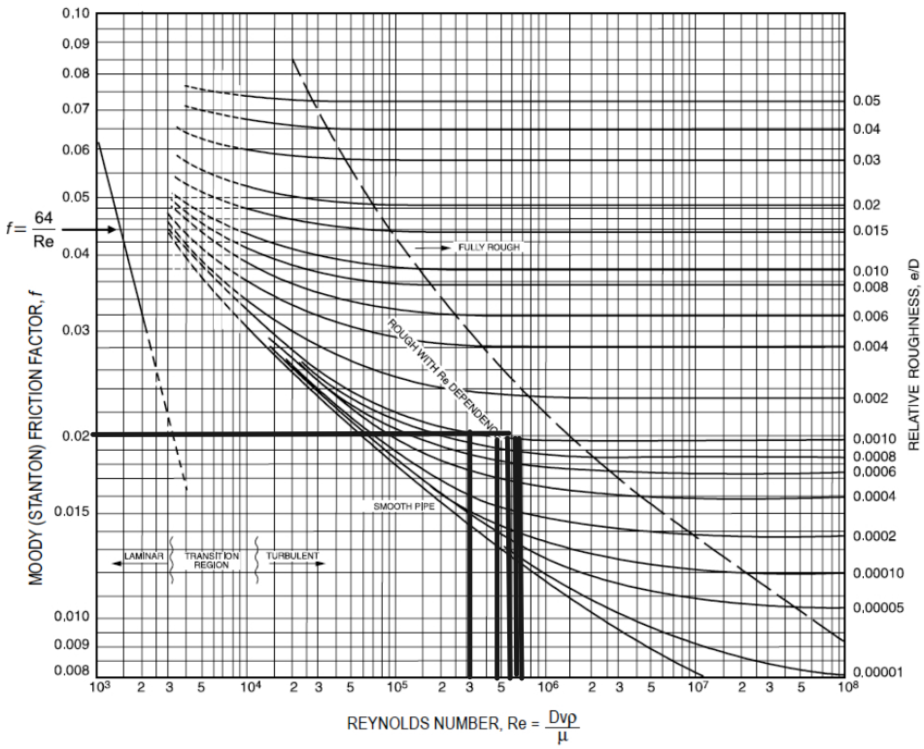


Figure 5: Moody-Stanton Chart

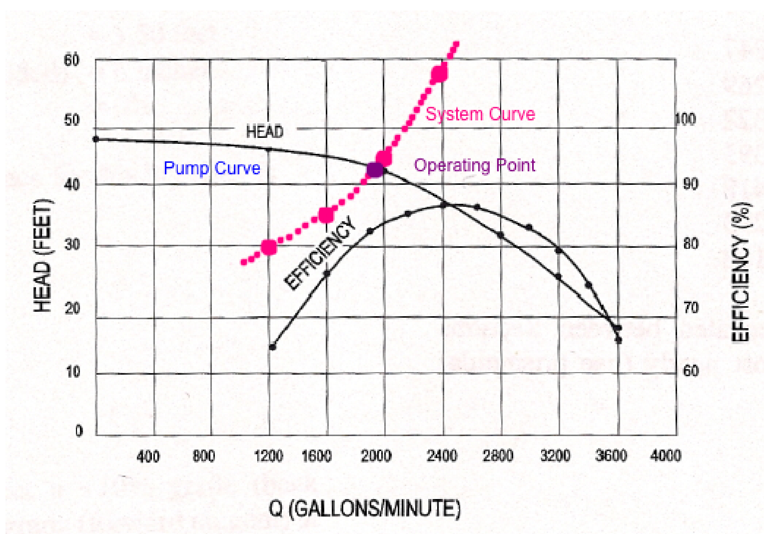


Figure 6: System and pump characteristic curve on same axes

g) The electric power supplied to the pump to lift the water at the operating point is

$$P = \frac{Q\rho g h_p}{\eta} = \frac{4.46 \times 62.4 \times 46.44}{0.85} = 15,205 \ \ \text{foot-pounds/second} \tag{4}$$

The efficiency value was taken directly from the pump curve and at the operating point, the value of efficiency is about 85-percent.

Conversion to more common units is

$$15,205 \ \ \text{foot-pounds/second} \times 1.818 \times 10^{-3} \times 745.7 = 20,613 \ \ \text{Watts} = 20.6\text{kW} \tag{5}$$

Problem 2

This memorandum presents an analysis of a water transfer system that lifts water from one elevation to another.

Discussion

The solution applies the energy equation and pumping concepts, computes a system curve, and uses that curve to find an operating point. The remainder of this section presents the various steps required, with intermediate calculations shown and references imbedded into the memorandum. The results for each problem are presented in the narrative below; the by-hand analysis is attached to this memorandum.

ES5-P2

February 16, 2025

0.1 ES5-Problem 2

The figures below show the analysis for the problem

14. Water is to be pumped at a rate of 70 liters per second in a 1-kilometer meter long, 200 millimeter diameter pipeline between two reservoirs with an elevation difference of 20 meters. The roughness height of the steel pipe is 0.045 millimeters.

A: = 30 m
A:. = 16 m
A:: = 26 m

The Reynolds number for water is computed from

$$Re = \frac{VD}{\nu} \tag{3}$$

The kinematic viscosity of water in the system is

$$\nu = 1 \times 10^{-6} \mathrm{m}^2/\mathrm{s} \tag{4}$$

The Jain equation (Jain, 1976) that directly computes friction factor from Reynolds number, diameter, and roughness is

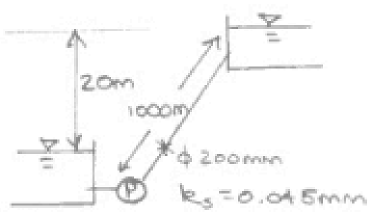
$$f = \frac{0.25}{[log(\frac{k_s}{3.7D} + \frac{5.74}{Re^{0.9}})]^2} \tag{5}$$

The Darcy-Weisbach head loss equation (for pipe losses) is

$$h_{loss} = f\frac{L}{D}\frac{V^2}{2g} \tag{6}$$

Using the description and these equations

a) Sketch the system – show the two reservoirs and the pump on the sketch.



+6

b) Convert the pipe diameter into meters (you will need this value below).

$$200\text{mm}\ \frac{1\text{m}}{1000\text{mm}} = 0.2\text{m}$$

+2

c) Convert the flow rate into cubic-meters-per-second (you will need this value below).

$$70.0\ \text{lps}\ \frac{1\text{m}^3}{1000\ \text{L}} = 0.07\ \text{m}^3/\text{s}$$

+2

d) Determine the pipeline velocity (in meters per second).

$$A = \frac{\pi D^2}{4} = \frac{\pi (0.2)^2}{4} = 0.0314 m^2 \quad V = \frac{Q}{A} = \frac{0.07 m^3/s}{0.0314 m^2} = 2.229 m/s$$

+2

e) Compute the Reynolds number for the system.

$$Re = \frac{(2.229 m/s)(0.2 m)}{1 \cdot 10^{-6} m^2/s} = 4.458 \cdot 10^5$$

f) Compute the friction factor from the Jain equation.

$$f = \frac{0.25}{\left[\log_{10}\left(\frac{0.045}{3.7(200)} + \frac{5.74}{(4.458 \cdot 10^5)^{0.9}}\right)\right]^2} = 0.0158$$

g) What is the pipe head loss in the system at 70 liters per second?

$$h_L = f \frac{L}{D} \frac{V^2}{2g} = 0.0158 \left(\frac{1000 m}{0.2 m}\right)\left(\frac{(2.229 m/s)^2}{2(9.8 m/s^2)}\right) = 20.02 m$$

h) What is the static lift (in meters of head)? (CHANGES FOR DIFFERENT VERSIONS

20 m (30 m) (16 m) (26 m)

A. A:. A:. A::

i) What is the sum of the frictional loss and the static lift (in meters of head)?

h_T = STATIC + h_L A. 20+20.02 = 40.02 m A:. 16+20.02 = 36.02 m

A:. 30+20.02 = 50.05 m A:: 26+20.02 = 46.02 m

Select a pump from one of the four on Figure 7 below. Indicate the operating point on the pump you select.

j) Which pump and operating impeller speed did you choose?

A. PUMP II, 4350 RPM A:. PUMP II, III, IV; ANY RPM

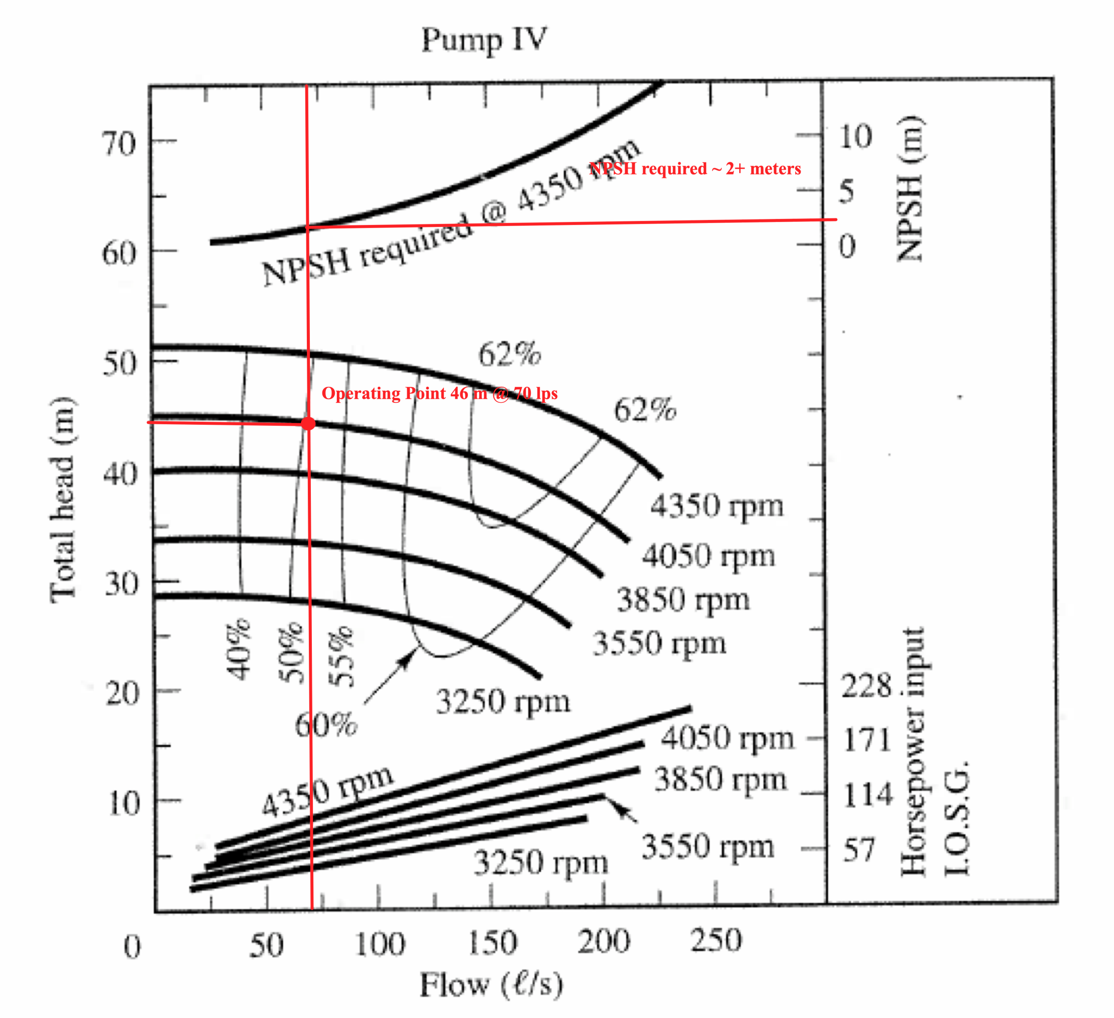
A:. PUMP III, 4350 RPM A:: PUMP IV, 4050 RPM

k) Estimate the required NPSH for the pump you choose.

A. ~4 m A:. ~3 m

A:. ~3 m A:: ~2 m

The solution to the problem is to use the static lift of 26 meters. (The A:: answer) Pump IV @ 4050 RPM is best choice , NPSHr is 2 meters based on pump curve.



Pump IV
NPSH required @ 4350 rpm
NPSH required ~ 2+ meters
Operating Point 46 m @ 70 lps
62%
62%
40%
50%
55%
60%
4350 rpm
4050 rpm
3850 rpm
3550 rpm
3250 rpm
4350 rpm
4050 rpm
3850 rpm
3550 rpm
3250 rpm
Total head (m)
NPSH (m)
Horsepower input
I.O.S.G.
Flow (ℓ/s)
228
171
114
57

[ ]:

Conclusion

This problems required analysis and application of principles and tools presented in Lecture on Head Loss Models, and Lecture on Pumps. The use of the Moody chart is enhanced by building the hydraulics calculation table, computing the Reynolds number and looking up the appropriate friction factor. The entire problem could be done entirely in a spreadsheet if a formula for friction factor was used. The particular conditions are along the zero-slope portion of the friction factor curve for the roughness ratio in this case so the friction factor values are essentially the same constant value.

Sincerely,
P. Olar Bear
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Attachment(s):
None – entire solution is embedded into the memorandum.