Flow Control Station on a Water Pipeline
CHE 4353-Process Control

Overview

A pump and piping network transfers water from an in-ground sump to a storage pond located on a nearby hill (Figure 1). Please design a flow control station just downstream of the pump (see green equipment). In particular, specify the details of orifice plate FO-100 and flow control valve FCV-100.

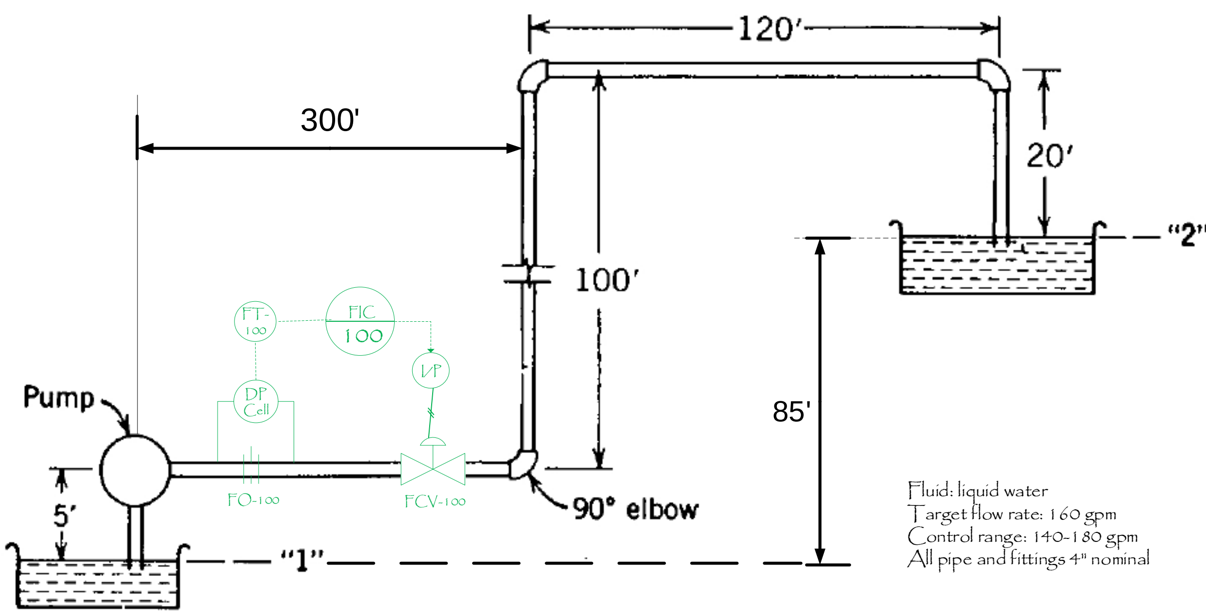


Figure 1. Water Transfer Network

Procedure

Attached to this PDF file is a HYSYS simulation of the network in Figure 1 (see screenshot). The FO and FCV are installed in pipe 3, however they are full-port devices (4.026" ID) and are taking no pressure drop in the .hsc file provided. The flow controller FIC-100 is set in "off mode", and does not influence the hydraulics of the network (Figure 2).

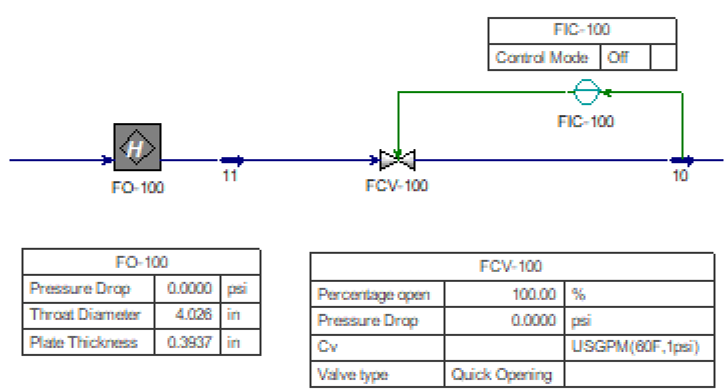


Figure 2. Orifice and Control Valve Blocks in the Simulation

Design the orifice and flow control valve by following these steps.

1) Establish the orifice diameter at the target flow rate.
2) Input your diameter in the FO block (Figure 3).

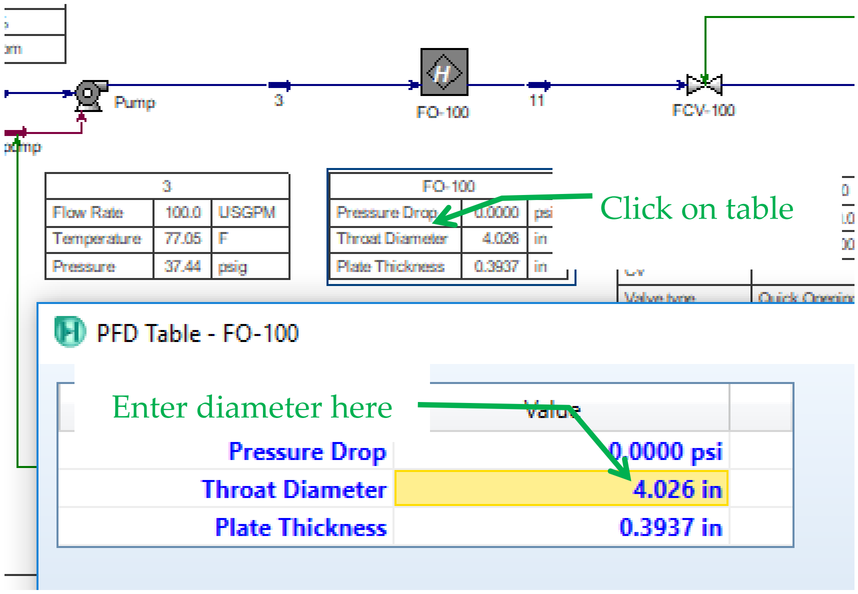


Figure 3. Entering the orifice plate diameter.

HYSYS will recalculate the system hydraulics automatically, including the pressure drop across the orifice. An adjustor (Figure 4) varies the power to the pump to obtain atmospheric pressure at outlet 10 (the surface of the storage pond), thus providing the total differential pressure requirement for the pump.

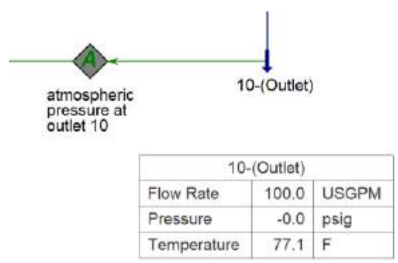


Figure 4. Outlet pressure adjustor.

During all recalculations you will see the error message in Figure 5. This message may be ignored throughout the calculation of the system curves. It does not affect the results, and will disappear when you enter the allowable pressure drop across the control valve in step 6)

```
   Target Value:     -0.921441 psig   Adjust Value:       3.33915 hp
   Match Value:              0 psig
Delta P is too small, cannot size the valve
atmospheric pressure at outlet 10: Iter 5
   Target Value: -9.93838e-009 psig   Adjust Value:       3.41863 hp
   Match Value:              0 psig
```

Figure 5. Water Transfer Network

3) Compute and plot the system curve, including the pressure drop across the orifice but *without* the control valve, over a range of flows slightly broader than the control range. The points on the system curve are obtained from HYSYS as illustrated in Figure 6

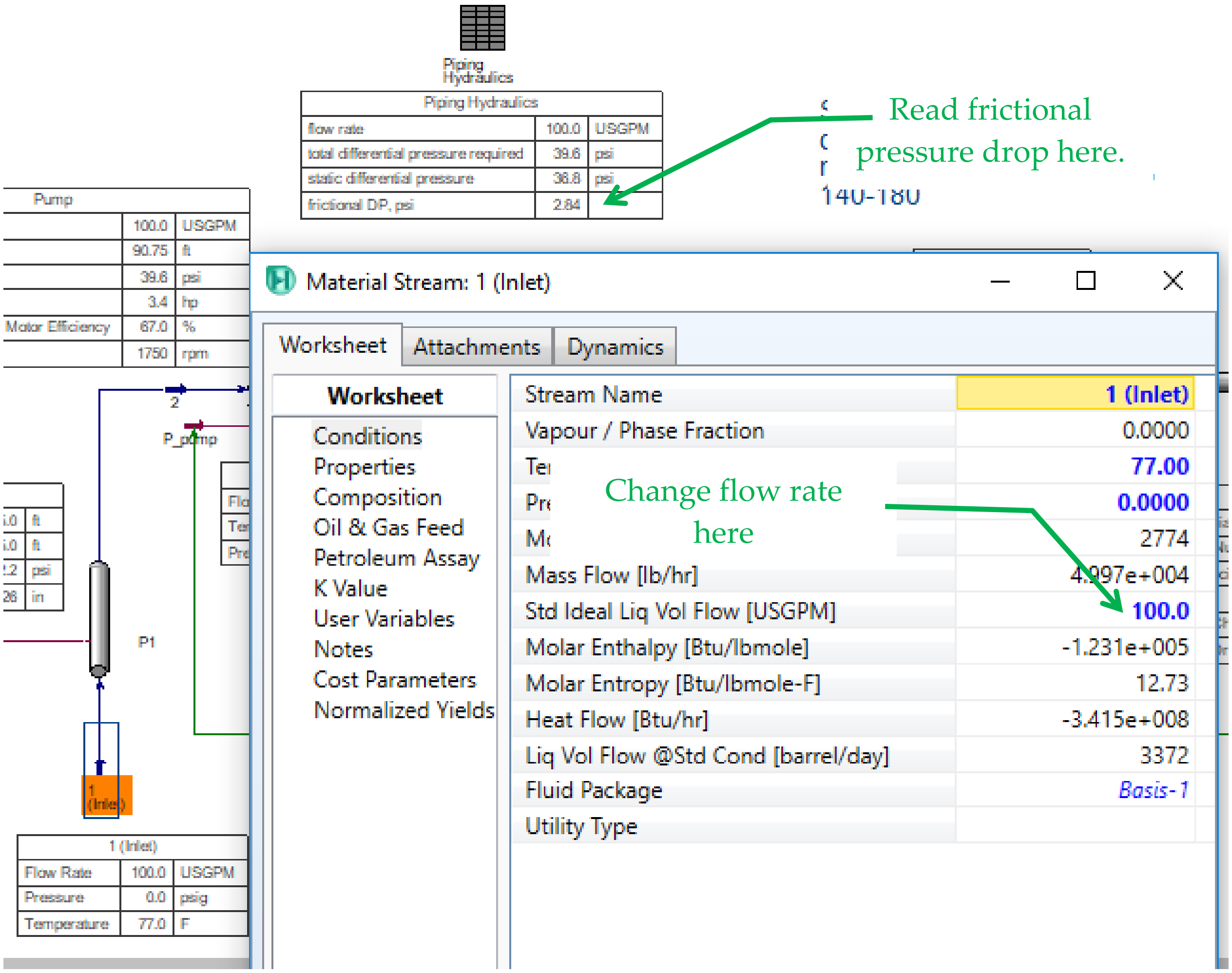


Figure 6. Obtaining points for the system curve.

Control valves only affect the frictional pressure drop of the piping system, not the static pressure difference. Therefore, the system curve is computed only for the frictional pressure drop in the system.

$$\Delta P_f = \Delta P_{pump} - \Delta P_{static} \tag{1}$$

In equation (1) ΔP_f is the frictional pressure drop, ΔP_{pump} is the total differential pressure developed by the pump, and ΔP_{static} is the static pressure requirement. This is a constant, 36.8 psi, corresponding to 85 feet of water column.

4) Compute the pump curve, which follows the equation

$$\Delta P_{curve} = 8.875 \cdot psi + 0.063 \cdot \frac{psi}{gpm} F_v - 2.969 \times 10^{-4} \cdot \frac{psi}{gpm^2} F_v^{\,2} \tag{2}$$

In (2), F_v is the flow through the piping network, and hence the flow through the valve. Co-plot the pump curve with system curve in a neat, computer-generated plot such as provided by MS Excel.

5) Design the control valve using the heuristics presented in class. Give the results of your design by filling in the blocks highlighted in yellow on the IEC 60534-7 control valve spec sheet. The spec sheet is in Excel format, and attached to this PDF. The spec sheet must be filled out using the American system of units. Especially important is the value of C_v at 100% open in $gpm/\sqrt{psi}$.
6) Enter your values for valve open percentage, valve pressure drop, and valve mass flow rate at the design flow rate into HYSYS as indicated in Figure 7. Size the valve using the utility provided by HYSYS.

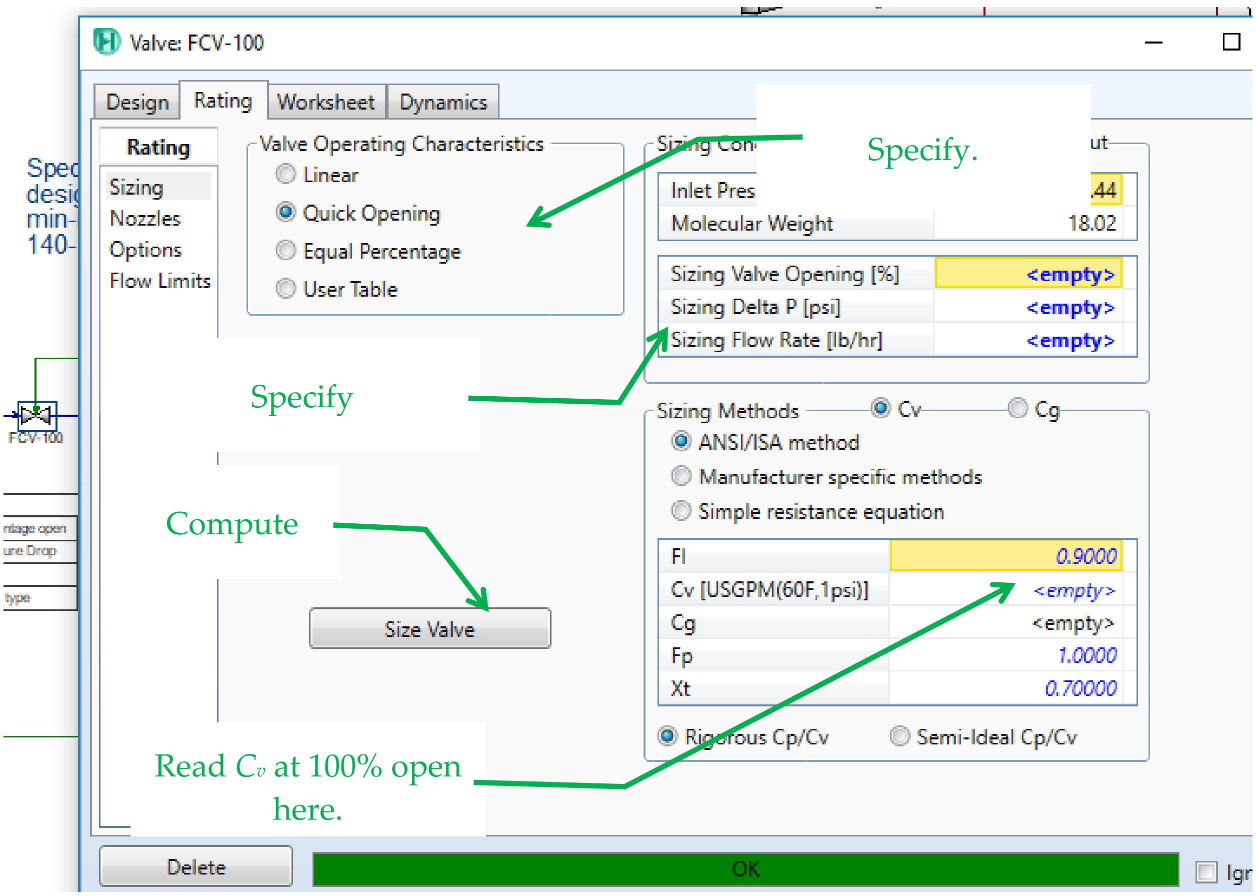


Figure 7. Sizing the control valve.

How does your manually calculated value of C_v at 100% open compare to the value given by HYSYS?

7) Using the HYSYS-generated value of C_v, compute the system curve *with* the control valve using the same procedure as you employed in step 3). Co-plot this system curve with the previous system curve and the pump curve. Confirm that the system curve with the control valve intersects the pump curve at the design flow rate. You should finally obtain a plot similar to Figure 8.

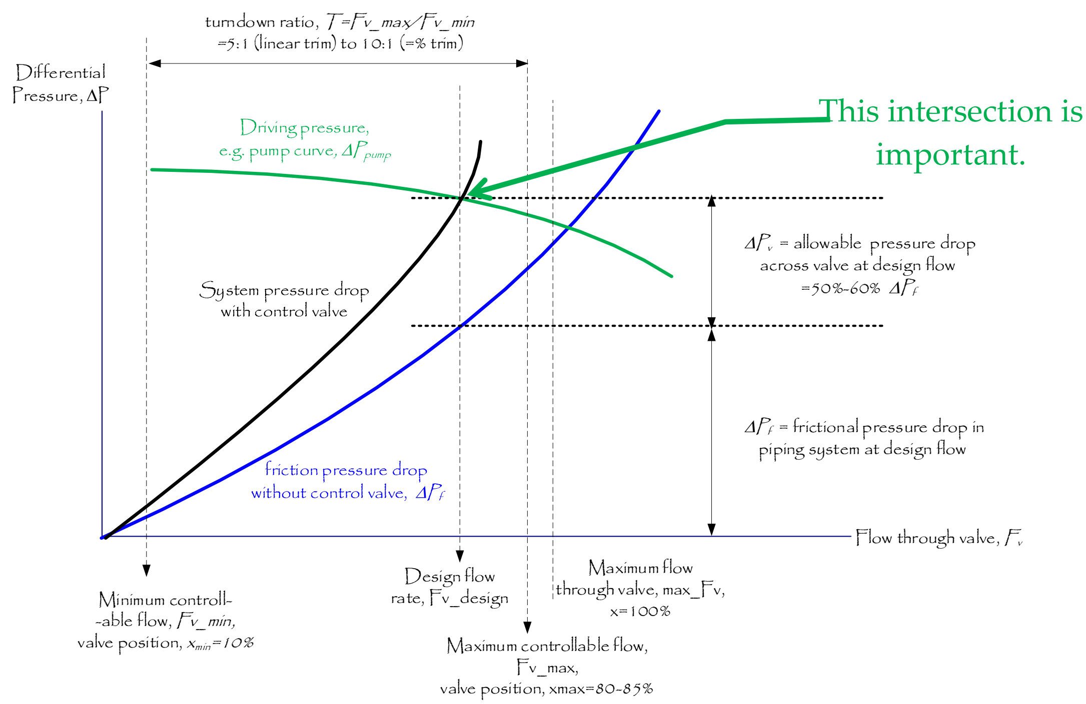


Figure 8. Schematic of system and pump curves

Deliverables

Table 1. Deliverables for Flow Control Station Project

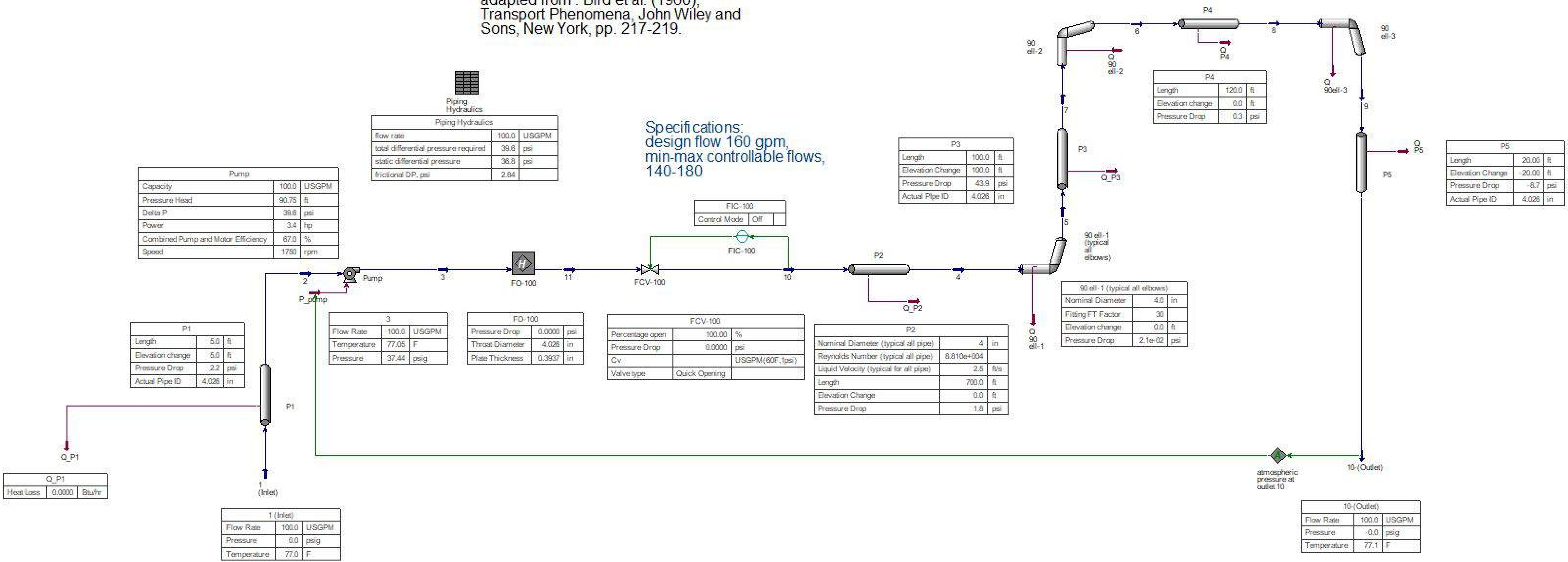
Item	Points Possible	Points Earned
a. Plot of pump and system curves like Figure 8	25	
b. Calculations of orifice diameter	5	
c. IEC 60534-7 spec sheet with requested data correctly filled in	10	
d. Calculations showing how calculated values on spec sheet were obtained.	45	
e. Comparison of hand-calculated C_v with HYSYS C_v	5	
f. Converged HYSYS file with correct orifice and valve installed	10	
Totals	100	

Compile items *a* through *e* into a single PDF file. Attach the PDF file and the converged HYSYS file separately to your submission on Blackboard.

Flow Control Station on Water Line

adapted from : Bird et al. (1960), Transport Phenomena, John Wiley and Sons, New York, pp. 217-219.

Specifications:
design flow 160 gpm,
min-max controllable flows,
140-180



Piping Hydraulics		
flow rate	100.0	USGPM
total differential pressure required	39.6	psi
static differential pressure	36.8	psi
frictional DP, psi	2.84	

Pump		
Capacity	100.0	USGPM
Pressure Head	90.75	ft
Delta P	39.6	psi
Power	3.4	hp
Combined Pump and Motor Efficiency	67.0	%
Speed	1750	rpm

FIC-100	
Control Mode	Off

P1		
Length	5.0	ft
Elevation change	5.0	ft
Pressure Drop	2.2	psi
Actual Pipe ID	4.026	in

3		
Flow Rate	100.0	USGPM
Temperature	77.05	F
Pressure	37.44	psig

FO-100		
Pressure Drop	0.0000	psi
Throat Diameter	4.026	in
Plate Thickness	0.3937	in

FCV-100		
Percentage open	100.00	%
Pressure Drop	0.0000	psi
Cv		USGPM(60F,1psi)
Valve type	Quick Opening	

P2		
Nominal Diameter (typical all pipe)	4	in
Reynolds Number (typical all pipe)	8.810e+004	
Liquid Velocity (typical for all pipe)	2.5	ft/s
Length	700.0	ft
Elevation Change	0.0	ft
Pressure Drop	1.8	psi

P3		
Length	100.0	ft
Elevation Change	100.0	ft
Pressure Drop	43.9	psi
Actual Pipe ID	4.026	in

90 ell-1 (typical all elbows)		
Nominal Diameter	4.0	in
Fitting FT Factor	30	
Elevation change	0.0	ft
Pressure Drop	2.1e-02	psi

P4		
Length	120.0	ft
Elevation change	0.0	ft
Pressure Drop	0.3	psi

P5		
Length	20.00	ft
Elevation Change	-20.00	ft
Pressure Drop	-8.7	psi
Actual Pipe ID	4.026	in

Q_P1		
Heat Loss	0.0000	Btu/hr

1 (Inlet)		
Flow Rate	100.0	USGPM
Pressure	0.0	psig
Temperature	77.0	F

10-(Outlet)		
Flow Rate	100.0	USGPM
Pressure	-0.0	psig
Temperature	77.1	F