Appendix C
Design Example

The following paragraphs present an example design that utilizes the material and information contained in Chapters 1 through 12, and Appendix B. The calculations and assumptions are specific to the example conditions presented, and may not necessarily represent conditions at an actual, specific site.

C-1. Design Example

A facility requires an upgrade and retrofit to their existing wastewater pretreatment system. The pretreatment system is required to reduce the dissolved metal content of two process waste waters before introduction into a biologically based central treatment plant. Due to process changes over the years and reduced effluent limits, the existing pretreatment facility no longer removes enough metals to consistently meet effluent requirements.

The waste waters are produced from a plating process (Process A) and from the finishing stages of a metal fabrication facility (Process B). The latter could include metal cleaning using organic solvents and painting operations. The retrofit is to include the renovation and splitting of an existing, covered, concrete wetwell (P1560). Half of the wetwell will now act as an influent wetwell (P1560) to a new treatment train and the other half will act as the clearwell (P1510) for the effluent from the new treatment system. The new treatment system will include a low-profile air stripper to reduce solvent concentrations followed by a ferrous-based precipitation reactor and associated flocculation tank and clarifier. Figure C-1 is the flow diagram of the proposed pretreatment system renovation, and Figure C-2 is the piping and instrumentation diagram. Figure C-3 is the general equipment arrangement with the anticipated piping layout.

The influent to the pretreatment system averages 3.79 x 10^{-3} m^3/s with a maximum future flow of 5.36 x 10^{-3} m^3/s and a process temperatures of 16EC-minimum, 23.9EC-normal, and 46EC-maximum. The average pH is 5.4 due to the presence of chromic and sulfuric acids, although occasional upsets have produced pH as low as 3.6. The pollutant concentrations are summarized in Table C-1.

Table C-1
Pollutant Concentrations

Parameter	Maximum (mg/l)	Average (mg/l)
Total Cyanide	0.368	0.078
Chromium	80.2	24.9
Nickel	74.9	15.3
Copper	6.29	0.71
Zinc	10.3	0.88
Lead	12.8	1.57
Silver	0.84	0.21
Cadmium	3.24	0.77
Xylene	210	53.2
Toluene	180	45.1
111-Trichloroethylene	500	48.3
Ethyl Ether	54.3	15.2

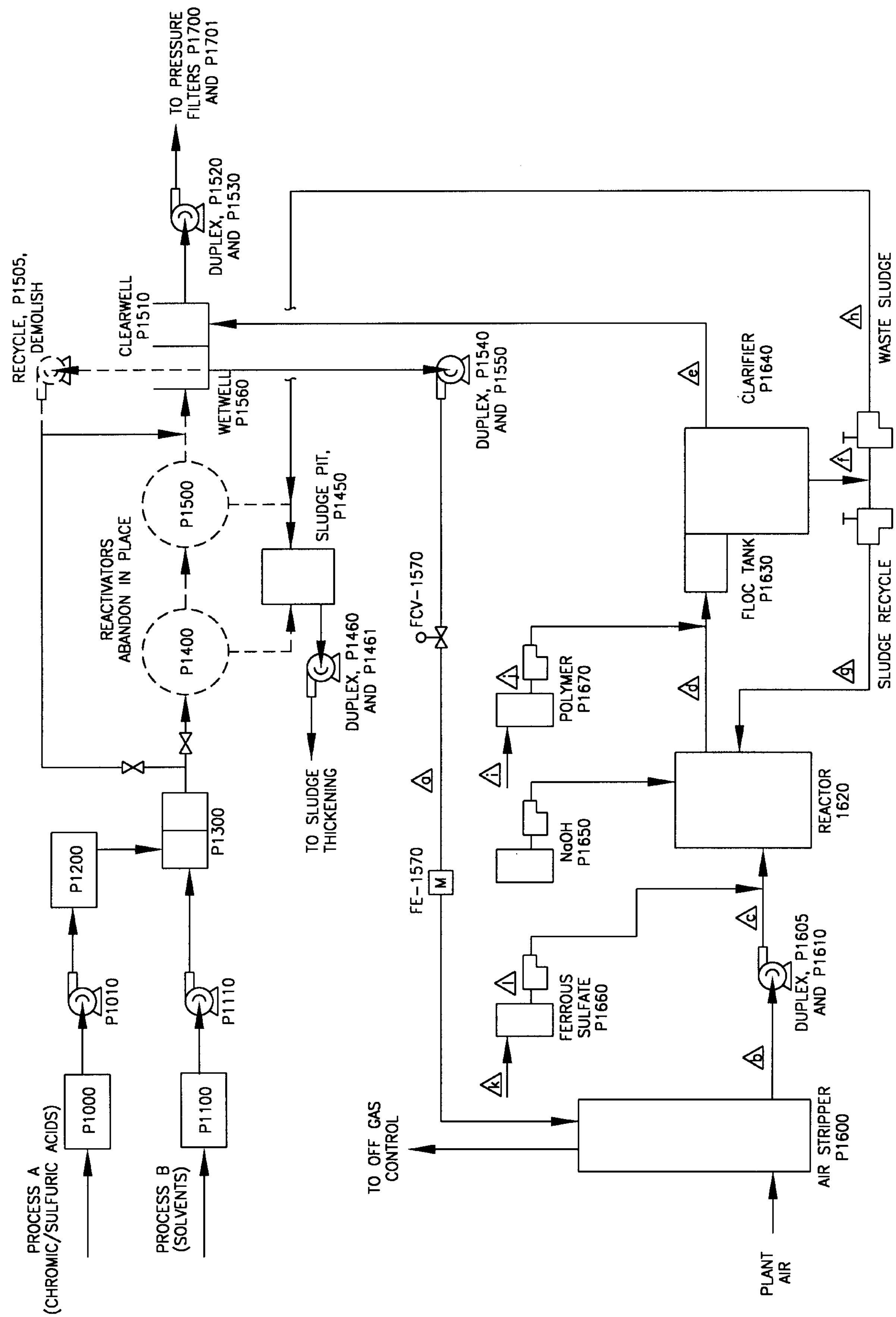


Figure C-1. Design Example Process Flow Diagram
(Process Conditions Table continued on next page)

Table C-2
Process Conditions, Design Example Process
Flow Diagram, Continued

Point	Line Designation	Normal			Maximum			Minimum		
		Flow ($m^3/s \times 10^{-3}$)	Temp. (EC)	Pressure (kPa)	Flow ($m^3/s \times 10^{-3}$)	Temp. (EC)	Pressure (kPa)	Flow ($m^3/s \times 10^{-3}$)	Temp. (EC)	Pressure (kPa)
a	XXX-INF-1500	3.79	23.9	tbd	5.36	46.0	tbd	3.79	16.0	tbd
b	XXX-IAS-1600	3.79	23.9	tbd	5.36	46.0	tbd	3.79	16.0	tbd
c	XXX-IAS-1620	3.79	23.9	tbd	5.36	46.0	tbd	3.79	16.0	tbd
d	XXX-PRI-1630	3.79	23.9	gravity flow	5.36	46.0	gravity flow	3.79	16.0	gravity flow
e	XXX-EFF-1640	3.79	23.9	gravity flow	5.36	46.0	gravity flow	3.79	16.0	gravity flow
f	XXX-SLG-1650	2.30	23.9	250	2.75	46.0	250	2.30	16.0	250
g	XXX-SLG-1651	0.36	23.9	250	2.75	46.0	250	0.36	16.0	250
h	XXX-SLG-1660	1.94	23.9	250	2.75	46.0	250	1.94	16.0	250
I	XXX-PYS-101	0.438	23.9	tbd	0.438	46.0	79.5	0.438	16.0	tbd
j	XXX-PYS-102	0.00105	23.9	tbd	0.00131	46.0	79.5	0.00105	16.0	tbd
k	XXX-FES-111	0.842	23.9	tbd	0.842	46.0	79.5	0.842	16.0	tbd
l	XXX-FES-112	0.0105	23.9	tbd	0.0131	46.0	79.5	0.0105	16.0	tbd

Notes:

XXX - line size to be determined in calculations
tbd - to be determined

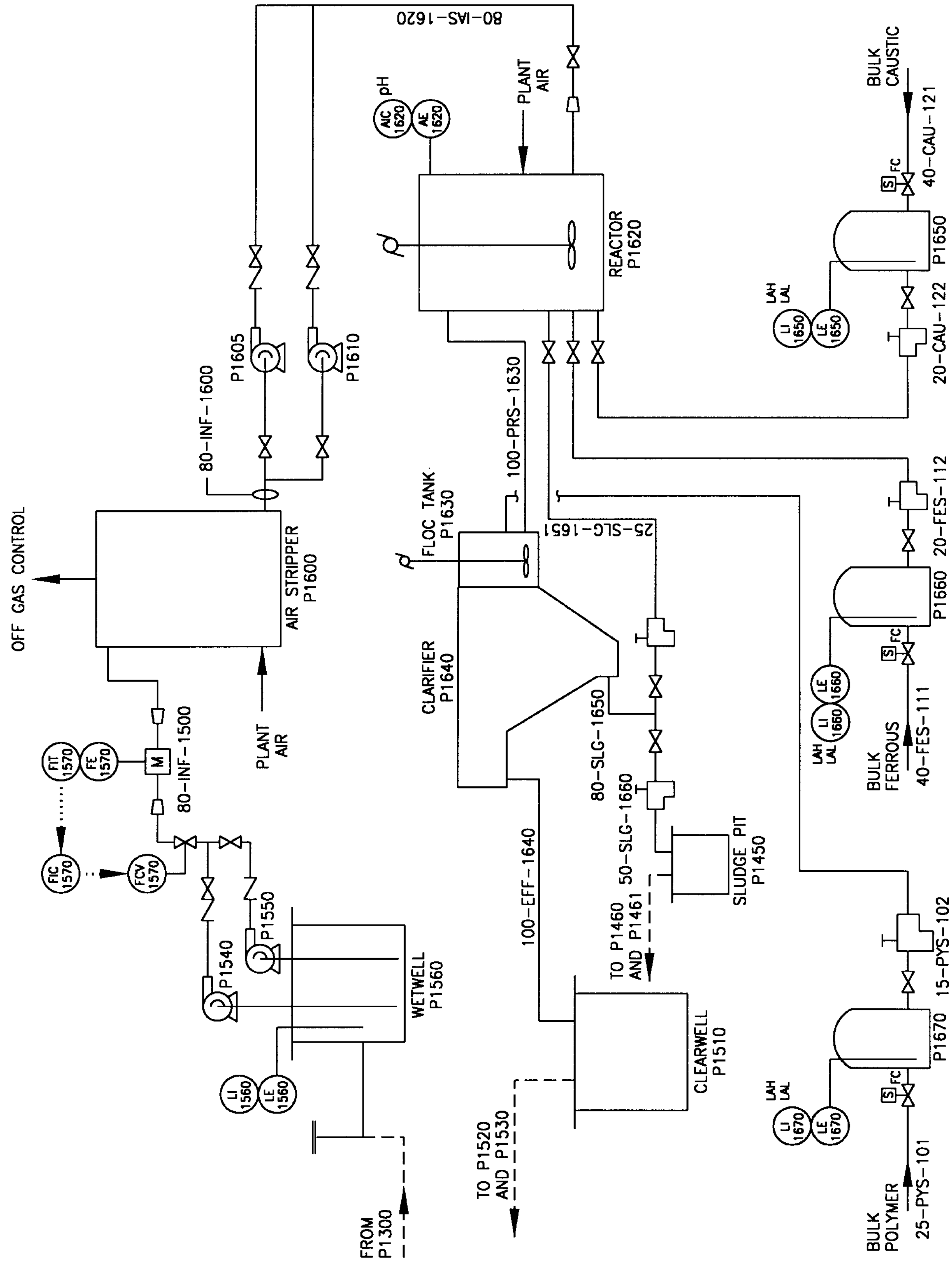


Figure C-2. Design Example Piping and Instrumentation Diagram

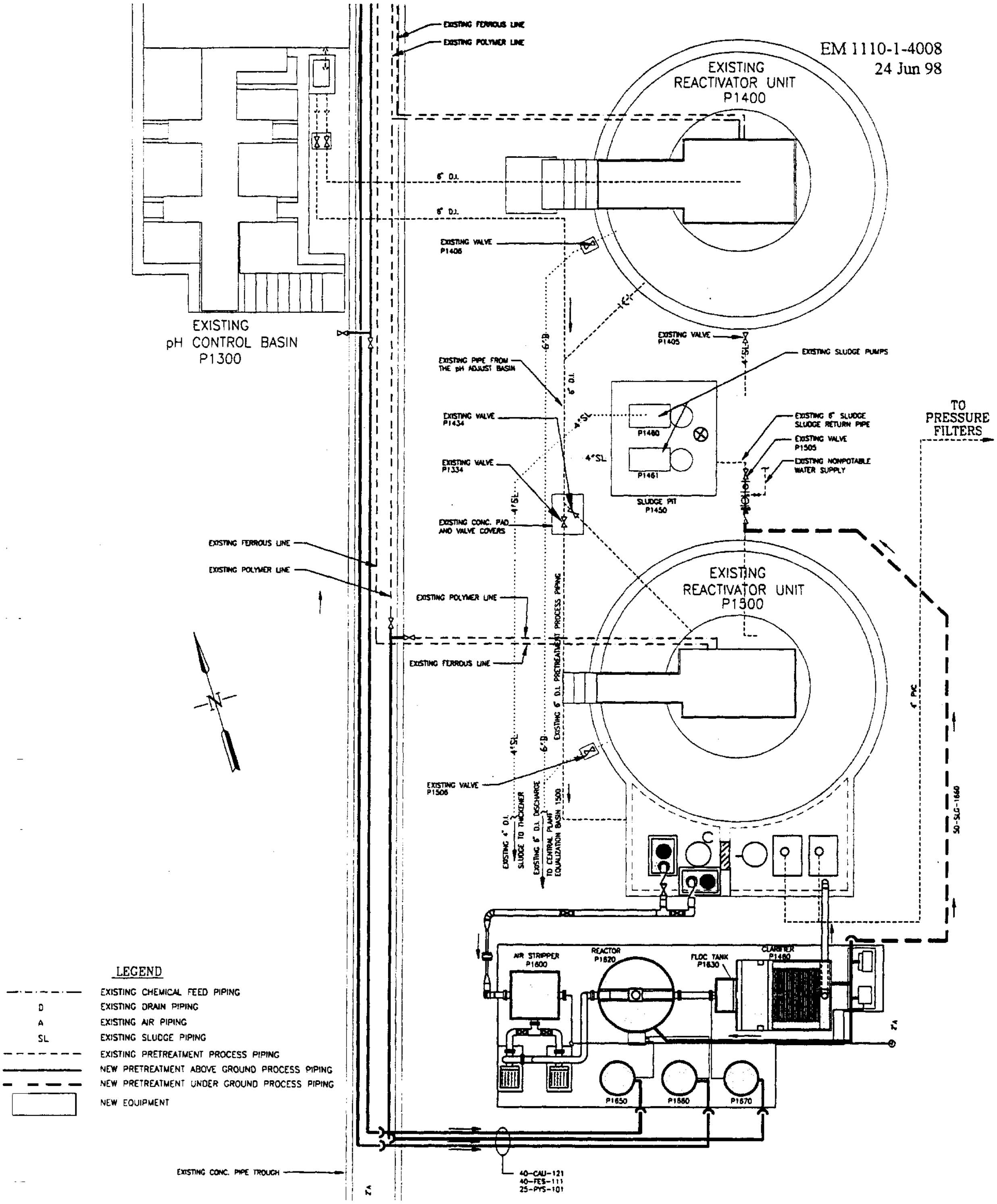
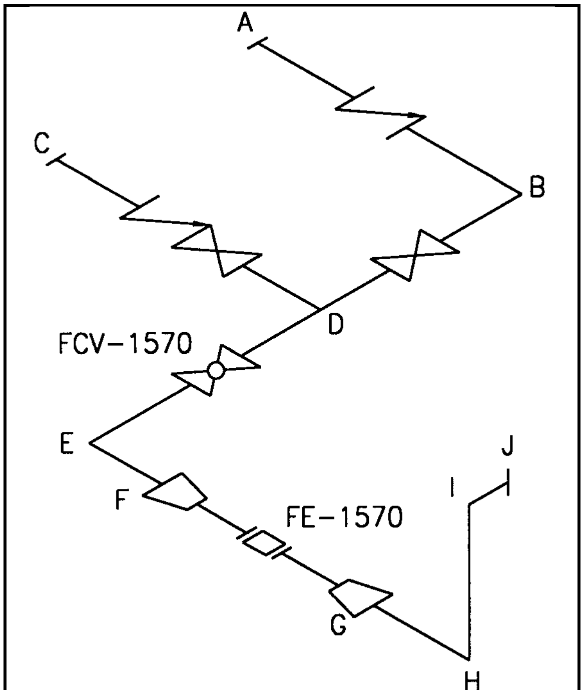


Figure C-3. Piping Layout Plan

C-2. Solution

a. Line XXX-INF-1500
Influent from Wetwell P1560 to Air Stripper P1600



Sketch C-1

Flow is either through A-D or C-D, but not both simultaneously

Maximum Flowrate, Q = 5.36 x 10^{-3} m^3/s

Elevation Change (H-I) = 2.44 m (= 23.9 kPa head)

Total run = 7.84 m for A-J
= 7.33 m for C-J

Fittings (identical for either A-J or C-J)
1 swing check valve
1 gate valve (isolation)
1 flow control valve
1 reducer
1 expansion

MATERIAL OF CONSTRUCTION

Referring to the fluid/material matrix in Appendix B, the potential for mixed acids eliminates aluminum, bronze, copper, carbon steel and stainless steel alloys; and the solvent content in the wastewater eliminates ABS, PVC, CPVC, HDPE and FRP. Similarly, examining the potential use of lined piping, the solvents eliminate rubber, PP and PVDC, However, PTFE and PVDF liners are acceptable.

The design specifications shall be developed to allow a liner of either PVDF , minimum thickness of 4.45 mm (confirm with pipe sizing), or PTFE (to be provided with weep vents) and a carbon steel shell of ASTM A 106, Grade A. The shell is to be joined with chamfered threaded flanges. The PVDF liner is selected for the example calculations.

PIPE SIZING/PRESSURE DROP

Step 1. Select pipe size by dividing the volumetric flowrate by the desired velocity (normal service, V = 2.1 m/s with the mid-range preferred for most applications).

$$A = \pi \frac{D_i^2}{4} = \frac{Q}{V}$$

$$D_i = \left[\frac{4}{\pi} \frac{(5.36 \ x \ 10^{-3}) \ m^3/s}{2.1 \ m/s}\right]^{0.5} \left(1000 \ \frac{mm}{m}\right)$$

$$= 57 \ mm$$

Step 2. From Table 1-1, the next largest nominal diameter is 65 mm. The commercial availability of 65 mm lined pipe is checked (65 mm is not a commonly used pipe size). This size is not available except through special order. The size choices are 50 mm or 80 mm.

50 mm pipe: From Table 9-8, a PVDF thickness of 4.37 mm is required to prevent permeation.

$$D_i = 50\ mm - (4.37\ mm)(2) = 41.3\ mm$$

$$V = \frac{Q}{A} = \frac{Q}{\frac{\pi}{4} D_i^2}$$

$$= \frac{5.36\ x\ 10^{-3}\ m^3/s}{\frac{\pi}{4}(0.0413\ m)^2} = 4.0\ m/s$$

The actual velocity, 4.0 m/s, > the acceptable range, 2.1 ± 0.9 m/s. Therefore, the 50 mm pipe size is rejected.

80 mm pipe: From Table 9-8, a PVDF thickness of 4.45 mm is required to prevent permeation.

$$D_i = 80\ mm - (4.45\ mm)(2) = 71.1\ mm$$

$$V = \frac{Q}{A} = \frac{Q}{\frac{\pi}{4} D_i^2}$$

$$= \frac{5.36\ x\ 10^{-3}\ m^3/s}{\frac{\pi}{4}(0.0711\ m)^2} = 1.35\ m/s$$

The actual velocity, 1.35 m/s, is within the acceptable range, 2.1 ± 0.9 m/s.

Therefore, the 80 mm PVDF lined pipe is specified and D_i = 71.1 mm, D_o = 90 mm and the structural wall thickness = 5 mm. The line designation is amended to: 80-INF-1500.

In addition, a pipe reduction is required to accommodate a magnetic flowmeter. From an instrument vendor nomograph over the process flow range, the magmeter should have a 40 mm bore with minimum straight, unobstructed runs of 3 x D_i upstream and 2 x D_i downstream. From lined piping catalogs, lined piping typically has a minimum section length. For 40 mm pipe, one vendor has fixed flange spools available with a minimum length of 819 mm. Use a 80 mm by 40 mm concentric reducer/expansion at one end of each straight pipe run; see Sketch C-2.

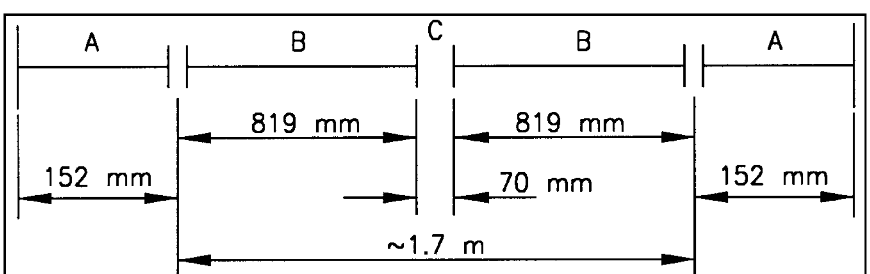
The actual velocity through the reduced section is required for pressure drop calculations. From Table 9-8, a PVDF thickness of 4.07 mm is required to prevent permeation.

$$D_i = 40\ mm - (4.07\ mm)(2) = 31.9\ mm$$

$$V = \frac{Q}{A} = \frac{Q}{\frac{\pi}{4} D_i^2}$$

$$= \frac{5.36\ x\ 10^{-3}\ m^3/s}{\frac{\pi}{4}(0.0319\ m)^2} = 6.71\ m/s$$

The 40 mm spools have a length of 819 mm which equals 25.7 x D_i. Therefore, the minimum unobstructed run requirement for the meter is satisfied.



Sketch C-2

Notes:
A= identical 80 mm by 40 mm concentric reducers, β = 0.5, θ = 7.56°
B = identical 40 mm spools with flanged ends, 819 mm length
C = wafer style mag-meter, lay length is 70 mm.

Step 3. At 23.9°C, $\nu = 8.94 \times 10^{-7}$ m²/s and the Darcy-Weisbach equation is used to calculate the pressure drop through the piping.

Ref. p. 3-8.

$$h_L = \left[\left(\frac{f\,L}{D_i} + \Sigma K\right)\frac{V^2}{2\,g}\right]_{80\ mm}$$

$$+ \left[\left(\frac{f\,L}{D_i} + \Sigma K\right)\frac{V^2}{2\,g}\right]_{40\ mm}$$

80 mm pipe:

Ref. p. 3-8.

$$R_e = \frac{D_i\ V}{\nu} = \frac{(0.0711\ m)(1.35\ m/s)}{8.94\ x\ 10^{-7}\ m^2/s}$$

$$= 1.1\ x\ 10^5 - turbulent\ flow$$

$$\varepsilon = 0.0015\ mm\ from\ Table\ 3\text{-}1$$

$$\varepsilon/D_i = \frac{0.0015\ mm}{71.1\ mm} = 0.00002$$

Therefore, f = 0.028 from the Moody Diagram (Figure 3-1).

From Sketch C-1, for run A-J the sum of the minor loss coefficients from Table 3-3:

Table C-3
Minor Losses for 80-INF-1500: Run A-J

Minor Loss	K
1 gate valve (open)	0.2
1 swing check valve	2.5
4 x 90° elbows	4(0.9)
1 tee-flow through	0.6
1 concentric reducer	0.08
1 exit	1.0
ΣK =	7.98

$$h_{L80} = \left(\frac{f\,L}{D_i} + \Sigma K\right)\frac{V^2}{2\,g}$$

$$= \left[\frac{(0.028)(7.84 - 1.7\ m)}{0.0711\ m} + 7.98\right]\frac{(1.35\ m/s)^2}{2\ (9.81\ m/s^2)}$$

$$= 0.97\ m$$

From Sketch C-1, for run C-J the sum of the minor loss coefficients from Table 3-3:

Table C-4
Minor Losses for 80-INF-1500: Run C-J

Minor Loss	K
1 swing check valve	2.5
3 x 90° elbows	3(0.9)
1 tee-branch flow	1.6
1 concentric reducer	0.08
1 exit	1.0
ΣK =	8.08

$$h_{L80} = \left(\frac{f\,L}{D_i} + \Sigma K\right)\frac{V^2}{2\,g}$$

$$= \left[\frac{(0.028)(7.33 - 1.7\ m)}{0.0711\ m} + 8.08\right]\frac{(1.35\ m/s)^2}{2\ (9.81\ m/s^2)}$$

$$= 0.96\ m$$

Therefore, use run A-J as worst case for the 80 mm pipe section; h_L = 0.97 m.

40 mm pipe section:

Ref. p. 3-8.

$$R_e = \frac{D_i\ V}{\nu} = \frac{(0.0319\ m)(6.71\ m/s)}{8.94\ x\ 10^{-7}\ m^2/s}$$

$$= 2.4\ x\ 10^5 - turbulent\ flow$$

$$\varepsilon = 0.0015\ mm\ from\ Table\ 3-1$$

$$\varepsilon/D_i = \frac{0.0015\ mm}{31.9\ mm} = 0.00005$$

Therefore, f = 0.026 from the Moody Diagram (Figure 3-1).

From Sketch C-1, for run FG the sum of the minor loss coefficients from Table 3-3:

Table C-5
Minor Losses for 80-INF-1500: Run F-G

MinorLoss	K
1 enlargement	-0.19 (pressure gain)
Σ K =	-0.19

$$h_{L40} = \left(\frac{f\,L}{D_i} + \Sigma K\right)\frac{V^2}{2\,g}$$

$$= \left[\frac{(0.026)(1.7\ m)}{0.0319\ m} + (-0.19)\right]\frac{(6.71\ m/s)^2}{2\ (9.81\ m/s^2)}$$

$$= 2.74\ m$$

The total pressure drop through line 80-INF-1500: h_L = 0.97 m. + 2.74 m = 3.71 m or 35.4 kPa. This does not include the pressure drop resulting from the control valve, FCV-1570.

Step 4. Size the control valve, FCV-1570, such that the pressure drop through FCV-1570 = 33% of the piping system loss = 0.33 (36.4 kPa) = 12.0 kPa. The flow measurement device is proportional to flow squared so that an equal percentage for characteristic is desired. Assume a ball valve with V-port will be used so let F_d = 1.0, and R_m = 0.9 (from Table 10-9). From reference materials, s.g. = 1.0.

Ref. p. 10-13.

$$C_v = \frac{Q}{N_1}\sqrt{\frac{s.g.}{\Delta P}}$$

$$= \frac{(5.36\ x\ 10^{-3}\ m^3/s)(3600\ s/hr)}{0.085}\sqrt{\frac{1.0}{12.0\ kPa}}$$

$$= 65.5$$

$$Re_v = \frac{N_4\ F_d\ Q}{\nu\ R_m^{1/2} C_V^{1/2}}\left[\frac{R_m^2\ C_v^2}{N_2\ d^4} + 1\right]^{1/4} =$$

$$\frac{(76{,}000)(1.0)[(5.36\ x\ 10^{-3})(3600)]}{(.894)(0.9)^{1/2}(65.5)^{1/2}}\ x$$

$$\left[\frac{(0.9)^2(65.5)^2}{(0.00214)(80)^4} + 1\right]^{1/4} = 2.2\ x\ 10^5$$

F_R = 1.0 from Figure 10-4 (a viscosity correction is not required due to the high Reynolds number).

Ref. p. 10-13.

$$C_{vc} = (C_v)(F_R) = (65.5)(1.0) = 65.5$$

From manufacturer's data (see Table C-6), a 80 mm, 60° V-port ball valve at 80% travel in a 80 mm pipe has a C_v of 67.2 and a R_m of 0.86.

Ref. p. 10-13.

$$\Delta P_{actual} = \frac{s.g.}{\left(\frac{N_1\ C_v}{Q}\right)^2}$$

$$= \frac{1.0}{\left(\frac{(0.085)(67.2)}{(5.36\ x\ 10^{-3})(3600)}\right)^2} = 11.4\ kPa$$

Step 5. The required pump head is equal to the sum of the elevation change, the piping pressure drop and the valve pressure loss.

$$P_{head} = 23.9\ kPa + 36.4\ kPa + 11.4\ kPa$$
$$= 71.7\ kPa\ x\ 1.25\ safety\ factor$$
$$= 89.6\ kPa$$

Step 6. The control valve ΔP is checked. The valve inlet pressure, Pi, is equal to the required pump head less the piping losses from the pump to the valve (C-FCV on Sketch 1; approximately 4.9 kPa).

$$P_i = 89.6\ kPa - 4.9\ kPa = 84.7\ kPa$$

Ref. p. 10-17.

$$\Delta P_{allow} = R_m^2\ (P_i - r_c\ P_v)$$
$$= (0.86)^2\ [84.7\ kPa - (0.96)(13.17\ kPa)]$$

$$\Delta P_{allow} = 60.4\ kPa \geq \Delta P_v\ ,$$
$$so\ the\ valve\ is\ acceptable.$$

PRESSURE INTEGRITY

The design pressure is equal to the required pump head = 89.6 kPa. No potential pressure transients exist because the valve fails in the last position. An external corrosion allowance of 2 mm is to be designed. Pressure integrity is acceptable if the minimum wall thicknesses for both the 80 mm and 40 mm pipe sections meet ASME 31.3 code. For ASTM A 106, Grade A pipe, ASME B31.3 tables provide S = 110 MPa, E = 1.0, and y = 0.4.

Ref. p. 3-15.

$$t_m = t + A = \frac{P\ D_o}{2\ (S\ E + P\ y)} + A$$

80 mm pipe:

$$t_m = \frac{(0.0896\ MPa)(90\ mm)}{2[(110\ MPa)(1.0) + (0.0896\ MPa)(0.4)]}$$
$$+ 2\ mm = 2.04\ mm$$

The commercial wall thickness tolerance for seamless rolled pipe is +0, -12½%.

$$t_{NOM} = \frac{2.04\ mm}{1.0 - 0.125} = 2.3\ mm$$

Nominal 80 mm pipe has a thickness of 5 mm; therefore, the 80 mm pipe section satisfies pressure intergrity.

Table C-6
Flow Coefficient - C_v - Characterized Seat Control Valves

Valve Size mm (in)	Line Size mm (in)	Percent of Rated Travel (Degree of Rotation)									
		10 (9)	20 (18)	30 (27)	40 (36)	50 (45)	60 (54)	70 (63)	80 (72)	90 (81)	100 (90)
12.7 (0.5), 6.35	15 (½)	0.02	0.03	0.07	0.12	0.16	0.20	0.24	0.28	0.32	0.36
(0.25), 0.79 (0.0313)	20 (3/4)	0.02	0.03	0.07	0.10	0.14	0.18	0.21	0.25	0.29	0.32
Wide Slot	25 (1)	0.02	0.03	0.06	0.10	0.13	0.16	0.18	0.21	0.27	0.30
12.7 (0.5), 6.35	15 (½)	0.02	0.07	0.20	0.33	0.46	0.60	0.73	0.86	0.99	1.10
(0.25), 1.59 (0.0625)	20 (3/4)	0.02	0.06	0.18	0.29	0.41	0.53	0.65	0.77	0.88	0.98
Wide Slot	25 (1)	0.02	0.06	0.17	0.27	0.38	0.50	0.61	0.71	0.82	0.91
12.7 (0.5),	15 (½)	0.02	0.10	0.20	0.34	0.55	0.83	1.11	1.59	2.08	2.50
6.35 (0.25)	20 (3/4)	0.02	0.09	0.18	0.30	0.49	0.74	0.99	1.41	1.85	2.22
30EV	25 (1)	0.02	0.08	0.17	0.28	0.46	0.69	0.92	1.32	1.73	2.07
12.7 (0.5),	15 (½)	0.02	0.12	0.33	0.90	0.84	1.35	1.95	3.10	4.37	5.92
6.35 (0.25)	20 (3/4)	0.02	0.10	0.29	0.44	0.75	1.20	1.74	2.76	3.90	5.27
60EV	25 (1)	0.02	0.10	0.27	0.41	0.70	1.12	1.62	2.57	3.63	4.91
25 (1)	25 (1)	0.02	0.21	0.56	0.96	1.58	2.39	3.43	4.62	6.15	7.26
30EV	40 (1.5)	0.02	0.16	0.44	0.75	1.23	1.86	2.68	3.60	4.80	5.66
	50 (2)	0.02	0.15	0.40	0.69	1.14	1.72	2.47	3.33	4.43	5.23
25 (1)	25 (1)	0.02	0.30	0.78	1.24	2.27	3.59	5.28	8.29	11.6	15.5
60EV	40 (1.5)	0.02	0.23	0.61	0.97	1.77	2.80	4.12	6.47	9.05	12.1
	50 (2)	0.02	0.22	0.56	0.89	1.63	2.58	3.80	5.97	8.35	11.2
50 (2)	50 (2)	0.02	0.55	1.72	3.41	5.65	8.26	12.1	16.6	22.2	26.5
30EV	80 (3)	0.02	0.45	1.41	2.80	4.63	6.77	9.92	13.6	18.2	21.7
	100 (4)	0.02	0.41	1.27	2.52	4.18	6.11	8.95	12.3	16.4	19.6
50 (2)	50 (2)	0.02	0.70	2.64	4.90	9.32	15.5	22.2	32.1	47.2	61.6
60EV	80 (3)	0.02	0.57	2.16	4.02	7.64	12.7	18.2	26.3	38.7	50.5
	100 (4)	0.02	0.52	1.95	3.63	6.90	11.5	16.4	23.8	34.9	45.6
80 (3)	80 (3)	0.02	0.75	2.68	6.00	10.2	16.9	24.5	33.9	44.8	54.2
30EV	100 (4)	0.02	0.54	1.93	4.32	7.34	12.2	17.6	24.4	32.3	39.0
	150 (6)	0.02	0.41	1.47	3.30	5.61	9.30	13.5	18.6	24.6	29.8
80 (3)	80 (3)	0.02	0.95	4.25	10.1	18.6	29.4	46.3	**67.2**	94.4	124.6
60EV	100 (4)	0.02	0.68	3.06	7.27	13.4	21.2	33.3	48.4	68.0	89.7
	150 (6)	0.02	0.52	2.34	5.56	10.2	16.2	25.5	37.0	51.9	68.5
100 (4)	100 (4)	0.02	0.80	3.59	8.50	16.1	26.8	40.2	56.6	72.5	89.8
30EV	150 (6)	0.02	0.52	2.33	5.53	10.5	17.4	26.1	36.8	47.1	58.4
	200 (8)	0.02	0.44	1.97	4.68	8.86	14.7	22.1	31.1	39.9	49.4
	100 (4)	0.02	0.90	5.69	15.4	28.8	48.6	73.4	107.0	150.7	200.0
100 (4)	150 (6)	0.02	0.59	3.70	10.0	18.7	31.6	47.7	69.6	98.0	130.0
60EV	200 (8)	0.02	0.50	3.13	8.47	15.8	26.7	40.4	58.9	82.9	110.0
R_M		0.96	0.95	0.94	0.93	0.92	0.90	0.88	**0.86**	0.82	0.75

Note: C_v is defined as the flow of liquid in gallons per minute through a valve with a pressure drop of 1 psi across the valve.
Source: Table condensed from Worchester Controls "Series CPT Characterized Seat Control Valve", PB-V-3, Supplement 1.

40 mm pipe:

$$t_m = \frac{(0.0896\ MPa)(50\ mm)}{2[(110\ MPa)(1.0) + (0.0896\ MPa)(0.4)]} + 2\ mm = 2.02\ mm$$

The commercial wall thickness tolerance for seamless rolled pipe is +0, -12½%.

$$t_{NOM} = \frac{2.02\ mm}{1.0 - 0.125} = 2.3\ mm$$

Nominal 40 mm pipe has a thickness of 5 mm; therefore, the 40 mm pipe section satisfies pressure intergrity.

LOADS

Step 1. Pressure - See the pressure integrity calculations for the design pressure.

Step 2. Weight - The 80-INF-1500 dead weight is strictly the piping. 80-INF-1500 will not be insulated because it will be under continuous use. Because the piping section will be continuously full, the weight of the fluid will be determined as part of the dead weight.

$$W = W_P + W_L = A_P\ \gamma_P + \frac{\pi}{4}\ D_i^2\ \gamma_L$$

From a lined piping manufacturer, $(A_P)(\gamma_P)$ = 133 N/m for 80 mm lined piping and 67.1 N/m for 40 mm lined piping.

80 mm pipe:

$$W_{80} = 133\ N/m + \frac{\pi}{4}\ 71.1\ mm^2\ (9781\ N/m^3)\ x\ (10^{-6} m^2/mm^2) = 172\ N/m;\ uniformly\ distributed$$

40 mm pipe:

$$W_{40} = 67.1\ N/m + \frac{\pi}{4}\ 31.9\ mm^2\ (9781\ N/m^3)\ x\ (10^{-6} m^2/mm^2) = 74.9\ N/m;\ uniformly\ distributed$$

Step 3. Wind - From TI 809-01, the basic wind speed is 40.2 m/s. The plant is located in an area with exposure C (open terrain with scattered obstructions having heights less than 10 m) so a gust factor of 33% is added to the basic wind speed to determine the design wind speed, V_{dw}.

$$V_{dw} = (40.2\ m/s)\ (1.33) = 53.5\ m/s$$

$$(or\ 192.6\ km/hr, > minimum\ of\ 161\ km/hr)$$

80 mm pipe:

Ref. p. 2-7.

$$R_{e80} = C_{W2}\ V_W\ D_o = 6.87\ (53.5\ m/s)\ (90\ mm) = 3.3\ x\ 10^4$$

Using the R_e value in the ASCE 7 drag coefficient chart and assuming an infinite circular cylinder (i.e., L:D > 5:1), C_D = 1.21.

Ref. p. 2-7.

$$F_{W80} = C_{W1}\ V_W^2\ C_D\ D_o = (2.543 x 10^{-6})(53.5\ m/s)^2(1.21)[90\ mm + 2(0)] = 0.79\ N/m$$

40 mm pipe:

Ref. p. 2-7.

$$R_{e40} = C_{W2}\ V_W\ D_o$$

$$= 6.87\ (53.5\ m/s)\ (50\ mm) = 1.8\ x\ 10^4$$

Using the R_e value in the ASCE 7 drag coefficient chart and assuming an infinite circular cylinder (i.e., L:D > 5:1), C_D = 1.21.

Ref. p. 2-7.

$$F_{W40} = C_{W1}\ V_W^2\ C_D\ D_o$$

$$= (2.543 x 10^{-6})(53.5\ m/s)^2 (1.21)[50\ mm + 2(0)]$$

$$= 0.44\ N/m$$

The design wind loads are uniformly distributed horizontally (i.e., perpendicular to the weight load).

Step 4. Snow - From TI 809-01, the basic snow load is 239 kPa.

80 mm pipe:

Ref. p. 2-8.

$$W_{s80} = \frac{1}{2}\ n\ D_o\ S_L$$

$$= \frac{1}{2}\ (10^{-3}\ m/mm)\ [90\ mm + 2(0)]\ (239\ kPa)$$

$$= 10.8\ N/m$$

40 mm pipe:

Ref. p. 2-8.

$$W_{s40} = \frac{1}{2}\ n\ D_o\ S_L$$

$$= \frac{1}{2}\ (10^{-3}\ m/mm)\ [50\ mm + 2(0)]\ (239\ kPa)$$

$$= 5.98\ N/m$$

The design snow loads are uniformly distributed and additive to the weight.

Step 5. Ice - No data is readily available; therefore, assume a maximum buildup of 12.5 mm.

80 mm pipe:

Ref. p. 2-8.

$$W_{I80} = \pi\ n_3\ S_I\ t_I\ (D_o + t_I) = \pi\ (10^{-6} m^2/mm^2)\ x$$

$$(8820\ N/m^3)(12.5\ mm)(90 + 12.5\ mm)$$

$$= 35.5\ N/m$$

40 mm pipe:

Ref. p. 2-8.

$$W_{I40} = \pi\ n_3\ S_I\ t_I\ (D_o + t_I) = \pi\ (10^{-6} m^2/mm^2)\ x$$

$$(8820\ N/m^3)(12.5\ mm)(50 + 12.5\ mm)$$

$$= 21.6\ N/m$$

The design ice loads are uniformly distributed and additive to the weight.

Step 6. Seismic - From TM 5-809-10, the facility is located in a seismic zone 0; therefore, the seismic loading is not applicable.

Step 7. Thermal - Thermal loads will be examined under the stress analysis. The coefficient of thermal expansion = 1.11×10^{-5} mm/mm-°C over the range 16 to 46 °C.

STRESS ANALYSIS

Step 1. Internal Stresses - 80-INF-1500 meets the pressure integrity requirements; therefore, the limits of stress due to internal pressure are satisfied.

Step 2. External Stresses - For sustained loads, the sum of the longitudinal stresses must be less than the allowable stress at the highest operating temperature:

Ref. p. 3-17.

$$\Sigma\ S_L \leq S_h;$$

and for occasional loads, the sum of the longitudinal stresses due to both sustained and occasional loads must be less than 1.33 S_h:

$$\Sigma S'_L \leq 1.33 \ S_h;$$

To determine the longitudinal stress due to uniformly distributed loads, the support spans and spacing must first be determined. Note that because the liner does not add structural strength, the liner thickness is not included as part of D_i for the purposes of calculating support spans.

80 mm pipe:

Ref. p. 3-25.

$$Z_{80} = \frac{\pi}{32} \frac{D_o^4 - D_i^4}{D_o}$$

$$= \frac{\pi}{32} \frac{(90 \ mm)^4 - (80 \ mm)^4}{(90 \ mm)}$$

$$= 2.69 \ x \ 10^4 \ mm^3$$

It is assumed that snow and ice will not occur concurrently and since the ice loading is greater than the snow loading, the sustained loads are equal to the weight of the piping system and the ice.

$$W'_{80} = 172 \ N/m + 35.5 \ N/m$$

$$= 208 \ N/m \ (10^{-3} \ m/mm) = 0.208 \ N/mm$$

Ref. p. 3-25.

$$l_{80} = n \left(m \ C' \frac{Z \ S}{W} \right)^{0.5} = (10^{-3} \ m/mm) \ x$$

$$\left[(76.8) \left(\frac{5}{48} \right) \frac{(2.69 \ x \ 10^4 \ mm^3) \ (10.3 \ MPa)}{(0.208 \ N/mm)} \right]^{0.5}$$

$$= 3.26 \ m$$

The span length is less than the MSS SP-69 guidance for schedule 40 carbon steel filled with water (3.7 m), so length is acceptable.

40 mm pipe:

Ref. p. 3-25.

$$Z_{40} = \frac{\pi}{32} \frac{D_o^4 - D_i^4}{D_o}$$

$$= \frac{\pi}{32} \frac{(50 \ mm)^4 - (40 \ mm)^4}{(50 \ mm)}$$

$$= 7.25 \ x \ 10^3 \ mm^3$$

It is assumed that snow and ice will not occur concurrently and since the ice loading is greater than the snow loading, the sustained loads are equal to the weight of the piping system and the ice.

$$W'_{40} = 74.9 \ N/m + 21.6 \ N/m$$

$$= 96.5 \ N/m \ (10^{-3} \ m/mm) = 9.65 \ x \ 10^{-2} \ N/mm$$

Ref. p. 3-25.

$$l_{40} = n \left(m \ C' \frac{Z \ S}{W} \right)^{0.5} = (10^{-3} \ m/mm) \ x$$

$$\left[(76.8) \left(\frac{5}{48} \right) \frac{(7.25 \ x \ 10^3 \ mm^3)(10.3 \ MPa)}{(9.65 \ x \ 10^{-2} \ N/mm)} \right]^{0.5}$$

$$= 2.49 \ m$$

The span length is less than the MSS SP-69 guidance for schedule 40 carbon steel filled with water (2.7 m), so length is acceptable.

Therefore, the check for longitudinal stresses from sustained loads is as follows.

80 mm pipe:

Ref. p. 3-17.

$$\Sigma S_{L80} = \frac{P\ D_o}{4\ t} + 0.1 \frac{W\ L^2}{n\ Z}$$

$$= \frac{(0.0896\ MPa)(90\ mm)}{4\ (5\ mm)} + 0.1\ \frac{(172\ N/m)(3.26\ m)^2}{(10^{-3} m/mm)(2.69\ x\ 10^4 mm^3)} = 6.6\ MPa$$

40 mm pipe:

Ref. p. 3-17.

$$\Sigma S_{L40} = \frac{P\ D_o}{4\ t} + 0.1 \frac{W\ L^2}{n\ Z}$$

$$= \frac{(0.0896\ MPa)(50\ mm)}{4\ (5\ mm)} + 0.1\ \frac{(74.9\ N/m)(1.7\ m)^2}{(10^{-3} m/mm)(7.25\ x\ 10^3 mm^3)} = 2.9\ MPa$$

From ASME B31.3, Table A-1, S_h = 110 MPa. For both pipes, $\Sigma S_L \leq S_h$; therefore, the pipes are acceptable for sustained loads.

Assuming that snow and ice will not occur simultaneously and ignoring the wind load (small and horizontal to the snow/ice load), the ice load will be the worst case and the check for occasional loads is as follows.

80 mm pipe:

Ref. p. 3-17.

$$\Sigma S'_{L80} = \Sigma S_{L80} + 0.1\ \frac{W\ L^2}{n\ Z} = 6.6\ MPa + 0.1\ \frac{(35.5\ N/m)(3.26\ m)^2}{(10^{-3} m/mm)(2.69\ x\ 10^4 mm^3)} = 8.0\ MPa$$

40 mm pipe:

Ref. p. 3-17.

$$\Sigma S'_{L40} = \Sigma S_{L40} + 0.1\ \frac{W\ L^2}{n\ Z} = 2.9\ MPa + 0.1\ \frac{(21.6\ N/m)(1.7\ m)^2}{(10^{-3} m/mm)(7.25\ x\ 10^3 mm^3)} = 3.8\ MPa$$

$$1.33\ S_h = 1.33\ (110\ MPa) = 146\ MPa$$

For both pipes, $\Sigma S'_L \leq 1.33 S_h$; therefore, the pipes are acceptable for the anticipated occasional loads.

Step 3. To ensure that piping systems have sufficient flexibility to prevent these failures, ASME B31.3 requires that the displacement stress range does not exceed the allowable displacement stress range. Due to the length of the 40 mm pipe section, flexibility is not a factor. Therefore, only the flexibility of the 80 mm pipe section will be checked. From ASME B31.3, Table 302.3.5 and with the assumption that the total process cycles over the process life will be less than 7000, f = 1.0. From ASME B31.1, Table A-1, $S_c = S_h$ = 110 MPa.

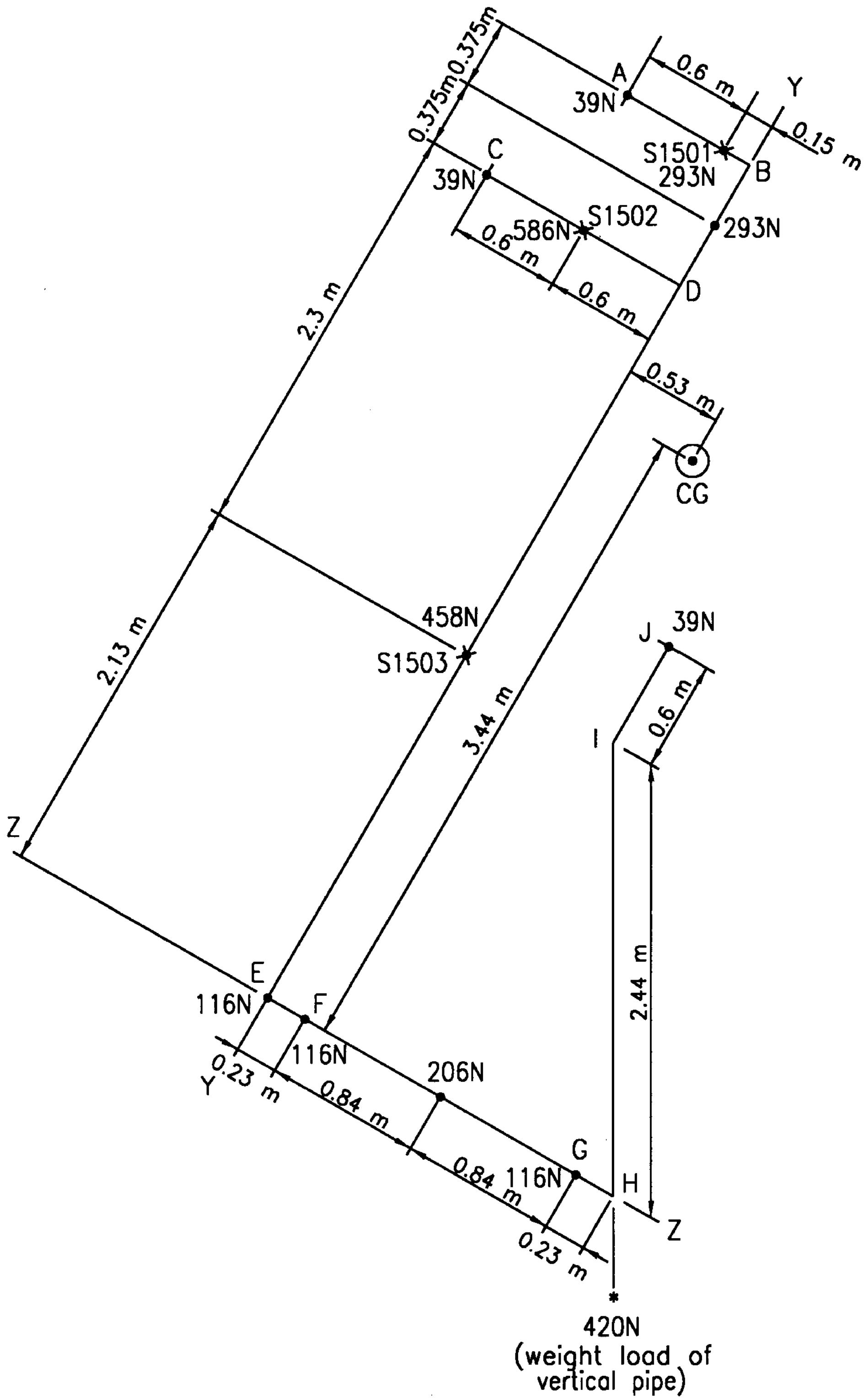
Ref. p. 3-18.

$$S_E \leq S_A;\ and\ S_A = f\ [1.25\ (S_c + S_h) - S_L]$$

$$S_A = 1.0[(1.25)(110\ MPa + 110\ MPa) - 7\ MPa]$$

$$= 268\ MPa;\ therefore,\ S_E \leq 268\ MPa$$

The center of gravity is located to review the stability of the system with respect to the fittings and equipment loads.


0.375m
0.375m
A
39N
0.6 m
Y
0.15 m
S1501
293N
B
C
39N
586N
S1502
293N
0.6 m
0.6 m
D
2.3 m
0.53 m
CG
458N
S1503
2.13 m
3.44 m
J
39N
0.6 m
I
Z
2.44 m
E
116N
F
116N
206N
Y
0.23 m
0.84 m
0.84 m
G
116N
H
Z
0.23 m
420N
(weight load of
vertical pipe)

Sketch C-3

Referencing Sketch C-3:
x = support location (S1501 supports a check valve, S1502 supports a check valve and a gate valve, and S1503 supports the control valve).
! = component load
u = center of gravity

The loads and their locations are as follows:

A - 39 N
S1501 - 293 N
BD - 293 N
C - 39 N
S1502 - 586 N
S1503 - 458 N
E - 116 N
F - 116 N
FG - 206 N
G - 116 N
H - 420 N
J - 39 N.

Table C-7 contains the results of the moment calculations. The center of gravity of the piping section is behind S1503; therefore, 2 more supports are needed for stability. Locate S1504 and S1505 at points F and G respectively. S1505 supports the vertical run and keeps the load off of the equipment flange.

Table C-7
Line 80-INF-1500 Moments

moment about axis y-y			**moment about axis z-z**		
N	m	N-m	N	m	N-m
39	-0.75	-29.3	39	0.6	23.4
293	-0.15	-44.0	103	0.3	30.9
129	-0.375	-48.4	39	5.18	202
39	-1.2	-46.8	293	5.18	1520
586	-0.6	-352	129	5.18	668
206	-0.6	-124	293	4.8	1410
39	2.14	83.5	39	4.43	173
103	2.14	220	586	4.43	2600
420	2.14	899	206	4.43	913
116	1.91	222	891	2.59	2710
206	1.07	220	458	2.13	976
116	0.23	26.7			
367	1.07	393			
2660		1420	3080		10600

$$\frac{1,420\ N\text{-}m}{2,660\ N} = 0.53\ m\ \text{from}\ y\text{-}y;$$

$$\frac{10,600\ N\text{-}m}{3,080\ N} = 3.44\ m\ \text{from}\ z\text{-}z.$$

The thermal expansion deflections are determined based on: 1) the manufacturer of the air stripper, P1600, has indicated that a 1.6 mm upward movement of the flange mating at point J will occur when operating conditions are established; 2) the flanges at points A and C mate with pumps and are not subject to movements; 3) support S1505, located at point G supports piping section H-I-J and will prevent vertical deflection at point H; and 4) given that the piping system will be installed at 21°C, the thermal expansion of the piping will be:

$$\Delta L = (1.11\ x\ 10^{-5}\ mm/mm\text{-}°C)\ x$$

$$(1,000\ mm/m)(46°C - 21°C) = 0.278\ mm/m.$$

Sketch C-4 depicts the approximate deflections that will occur. These deflections are:

- AB will deflect out at point B,(0.75 m) (0.278 mm/m) = 0.21 mm
- CD will deflect out at point D,(1.2 m) (0.278 mm/m) = 0.33 mm
- BE will deflect out at point E,(5.18 m) (0.278 mm/m) = 1.4 mm
- EH will deflect out at each end,[(0.5)(2.14 m)] (0.278 mm/m) = 0.30 mm
- HI will deflect up at point I,(2.44 m) (0.278 mm/m) = 0.68 mm
- IJ will deflect out at point I,(0.6 m) (0.278 mm/m) = 0.17 mm

From beam calculations,

1) for sections BE and EH:

$$M = \frac{3\ E\ I\ y}{a\ (l + a)}\ (n)$$

where:
a_{BE} = the length from S1503 to point E
a_{EH} = the length from S1504 to point E
n = 10^{-9} m^3/mm^3
E = 2.03 x 10^5 MPa (reference ASME B31.3, Table C-6)

$$I = \frac{\pi}{64}\ [(D_o)^4 - (D_i)^4]$$

$$= \frac{\pi}{64}\ [(90\ mm)^4 - (80\ mm)^4]$$

$$= 1.21\ x\ 10^6\ mm^4$$

2) for sections HI and IJ:

$$M = \frac{3\ E\ I\ y}{L^2}$$

where:
L_{HI} = length of HI
L_{IJ} = length of IJ

The displacement stress is now calculated from the deflections.

Ref. p. 3-18.

$$S_E = (S_b^2 + 4S_t^2)^{0.5}$$

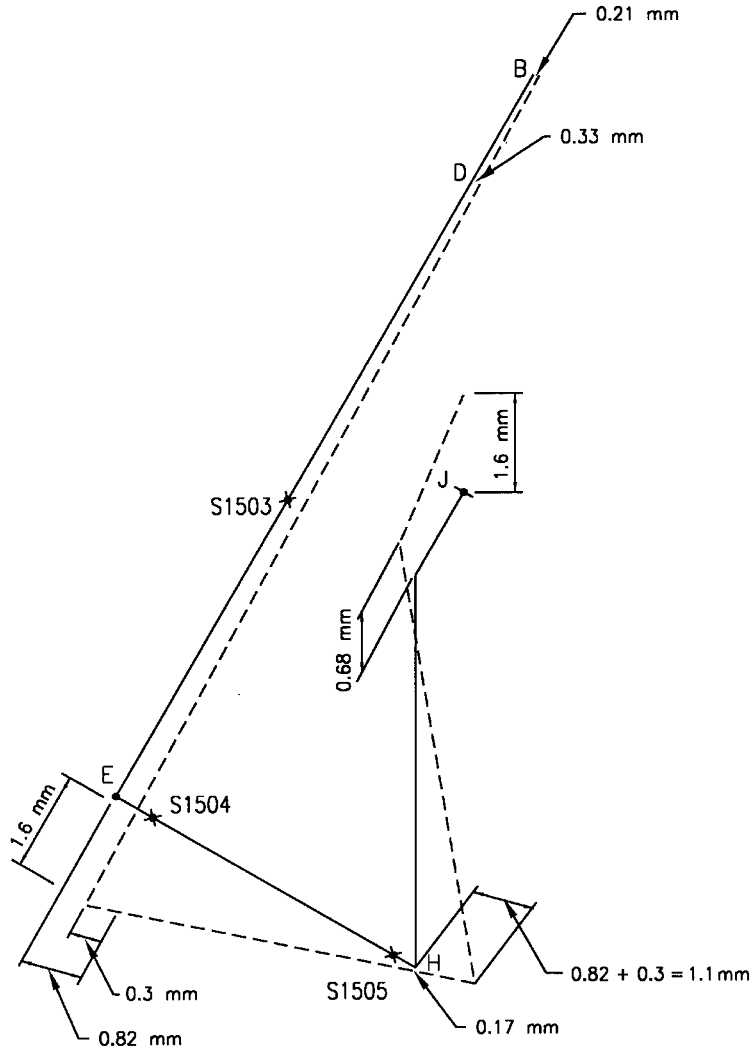
Ref. p. 3-18.

$$S_b = \frac{\left[(i_i\ M_i)^2 + (i_o\ M_o)^2\right]^{0.5}}{Z\ n};\ \text{and}$$

$$S_t = \frac{M_t}{2\ Z\ n}$$

where:
M_o = 0
i_i = i_o = 1.0
Z = 2.69 x 10^4 mm^3 (see page C-17 for calculation)
n = 10^{-3} m/mm

Table C-8 summarizes the results of the calculations for each piping segment.



Sketch C-4

Table C-8
Line 80-INF-1500 Displacement Stresses

Segment	M_i (N-m)	S_b (MPa)	M_t (N-m)	S_t (MPa)	S_E (MPa)
BE	20.0	0.74	0	0	0.74
EH	2395	89.0	42.0	0.78	89.0
HI	21.0	0.78	0	0	0.78
IJ	1883	70.0	272	5.1	70.7

In all of the piping segments, $S_E < S_A$ (268 MPa); therefore, line 80-INF-1500 satisfies required flexibility constraints.

SUPPORTS

The support spacing and spans were calculated as part of the stress analyses. The types of supports are selected based upon process temperature (see Table 3-8) and application (see Figure 3-2 and MSS SP-69).

Table C-9
Line 80-INF-1500 Supports

Support	Type (MSS SP-58)
S1501	36
S1502	36
S1503	36
S1504	36
S1505	37

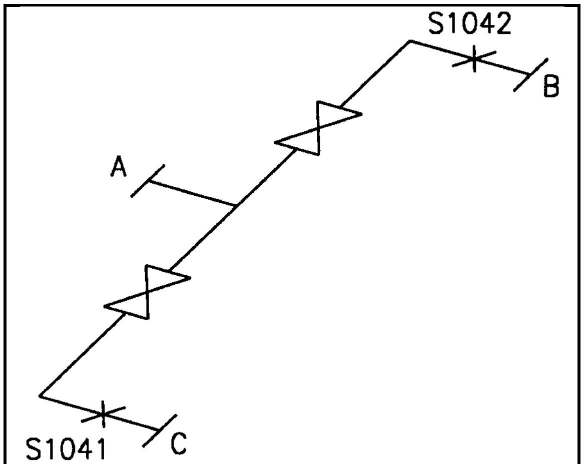
FLANGE CONNECTIONS

From Table 9-2, the flange connections for the thermoplastic lined 80-INF-1500 shall have the following bolting requirements:

80 mm flanges: 4 x 16 mm bolts per flange
ASTM A 193 bolts and nuts, lightly oiled
169 N-m bolt torque for PVDF lined piping.

40 mm flanges: 4 x 14 mm bolts per flange
ASTM A 193 bolts and nuts, lightly oiled
81 N-m bolt torque for PVDF lined piping.

b. Line XXX-IAS-1600
Air Stripper P1600 Effluent to Duplex Pumps P1605/1610



Sketch C-5

Flow is either through A-B or A-C, but not both simultaneously

Maximum Flowrate, Q = 5.36×10^{-3} m^3/s

MATERIAL OF CONSTRUCTION

Line XXX-IAS-1600 handles essentially the same fluid as 80-INF-1500 except that most of the volatile organic solvents have been stripped out. Therefore, for constructability purposes, make the materials of construction identical to 80-INF-1500:

The piping shall be ASTM A 106, Grade A, carbon steel lined with PVDF that has a minimum thickness of 4.45 mm. Because the line is on the influent side of the pumps, the piping shall be full vacuum rated pursuant to ASTM F 423. Joints and fittings shall be chamfered threaded flanges.

The sizing is identical to 80-INF-1500 because the maximum flowrate is identical. Therefore, the line designation is amended to 80-IAS-1600.

The pressure integrity, loads, stress analysis and flexibility are similar to 80-INF-1500; therefore, line 80-IAS-1600 is acceptable.

SUPPORTS

Locate supports as shown (spans are less than the maximum spans calculated for 80-INF-1500); support type as follows.

Table C-10
Line 80-IAS-1600 Supports

Support	Type (MSS SP-58)
S1041	36
S1042	36

FLANGE CONNECTIONS

From Table 9-2, the flange connections for the thermoplastic lined 80-IAS-1600 shall have the following bolting requirements:

80 mm flanges: 4 x 16 mm bolts per flange
ASTM A 193 bolts and nuts, lightly oiled
169 N-m bolt torque for PVDF lined piping.

---

c. Line XXX-IAS-1620
Duplex Pumps P1605/1610 Discharge to Reactor P1620

Referencing Sketch C-6:

Flow is either through A-D or C-D, but not both simultaneously

Maximum Flowrate, Q = 5.36 x 10^{-3} m^3/s

Elevation Change = -0.61 m (= -5.98 kPa)

Total run
= 8.55 m for A-H
= 7.19 m for C-H

Back-pressure from liquid level in Reactor P1620 = 3.65 m (35.8 kPa).

Fittings (identical for either A-H or C-H)
1 swing check valve
2 gate valves (isolation)

MATERIAL OF CONSTRUCTION

Line XXX-IAS-1620 handles essentially the same fluid as 80-IAS-1600. Therefore, for constructability purposes, make the materials of construction identical to 80-INF-1500 and 80-IAS-1600:

The piping shall be ASTM A 106, Grade A, carbon steel lined with PVDF that has a minimum thickness of 4.45 mm. Because the line is on the influent side of the pumps, the piping shall be full vacuum rated pursuant to ASTM F 423. Joints and fittings shall be chamfered threaded flanges.

SIZING/PRESSURE DROP

The sizing is identical to 80-INF-1500 and 80-IAS-1600 because the maximum flowrate is identical: lined D_i = 71.1 mm, V = 1.35 m/s, and D_o = 90 mm (5 mm wall thickness). Therefore, the line designation is amended to 80-IAS-1620.

At 23.9°C, ν = 8.94 x 10^{-7} m^2/s and the Darcy-Weisbach equation is used to calculate the pressure drop through the piping. The worst case pressure drop will be run A-H due to the additional pipe length.

Ref. p. 3-8.

$$h_L = \left[\left(\frac{f\,L}{D_i} + \Sigma K\right)\frac{V^2}{2\,g}\right]$$

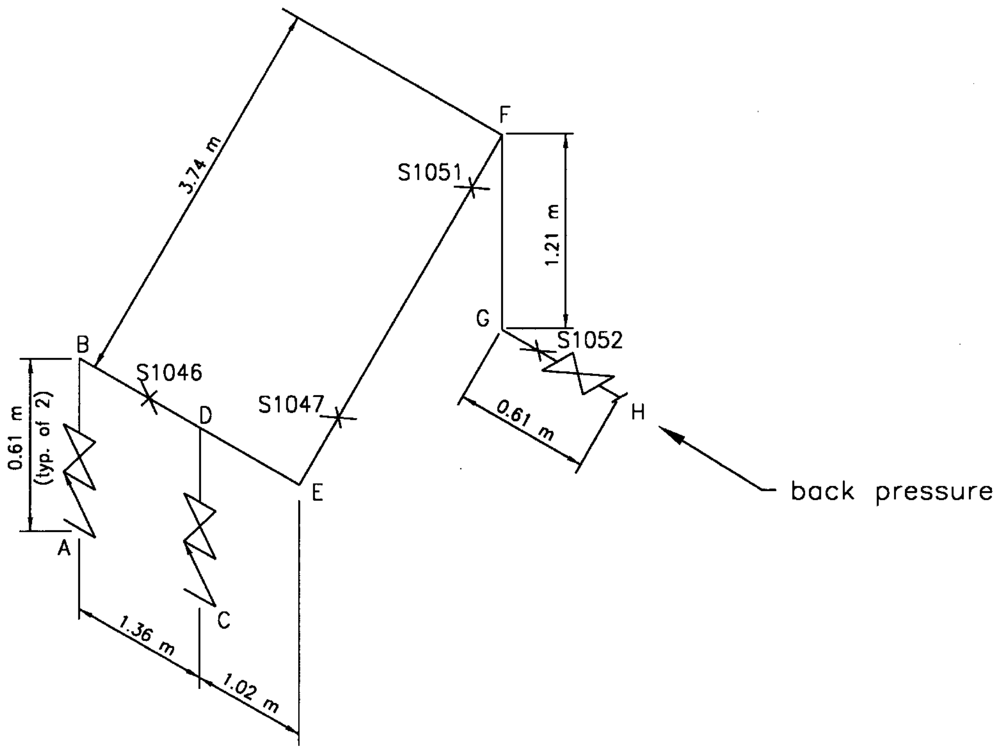
Ref. p. 3-8.

$$R_e = \frac{D_i\,V}{\nu} = \frac{(0.0711\ m)(1.35\ m/s)}{8.94\ x\ 10^{-7}\ m^2/s}$$

$$= 1.1\ x\ 10^5 - turbulent\ flow$$

$$\varepsilon = 0.0015\ mm\ from\ Table\ 3\text{-}1$$

$$\varepsilon/D_i = \frac{0.0015\ mm}{71.1\ mm} = 0.00002$$



Sketch C-6

Therefore, f = 0.028 from the Moody Diagram (Figure 3-1). From Sketch C-6, for run A-H the sum of the minor loss coefficients from Table 3-3:

Table C-11
Minor Losses for 80-IAS-1620: Run A-H

Minor Loss	K
2 gate valves (open)	2(0.2)
1 swing check valve	2.5
4 x 90° elbows	4(0.9)
1 tee-flow through	0.6
1 exit	1.0
ΣK =	8.1

$$h_L = \left(\frac{f\,L}{D_i} + \Sigma K\right)\frac{V^2}{2\,g}$$

$$= \left[\frac{(0.028)(8.55\ m)}{0.0711\ m} + 8.1\right]\frac{(1.35\ m/s)^2}{2\ (9.81\ m/s^2)}$$

$$= 1.1\ m\ (10.8\ kPa)$$

The required pump head is equal to the sum of the elevation change, the piping pressure drop and the back pressure from the reactor P1620.

$$P_{head} = -5.98\ kPa + 10.8\ kPa + 35.8\ kPa$$

$$= 40.6\ kPa\ x\ 1.25\ safety\ factor = 50.8\ kPa$$

PRESSURE INTEGRITY

The design pressure is equal to the required pump head = 50.8 kPa. No potential pressure transients exist. The design external corrosion allowance is 2 mm. Pressure integrity is acceptable if the minimum wall thickness meets ASME 31.3 code. According to ASME B31.3, for ASTM A 106, Grade A pipe, S = 110 MPa, E = 1.0, and y = 0.4.

Ref. p. 3-15.

$$t_m = t + A = \frac{P\ D_o}{2\ (S\ E + P\ y)} + A$$

$$t_m = \frac{(0.0508\ MPa)(90\ mm)}{2[(110\ MPa)(1.0) + (0.0508\ MPa)(0.4)]} + 2\ mm = 2.02\ mm$$

The commercial wall thickness tolerance for seamless rolled pipe is +0, -12½%.

$$t_{NOM} = \frac{2.02\ mm}{1.0 - 0.125} = 2.3\ mm$$

Nominal 80 mm pipe has a thickness of 5 mm; therefore, the 80 mm piping satisfies pressure integrity.

LOADS

Step 1. Pressure - See the pressure integrity calculations for the design pressure.

Step 2. Weight - Load per unit length will be identical to 80-INF-1500; W = 172 N/m (including liquid content).

Step 3. Wind - Load per unit length will be identical to 80-INF-1500; F_w = 0.79 N/m (horizontal).

Step 4. Snow - Load per unit length will be identical to 80-INF-1500; W_s = 10.8 N/m.

Step 5. Ice - Load per unit length will be identical to 80-INF-1500; W_I = 35.5 N/m.

Step 6. Seismic - From TM 5-809-10, the facility is located in a seismic zone 0; therefore, the seismic loading is not applicable.

Step 7. Thermal - Thermal loads will be examined under the stress analysis. The coefficient of thermal expansion = 1.11 x 10^{-5} mm/mm-°C over the range 16 to 46 °C.

STRESS ANALYSIS

Step 1. Internal Stresses - Line 80-IAS-1620 meets the pressure integrity requirements; therefore, the limits of stress due to internal pressure are satisfied.

Step 2. External Stresses - For sustained loads, the sum of the longitudinal stresses must be less than the allowable stress at the highest operating temperature:

Ref. p. 3-17.

$$\Sigma\ S_L \le S_h;$$

and for occasional loads, the sum of the longitudinal stresses due to both sustained and occasional loads must be less than 1.33 S_h:

$$\Sigma\ S'_L \le 1.33\ S_h;$$

To determine the longitudinal stress due to uniformly distributed loads, the support spans and spacing must first be determined: maximum support span length, L, = 3.26 m (see 80-INF-1500 stress analysis). Therefore, the check for longitudinal stresses from sustained loads is as follows.

Ref. p. 3-25.

$$Z_{80} = \frac{\pi}{32}\ \frac{D_o^4 - D_i^4}{D_o}$$

$$= \frac{\pi}{32}\ \frac{(90\ mm)^4 - (80\ mm)^4}{(90\ mm)}$$

$$= 2.69\ x\ 10^4\ mm^3$$

Ref. p. 3-17.

$$\Sigma S_L = \frac{P\,D_o}{4\,t} + 0.1\frac{W\,L^2}{n\,Z} = \frac{(0.0508 MPa)(90 mm)}{4\,(5 mm)}$$

$$+ 0.1\frac{(172\ N/m)(3.26\ m)^2}{(10^{-3} m/mm)(2.69\ x\ 10^4 mm^3)} = 7.02\ MPa$$

From ASME B31.3, Table A-1, S_h = 110 MPa. For 80-IAS-1620, $\Sigma S_L \leq S_h$; therefore, the pipe is acceptable for sustained loads.

Assuming that snow and ice will not occur simultaneously and ignoring the wind load (small and horizontal to the snow/ice load), the ice load will be the worst case and the check for occasional loads is as follows.

Ref. p. 3-17.

$$\Sigma S'_L = \Sigma S_L + 0.1\ \frac{W\,L^2}{n\,Z} = 7.02\ MPa +$$

$$0.1\ \frac{(35.5\ N/m)(3.26\ m)^2}{(10^{-3} m/mm)(2.69\ x\ 10^4 mm^3)} = 8.42\ MPa$$

For 80-IAS-1620, $\Sigma S'_L \leq 1.33 S_h$; therefore, the pipe is acceptable for the anticipated occasional loads.

Step 3. To ensure that piping systems have sufficient flexibility to prevent failures resulting from displacement strains, ASME B31.3 requires that the displacement stress range does not exceed the allowable displacement stress range. From ASME B31.3, Table 302.3.5 and with the assumption that the total process cycles over the process life will be less than 7000, f = 1.0. From ASME B31.1, Table A-1, $S_c = S_h$ = 110 MPa.

Ref. p. 3-18.

$$S_E \leq S_A;\ and\ S_A = f\ [1.25\ (S_c + S_h) - S_L]$$

$$S_A = 1.0[(1.25)(110\ MPa + 110\ MPa) - 7\ MPa]$$

$$= 268\ MPa;\ therefore,\ S_E \leq 268\ MPa$$

Referencing Sketch C-7:
x = support location
! = component load

The loads and their locations are as follows:

B	- 807 N
D	- 807 N
E	- 116 N
F	- 116 N
G	- 116 N
S1052	- 293 N
H	- 39 N.

Based upon the symmetry of the piping segment, the system is stable with the supports located where shown. Support S1046 supports the two vertical runs AB and CD, and the check valves and gate valve at the pump outlets, and S1052 supports the vertical run FG and keeps that load off of the equipment flange. Supports S1047 and S1051 are needed for stability and to keep the maximum span length within the constraint.

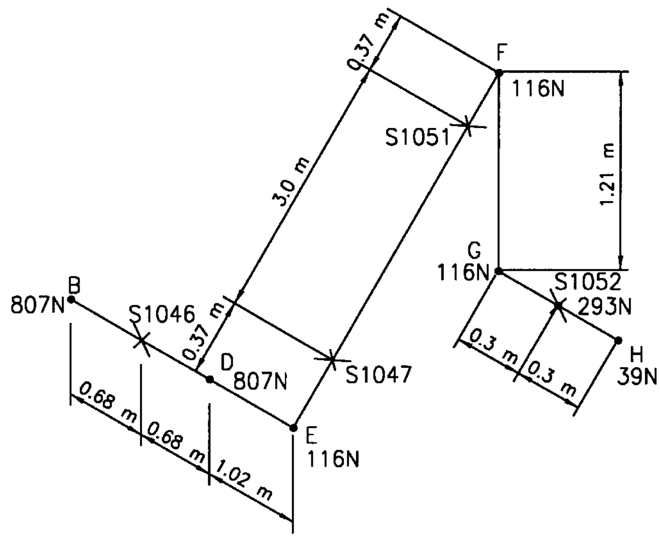
The thermal expansion deflections are determined based on: 1) the assumption that no substantial movement of the flange mating at point H will occur when operating conditions are established; 2) the flanges at points A and C mate with pumps and are not subject to movements; 3) support S1052, will prevent vertical deflection at point G; and 4) given that the piping system will be installed at 21°C, the thermal expansion of the piping will be:

$$\Delta L = (1.11\ x\ 10^{-5}\ mm/mm{-}°C)$$

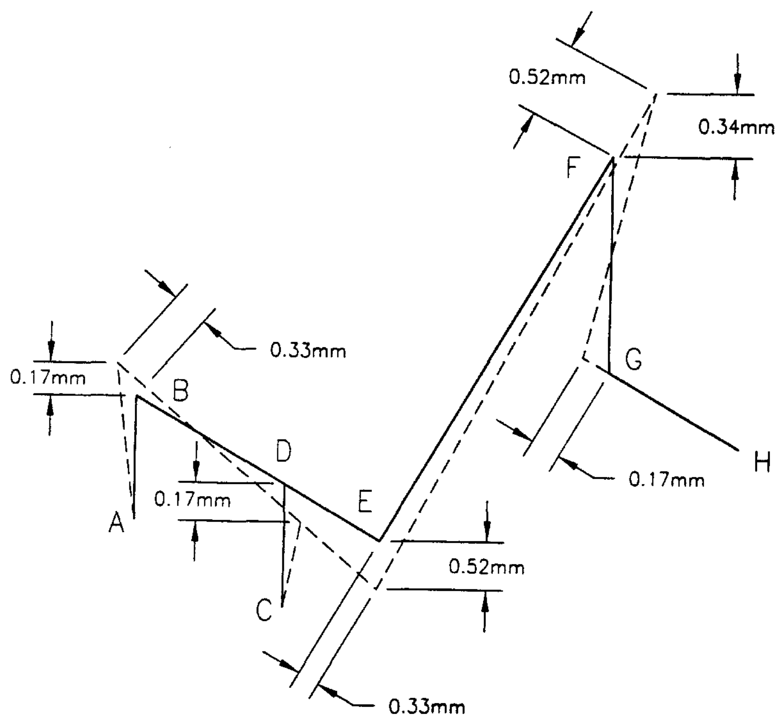
$$x\ (1{,}000\ mm/m)(46°C - 21°C) = 0.278\ mm/m$$

Sketch C-8 depicts the approximate deflections that will occur. These deflections are:

- AB will deflect up at point B, (0.61 m) (0.278 mm/m) = 0.17 mm
- CD will deflect up at point D, (0.61 m) (0.278 mm/m) = 0.17 mm
- BE will deflect out at each end, [(0.5)(2.38 m) (0.278 mm/m) = 0.33 mm
- EF will deflect out at each end, [(0.5)(3.74 m)] (0.278 mm/m) = 0.52 mm
- FG will deflect up at point F, (1.21 m) (0.278 mm/m) = 0.34 mm
- GH will deflect out at point G, (0.61 m) (0.278 mm/m) = 0.17 mm



Sketch C-7



Sketch C-8

From beam calculations,

1) for sections BE (M_o caused) and EF (M_o and M_i caused):

$$M = \frac{3\ E\ I\ y}{a\ (l + a)}\ (n)$$

where:
a_{BE} = 0.37 m
a_{EH} = 1.7 m
n = 10^{-9} m^3/mm^3
E = 2.03 x 10^5 MPa (reference ASME B31.3, Table C-6)
I = 1.21 x 10^6 mm^4 (see 80-INF-1500 calculations)

2) for sections AB, CD and FG:

$$M = \frac{3\ E\ I\ y}{L^2}$$

where:
L_{AB} = length of AB
L_{CD} = length of CD
L_{FG} = length of FG

The displacement stress is now calculated from the deflections.

Ref. p. 3-18:

$$S_E = (S_b^2 + 4S_t^2)^{0.5}$$

$$S_b = \frac{\left[(i_i\ M_i)^2 + (i_o\ M_o)^2\right]^{0.5}}{Z\ n} \quad and \quad S_t = \frac{M_t}{2\ Z\ n}$$

where:
$i_i = i_o = 1.0$
Z = 2.69 x 10^4 mm3 (see page C-16 for calculation)
n = 10^{-3} m/mm

Table C-12 summarizes the results of the calculations for each piping segment.

In all of the piping segments, SE < SA (268 MPa); therefore, line 80-IAS-1620 satisfies required flexibility constraints.

Table C-12
Line 80-IAS-1620 Displacement Stresses

Segment	M_i (N-m)	M_o (N-m)	S_b (MPa)	M_t (N-m)	S_t (MPa)	S_E (MPa)
AB	654	0	24.3	135	2.51	24.8
CD	277	0	10.3	736	13.7	29.3
BE	67.6	31	2.76	35.8	0.67	3.07
EF	176	181	9.39	0	0	9.39
FG	262	85.6	10.2	0	0	10.2
GH	0	0	0	523	9.72	19.4

SUPPORTS

The support spacing and spans were calculated as part of the stress analyses. The types of supports are selected based upon process temperature (see Table 3-8) and application (see Figure 3-2 and MSS SP-69).

Table C-13
Line 80-IAS-1620 Supports

Support	Type (MSS SP-58)
S1046	38
S1047	38
S1051	38
S1052	37

FLANGE CONNECTIONS

From Table 9-2, the flange connections for the thermoplastic lined 80-IAS-1620 shall have the following bolting requirements:

80 mm flanges: 4 x 16 mm bolts per flange
ASTM A 193 bolts and nuts, lightly oiled
169 N-m bolt torque for PVDF lined piping.

d. Line 100-PRI-1630
Process Flow from Reactor P1620 to Floc Tank P1630

The line is gravity flow. Design in accordance with TI 814-10 Wastewater Collection; Gravity Sewers and Appurtenances.

e. Line 100-EFF-1640
Clarifier P1640 Effluent to Clearwell P1510

The line is gravity flow. Design in accordance with TI 814-10 Wastewater Collection; Gravity Sewers and Appurtenances.

f. Line 80-SLG-1650
Sludge Discharge from Clarifier P1640 to Sludge Pumps

The line is supplied by the process system manufacturer. Provide performance requirements for the piping in the equipment specifications.

g. Line 25-SLG-1651
Sludge Recycle from Sludge Pumps to Reactor P1620

The line is supplied by the process system manufacturer. Provide performance requirements for the piping in the equipment specifications.

h. Line XXX-SLG-1660
Waste Sludge Discharge from Sludge Pumps to Sludge Pit P1450

Referencing Sketch C-9:

Maximum Flowrate, Q = 2.75×10^{-3} m^3/s

Total run = 22.0 m
= 20.3 m below grade

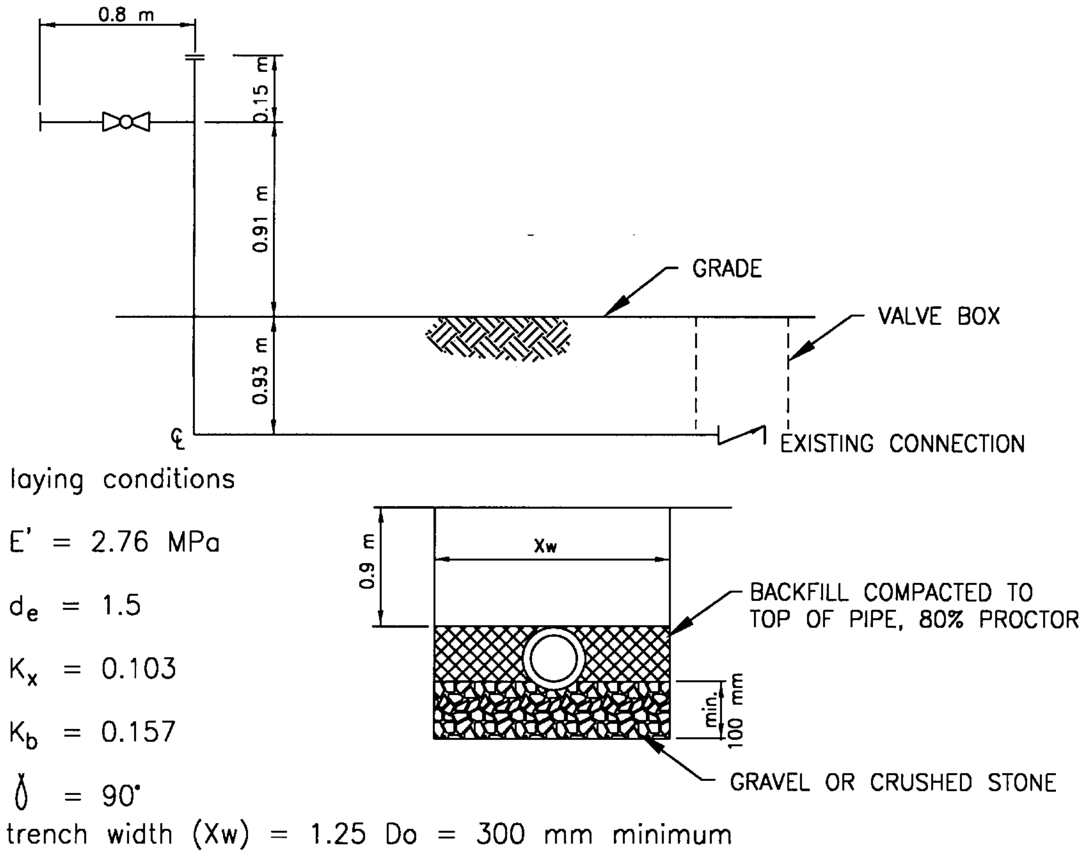
Buried depth = 0.9 m, t.o.p.

Fittings below grade:
3 x 90E elbows
2 x 45E bends
1 x swing check valve

Sludge Pump Head = 250 kPa.

MATERIAL OF CONSTRUCTION

To match other materials at the facility, the piping shall be zinc coated ASTM A 53, Type E, Grade A, carbon steel. Joints shall be buttwelded with chill rings. Below grade fittings shall be forged ASTM A 105M steel of the same thickness of the piping and shall conform to ASME B 16.9, buttweld type. The exception to this shall be the connection to the swing check valve; this end connection shall be a welding neck flange and located in a valve box.



Sketch C-9

The flange connections to the existing sludge line should be field inspected to ensure a compatible connection. The above ground connection to the waste sludge pump, isolation ball valve and clean-out shall also be flanged. All flanges shall be constructed of ASTM A 105M material.

PIPE SIZING/PRESSURE DROP

Step 1. Select pipe size by dividing the volumetric flowrate by the desired velocity (normal service, V = 2.1 m/s).

$$A = \pi \frac{D_i^2}{4} = \frac{Q}{V}$$

$$D_i = \left[\frac{4}{\pi} \frac{(2.75 \; x \; 10^{-3}) \; m^3/s}{2.1 \; m/s}\right]^{0.5} \left(1000 \; \frac{mm}{m}\right)$$

$$= 40.8 \; mm$$

Step 2. From Table 1-1, the size choices are 40 mm or 50 mm. Select 40 mm as the actual pipe size and calculate actual velocity in the pipe.

$$V = \frac{Q}{A} = \frac{Q}{\frac{\pi}{4} D_i^2} = \frac{2.75x10^{-3} m^3/s}{\frac{\pi}{4} \; (0.040 \; m)^2} = 2.19 \; m/s$$

The actual velocity, 2.19 m/s, is within the normal acceptable range, 2.1 ± 0.9 m/s. Therefore, a 40 mm pipe is acceptable, the line designation is amended to 40-SLG-1660, and D_i = 40 mm, D_o = 50 mm, and V = 2.19 m/s.

At 23.9°C, $\nu = 8.94 \times 10^{-7}$ m^2/s and the Darcy-Weisbach equation is used to calculate the pressure drop through the piping.

Ref. p. 3-8.

$$h_L = \left[\left(\frac{f\,L}{D_i} + \Sigma K\right)\frac{V^2}{2\,g}\right]$$

Ref. p. 3-8.

$$R_e = \frac{D_i\,V}{\nu} = \frac{(0.040\ m)(2.19\ m/s)}{8.94\ x\ 10^{-7}\ m^2/s}$$

$$= 9.8\ x\ 10^4 - turbulent\ flow$$

$$\varepsilon = 0.061\ mm\ from\ Table\ 3\text{-}1$$

$$\varepsilon/D_i = \frac{0.061\ mm}{40\ mm} = 0.0015$$

Therefore, f = 0.024 from the Moody Diagram (Figure 3-1). From Sketch C-9, the sum of the minor loss coefficients from Table 3-3:

Table C-14
Minor Losses for 40-SLG-1660

Minor Loss	K
1 ball valve (open)	4.5
1 tee-branch flow	1.8
3 x 90° elbows	3(0.9)
2 x 45° bends	2(0.5)
1 swing check valve	2.5
1 exit	1.0
ΣK =	12.5

$$h_L = \left(\frac{f\,L}{D_i} + \Sigma K\right)\frac{V^2}{2\,g}$$

$$= \left[\frac{(0.024)(22.0\ m)}{0.040\ m} + 12.5\right]\frac{(2.19\ m/s)^2}{2\ (9.81\ m/s^2)}$$

$$= 6.28\ m\ (61.7\ kPa)$$

The maximum waste sludge pump head is 250 kPa which is adequate to overcome the piping pressure drop.

PRESSURE INTEGRITY

The design pressure is equal to the maximum pump head = 250 kPa. No potential pressure transients exist. An external corrosion allowance of 2 mm and an internal erosion allowance of 2 mm are to be designed. Pressure integrity is acceptable if the minimum wall thickness meets ASME 31.3 code. For ASTM A 53, Grade A pipe, ASME B31.3 tables provide S = 110 MPa, E = 1.0, and y = 0.4.

Ref. p. 3-15.

$$t_m = t + A = \frac{P\ D_o}{2\ (S\ E + P\ y)} + A$$

$$t_m = \frac{(0.250\ MPa)(50\ mm)}{2[(110\ MPa)(1.0) + (0.250\ MPa)(0.4)]}$$

$$+ 4\ mm = 4.06\ mm$$

The commercial wall thickness tolerance for seamless rolled pipe is +0, -12½%.

$$t_{NOM} = \frac{4.06\ mm}{1.0 - 0.125} = 4.64\ mm$$

Nominal 40 mm pipe has a thickness of 5 mm; therefore, the 40 mm piping satisfies pressure integrity.

LOADS

Based on the previous calculations for this site, the above ground piping segment will be acceptable for the loads applied. The below grade piping will be subject to internal and external pressure loads.

Step 1. Internal Pressure - See the pressure integrity calculations for the design pressure.

Step 2. External Pressure/Loads - The external pressure/loads will result from the earth load and perhaps a wheel load, a sustained load and an occasional load respectively.

Earth Load:

Ref. p. 2-7.

$$F_E = \frac{\rho H}{a} = \frac{(1{,}922\ kg/m^3)(0.9\ m)}{\left(102\ \frac{kg/m^2}{kPa}\right)} = 17.0\ kPa$$

Wheel Load:

Ref. pp. 2-9 - 2-10.

$$F_W = \frac{C\ R\ P\ F}{b\ D_o} = \frac{(0.098\ /m)(7{,}257\ kg)(1.5)}{\left(0.031\ \frac{kg/m}{kPa}\right)(50\ mm)} = 688\ kPa$$

STRESS ANALYSIS

Step 1. Internal Stresses - Line 40-SLG-1660 meets the pressure integrity requirements; therefore, the limits of stress due to internal pressure are satisfied.

Step 2. External Stresses - For sustained loads, the sum of the longitudinal stresses must be less than the allowable stress at the highest operating temperature:

Ref. p. 3-17.

$$\Sigma S_L \leq S_h$$

For occasional loads, the sum of the longitudinal stresses due to both sustained and occasional loads must be less than 1.33 S_h:

$$\Sigma S'_L \leq 1.33\ S_h$$

With below grade placement, the piping is continuously supported and sustained loads are a result of longitudinal pressure and earth pressure. Therefore, the check for longitudinal stresses from sustained loads is as follows.

Ref. p. 3-17.

$$\Sigma S_L = \frac{P\ D_o}{4\ t} + F_E = \frac{(275\ kPa)(50\ mm)}{4\ (5\ mm)} + 17.0\ kPa = 705\ kPa$$

From ASME B31.3, Table A-1, S_h = 110 MPa. For 40-SLG-1660, $\Sigma S_L \leq S_h$; therefore, the pipe is acceptable for sustained loads.

The only additional occasional load is a wheel load. Therefore, the check for occasional loads is as follows.

Ref. p. 3-17.

$$\Sigma S'_L = \Sigma S_L + F_W = 705\ kPa + 688\ kPa = 1.39\ MPa$$

For 40-SLG-1660, $\Sigma S'_L \leq 1.33 S_h$; therefore, the pipe is acceptable for the anticipated occasional loads.

FLANGE CONNECTIONS

The flange connections will be carbon steel welding neck flanges, raised face, and 1.03 MPa rated (class 150) pursuant to ASME B16.5.

Operating bolt load:

Ref. pp. 3-21 - 3-22.

$$W_{m1} = 0.785\ G^2\ P + (2\ b)(3.14\ G\ m\ P)$$

from ASME B16.5, Table E1, for a flange on a 40 mm pipe, G = 48.7 mm and b = 12.2 mm;
from Table 3-5, m = 0.5 for an elastomeric gasket;

$$W_{m1} = (0.785)(48.7\ mm)^2(0.250\ MPa)$$
$$+ (2)(12.2\ mm)(3.14)(48.7\ mm)(0.5)(0.250\ MPa)$$
$$= 932\ N$$

$$A_{m1} = \frac{W_{m1}}{S_b}$$

from ASME B31.3, Table A-2, for alloy steel ASTM A 193, B7M, S_b = 137 MPa.

$$A_{m1} = \frac{932\ N}{137\ MPa} = 6.80\ mm^2$$

Initial load during assembly:

Ref. p. 3-21.

$$W_{m2} = 3.14\ b\ G\ y$$

from Table 3-5, y = 0; therefore, W_{m2} = 0.

Thus the design is controlled by the operating condition and the bolting is selected to match the required bolt cross-sectional area:

Ref. p. 3-23.

$$A_s = 0.7854 \left(D - \frac{0.9743}{N}\right)^2$$

select 14 mm bolts with a coarse thread (pitch = 1/N = 2)

$$A_s = 0.7854 \left[(14) - \left(\frac{0.9743}{1/2}\right)\right]^2 = 114\ mm^2$$

$A_s > A_{m1}$; therefore, the selected bolting is acceptable.

CATHODIC PROTECTION
(See TM 5-811-7 Electrical Design, Cathodic Protection for Guidance)

40-SLG-1660 is a zinc coated steel pipe installed below grade; therefore, cathodic protection is required. Due to the small size of the structure, galvanic protection is selected. Existing data and the design bases are reviewed to obtain the following design data:

average soil resistivity (p) = 4,500 Ω-cm,
90 % coating (zinc) efficiency is anticipated,
20 year life is desired,
21.5 ma/m^2 is required, and
packaged type magnesium anodes are to be specified.

Step 1. The total area of the underground piping is calculated.

$$A = \pi\ D_o\ L = \pi\ (0.050\ m)(20.3\ m)$$
$$= 3.19\ m^2$$

and the total piping area to be protected is determined.

$$A_T = A\ (0.10) = (3.19\ m^2)\ (0.10) = 0.319\ m^2$$

Step 2. The maximum protective current, I, is:

$$I = (21.5\ ma/m^2)\ A_T$$
$$= (21.5\ ma/m^2)(0.319\ m^2) = 68.6\ ma$$

Step 3. The weight of the anode based on a 20 year life is calculated (see TM 5-811-7, eqn. C-1).

$$W = \frac{Y\ S\ I}{E}$$

$$= \frac{(20\ years)(4.0\ kg/A{-}yr)(0.0069\ A)}{0.50} = 1.10\ kg$$

Step 4. A standard, package anode will be used so this type of anode is reviewed to determine how many anodes are required to satisfy the current. The weight of a standard packaged magnesium anode is 1.4 kg (see TM 5-811-7, Table C-4). The current output to ground is calculated for the anode (see TM 5-811-7, eqn. C-2).

$$i = \frac{C\,f\,y}{P}$$

where:

C = 120,000 for a well coated structure (see TM 5-811-7)
f = 0.53 (see TM 5-811-7, Table C-4)
y = 1.0 (see TM 5-811-7, Table C-5)
P = average soil resistivity = 4,500 Ω-cm

$$i = \frac{C\,f\,y}{P} = \frac{(120{,}000)\ (0.53)\ (1.0)}{4{,}500\ \Omega \cdot cm} = 14.1\ ma$$

Step 5. The number of anodes required is determined (see TM 5-811-7, eqn. C-3).

$$\frac{I}{i} = \frac{6.85\ ma}{14.1\ ma} = 0.49$$

The 1.4 kg anode satisfies the current output requirements. Smaller packages anodes are not readily available.

THRUST BLOCKS
(see TI 814-03, Water Distribution, for guidance)

Thrust blocks are required at the 90° and 45° bends. Concrete thrust blocks will be used so the area of the thrust block will be determined. Because the pipes are already cathodically protected, additional protection or insulation between the concrete and the pipe is not required. The thrust at each bend is calculated first (see TI 814-03, eqn. C-1).

$$T = 2\ \pi \left(\frac{D_o}{2}\right)^2\ P\ \sin\left(\frac{\theta}{2}\right)$$

where:

T = thrust generated, N
D_o = outer diameter of pipe, mm
P = design pressure, MPa
θ = angle of bend, degree

For the 90° bends:

$$T_{90} = 2\ \pi \left(\frac{50\ mm}{2}\right)^2\ (0.250\ MPa)\ \sin\left(\frac{90}{2}\right) = 694\ N$$

For the 45° bends:

$$T_{45} = 2\ \pi \left(\frac{50\ mm}{2}\right)^2\ (0.250\ MPa)\ \sin\left(\frac{45}{2}\right) = 376\ N$$

The area of the thrust block is calculated by (see TI 814-03 equation C-2):

$$A_{TB} = \frac{T}{a}\ f_s$$

where:

A_{TB} = area of thrust block (mm^2)
T = thrust generated, N
a = safe soil bearing value, MPa; assume 20.5 MPa
f_s = safety factor, typically 1.5

For the 90° bends:

$$A_{90TB} = \frac{694\ N}{20.5\ MPa}\ 1.5 = 51\ mm^2$$

For the 45° bends:

$$A_{90TB} = \frac{376\ N}{20.5\ MPa}\ 1.5 = 28\ mm^2$$

i. Line XXX-PYS-101
Chemical Feed from Bulk Polymer to Polymer Day Tank

Referencing Sketch C-10:

Polymer demand = 0.3785 m^3/day;
therefore, assuming a 15 minute fill the maximum flow rate,
$Q = 2.628 \times 10^{-2}$ m^3/min = 4.38×10^{-4} m^3/s

Existing run = 50.0 m
New run = 25.0 m

Maximum elevation change = 3.0 m

Existing polymer pump head = 8.1 m (79.5 kPa)

Fittings:
- 6 x 90° elbows
- 1 branch Tee
- 3 isolation ball valves

MATERIAL OF CONSTRUCTION

The existing polymer line is 25 mm diameter, schedule 80 PVC. The polymer makeup is proprietary but is approximately 99% water. From a site inspection there is no evidence of existing pipe erosion or breakdown. Therefore, the extension or new pipe run will also use 25 mm diameter, schedule 80 PVC with electrical heat tracing and insulation to maintain 20°C (maximum temperature differential will be 45°C).

PIPE SIZING/PRESSURE DROP

Step 1. Using the same size nominal pipe size of the existing pipe results in an actual D_i of 24.3 mm. Therefore, the liquid velocity is:

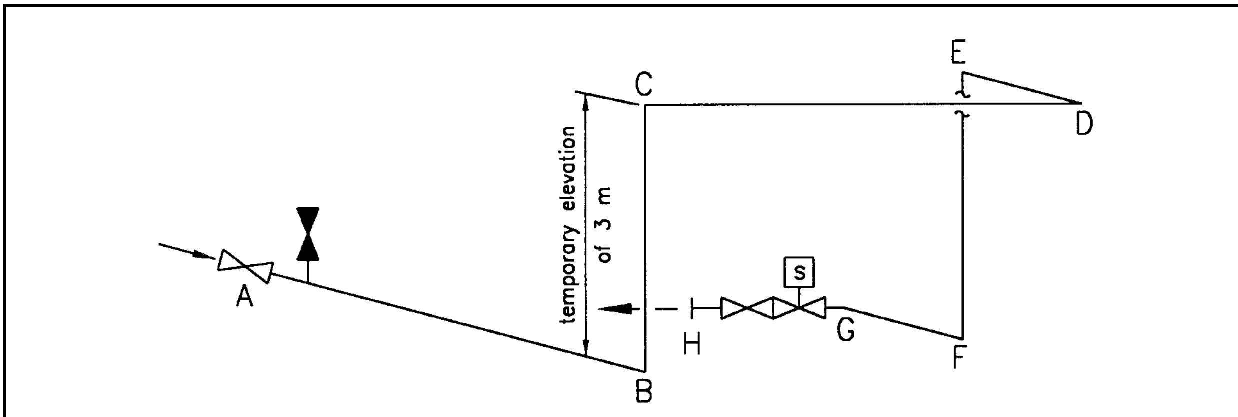
$$V = \frac{Q}{A} = \frac{Q}{\frac{\pi}{4} D_i^2} = \frac{4.38 \; x \; 10^{-4} m^3/s}{\frac{\pi}{4} \; (0.0243 \; m)^2}$$
$$= 0.94 \; m/s$$

The actual velocity, 0.94 m/s, is somewhat slower than the acceptable range, 2.1 ± 0.9 m/s, but the pressure drop will be checked using this velocity due to the limited pump head. The line designation is amended to 25-PYS-101.

Step 2. At 23.9°C, $\nu = 8.94 \times 10^{-7}$ m^2/s and the Darcy-Weisbach equation is used to calculate the pressure drop through the piping.

Ref. p. 3-8.

$$h_L = \left[\left(\frac{f \, L}{D_i} + \Sigma K \right) \frac{V^2}{2 \; g} \right]$$



Sketch C-10

Ref. p. 3-8.

$$R_e = \frac{D_i\ V}{\nu} = \frac{(0.0243\ m)(0.94\ m/s)}{8.94\ x\ 10^{-7}\ m^2/s}$$

$$= 2.56\ x\ 10^4 - turbulent\ flow$$

$$\varepsilon = 0.0015\ mm\ from\ Table\ 3-1$$

$$\varepsilon/D_i = \frac{0.0015\ mm}{24.3\ mm} = 0.00006$$

Therefore, f = 0.024 from the Moody Diagram (Figure 3-1). From Sketch C-10, the sum of the minor loss coefficients from Table 3-3:

Table C-15
Minor Losses for 25-PYS-101

Minor Loss	K
3 x ball valves (open)	3(4.5)
1 tee-flow through	0.6
6 x 90° elbows	6(0.5)
1 exit	1.0
ΣK =	18.1

$$h_L = \left(\frac{f\ L}{D_i} + \Sigma K\right)\frac{V^2}{2\ g}$$

$$= \left[\frac{(0.024)(75.0\ m)}{0.0243\ m} + 18.1\right]\frac{(0.94\ m/s)^2}{2\ (9.81\ m/s^2)}$$

$$= 4.15\ m$$

The total pump head required is the sum of the piping losses, h_L, and the temporary elevation of 3 m over the walkway. Therefore, the total pump head required is 7.15 m and the actual pump head available is 8.1 m. The pipe should not be sized smaller (even though the flow is below the desired range) unless the pump is to be replaced.

PRESSURE INTEGRITY

The design pressure is equal to the required pump head = 79.5 kPa. A pressure transients exists due to potential water hammer conditions from the solenoid valve at the tank inlet. Therefore, the transient will be minimized by having the valve be a "slow-opening" valve.

Ref. p. 3-6.

$$V_w = \left(\frac{E_s}{n_1\ \rho}\right)^{0.5}$$

$$= \left(\frac{2{,}180\ MPa}{(10^{-6} MPa/Pa)(998.2\ kg/m^3)}\right)^{0.5} = 1{,}478\ m/s$$

and

$$t_c = \frac{2\ L}{V_w} = \frac{2\ (75\ m)}{1{,}478\ m/s} = 0.10\ s$$

A gradual valve closure, t_v, = 20 x t_c = 2 s is to be provided. Therefore, the pressure rise is determined.

Ref. p. 3-6.

$$P_i' = \frac{2\ \rho\ L\ V\ n_1}{t_v} =$$

$$\frac{2\ (998.2\ kg/m^3)(75\ m)(0.94\ m/s)(10^{-3} kPa/Pa)}{2\ s}$$

$$= 70.4\ kPa$$

Because the pressure transient is significant (>10% of the operating pressure), it must be included as part of the design pressure.

$$P = 79.5\ kPa + 70.4\ kPa = 150\ kPa$$

From ASME B31.3, the minimum wall thickness, t_m, for thermoplastic pipe is:

$$t_m = \frac{P\ D_o}{(2\ S + P)}$$

S = hydrostatic design stress = 13.8 MPa (reference ASME B31.3, Table B-1)

$$t_m = \frac{(0.150\ MPa)(24.3\ mm)}{[2\ (13.8\ MPa) + (0.150\ MPa)]} = 0.131\ mm$$

Nominal 25 mm, schedule 80 pipe has a thickness of 4.5 mm; therefore, the 25 mm pipe section satisfies pressure integrity.

LOADS

Step 1. Pressure - See the pressure integrity calculations for the design pressure.

Step 2. Weight - The 25-PYS-101 dead weight is the piping and the insulation. Because the piping section will be continuously full, the weight of the fluid will be determined as part of the dead weight.

The insulation for the piping was selected pursuant to CEGS 15250 to be flexible cellular (elastomeric) foam, 9.525 mm thick and with a specific weight of approximately 314 N/m^3.

$$W = W_P + W_i + W_L$$

$$= A_P\ \gamma_{PVC} + \pi\ \gamma_I\ T_i\ (D_o + T_i\ ) + \frac{\pi}{4}\ D_i^2\ \gamma_L$$

$$W = (4.12\ x\ 10^{-4} m^2)(13{,}517\ N/m^3)$$

$$+ \pi\ (314\ N/m^3)(9.525\ mm)\ x$$

$$(32\ mm + 9.525\ mm)(10^{-6} m^2/mm^2)$$

$$+ \frac{\pi}{4}\ (24.3\ mm)^2 (9{,}795\ N/m^3)(10^{-6} m^2/mm^2)$$

$$= 10.5\ N/m;\ uniformly\ distributed$$

Step 3. Wind - From TI 809-01, the basic wind speed is 40.2 m/s. The plant is located in an area with exposure C (open terrain with scattered obstructions having heights less than 10 m) so a gust factor of 33% is added to the basic wind speed to determine the design wind speed, V_{dw}.

$$V_{dw} = (40.2\ m/s)\ (1.33) = 53.5\ m/s$$

$$(or\ 192.6\ km/hr,\ >\ minimum\ of\ 161\ km/hr)$$

Ref. p. 2-7.

$$R_e = C_{W2}\ V_W\ D_o$$

$$= (6.87)(53.5\ m/s)[32\ mm + 2\ (9.525\ mm)]$$

$$= 1.9\ x\ 10^4$$

Using the R_e value in the ASCE 7 drag coefficient chart and assuming an infinite circular cylinder (i.e., L:D > 5:1), C_D = 1.21.

Ref. p. 2-7.

$$F_W = C_{W1}\ V_W^2\ C_D\ D_o$$

$$= (2.543\ x\ 10^{-6})(53.5\ m/s)^2 (1.21)\ x$$

$$[32\ mm + 2\ (9.525\ mm)] = 0.45\ N/m$$

The design wind loads are uniformly distributed horizontally (i.e., perpendicular to the weight load).

Step 4. Snow - From TI 809-01, the basic snow load is 239 kPa.

Ref. p. 2-8.

$$W_s = \tfrac{1}{2}\, n\, D_o\, S_L$$

$$= \tfrac{1}{2}\,(10^{-3}\ m/mm)[32\ mm + 2\ (9.525\ mm)]\ x\ (239\ kPa) = 6.1\ N/m$$

The design snow loads are uniformly distributed and additive to the weight.

Step 5. Ice - No data is readily available; therefore, assume a maximum buildup of 12.5 mm.

Ref. p. 2-8.

$$W_I = \pi\, n_3\, S_I\, t_I\, (D_o + t_I)$$

$$= \pi\,(10^{-6}\ m^2/mm^2)(8{,}820\ N/m^3)(12.5\ mm)\ x\ [32\ mm + 2\ (9.525\ mm) + 12.5\ mm] = 22.0\ N/m$$

The design ice loads are uniformly distributed and additive to the weight.

Step 6. Seismic - From TM 5-809-10, the facility is located in a seismic zone 0; therefore, the seismic loading is not applicable.

Step 7. Thermal - Thermal loads will be examined under the stress analysis. The coefficient of thermal expansion = (54×10^{-6} mm/mm-°C) (45°C) = 2.43×10^{-3} mm/mm.

STRESS ANALYSIS

Step 1. Internal Stresses - 25-PYS-101 meets the pressure integrity requirements; therefore, the limits of stress due to internal pressure are satisfied.

Step 2. External Stresses - In accordance with ASME B31.3, for thermoplastic piping the sum of the external stresses resulting from loads must be less than 1.33 S_h:

Ref. p. 3-17.

$$\Sigma\, S_L \le 1.33\, S_h$$

From ASME B31.3, Table A-1, S_h = 13.8 MPa.

$$1.33 S_h = 1.33\ (13.8\ MPa) = 18.4\ MPa$$

To determine the longitudinal stress due to uniformly distributed loads such as weight, the support spans and spacing must first be determined. Referring to Figure C-3, Piping Layout Plan, all three chemical feed lines will be run parallel and will be supported on a pipe rack. As the smallest diameter pipe of the three chemical feed lines, 25-PYS-101 will control the support spacing. From manufacturer's data (see Table 5-4), the maximum support spacing, L, for 25 mm PVC pipe is 1.7 m; see Figure C-4, Piping Layout Plan with Support Locations.

Ref. p. 3-17.

$$\Sigma S_L = 0.1\ \frac{W\, L^2}{n\, Z}$$

Ref. p. 3-25.

$$Z = \frac{\pi}{32}\ \frac{D_o^4 - D_i^4}{D_o}$$

$$= \frac{\pi}{32}\ \frac{(32\ mm)^4 - (24.3\ mm)^4}{(32\ mm)} = 2{,}147\ mm^3$$

It is assumed that snow and ice will not occur concurrently and since the ice loading is greater than the snow loading, the sustained loads are equal to the weight of the piping system and the ice.

Ref. p. 3-17.

$$\Sigma S_L = (0.1)\ \frac{[(10.5\ N/m) + (22.0\ N/m)](1.7\ m)^2}{(10^{-3}\ m/mm)(2{,}147\ mm^3)} = 4.4\ MPa$$

For 25-PYS-101, $\Sigma S_L \le 1.33 S_h$; therefore, the system is acceptable for the design stress loading.

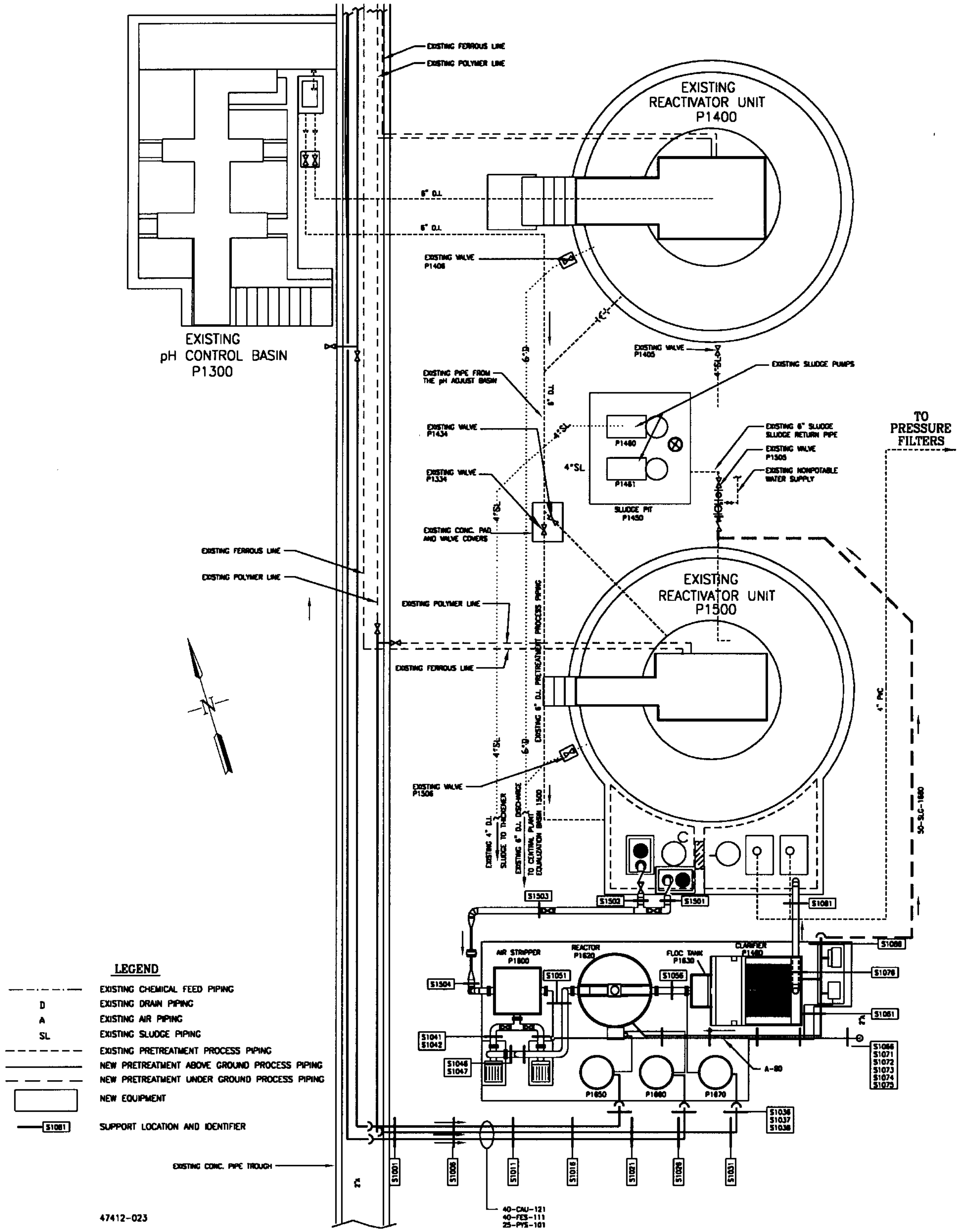
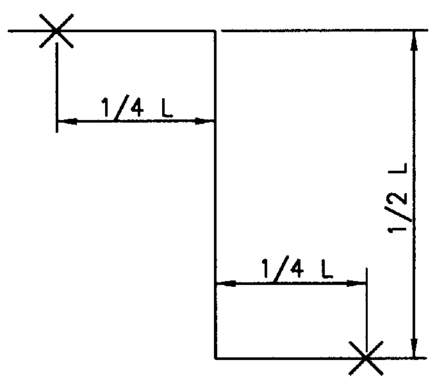


Figure C-4. Piping Layout Plan with Support Locations

Step 3. Stresses are imposed upon the piping system due to thermal expansion and contraction. To ensure that thermoplastic piping systems have sufficient flexibility to prevent these failures, a minimum offset is required between a bend and a restrained anchor. For 25-PYS-101, there are a series of Z-shaped arrangements: A-B-C-D, C-D-E-F, and E-F-G-H; see Sketch C-10.



Sketch C-11

Referencing Sketch C-11, for Z-shapes:

$$L = \frac{1\ m}{1{,}000\ mm}\left(\frac{3\ E\ D_o\ \alpha}{S}\right)^{0.5}$$

where:

L = offset pipe length, m
E = modulus of elasticity = 2,895 MPa
S = allowable stress = 13.8 MPa
D_o = outer pipe diameter = 32 mm
α = thermal expansion coefficient = 2.43 x 10^{-3} mm/mm

For pipe section A-B-C-D with a length of approximately 3 m:

$$L_{ABCD} = \frac{1\ m}{1{,}000\ mm}\ x$$

$$\left(\frac{3(2{,}895MPa)(32mm)[(2.43x10^{-3}\frac{mm}{mm})(3{,}000mm)]}{13.8MPa}\right)^{0.5}$$

$$= 0.38\ m,\ minimum.$$

Since ½ (B-C) = ½ (3 m) > L_{ABCD}, the flexibility of the piping segment is acceptable. The restraints (anchors) should be located at a minimum 1/4 L = 1/4 (0.38 m) = 0.10 m from the bends. That is, a pipe guide should be located at support no. S1006 and another within the existing pipe trench - field check rack location.

For pipe section C-D-E-F with a length of approximately 10.7 m:

$$L_{CDEF} = \frac{1\ m}{1{,}000\ mm}\ x$$

$$\left(\frac{3(2{,}895MPa)(32mm)[(2.43x10^{-3}\frac{mm}{mm})(10{,}700mm)]}{13.8MPa}\right)^{0.5}$$

$$= 0.72\ m,\ minimum.$$

Since ½ (D-E) = ½ (10.7 m) > L_{CDEF}, the flexibility of the piping segment is acceptable. The anchors should be located at a minimum 1/4 L = 1/4 (0.72 m) = 0.36 m from the bends. That is, a pipe guide should be located at support no. S1026 and a vertical guide 0.36 m from bottom of pipe (BOP) on support no. S1038.

For pipe section E-F-G-H with a length of approximately 1.5 m:

$$L_{EFGH} = \frac{1\ m}{1{,}000\ mm}\ x$$
$$\left(\frac{3(2{,}895MPa)(32mm)[(2.43x10^{-3}\frac{mm}{mm})(1{,}500mm)]}{13.8MPa}\right)^{0.5}$$
$$= 0.27\ m,\ minimum.$$

Since ½ (F-G) = ½ (3 m) > L_{EFGH}, the flexibility of the piping segment is acceptable. The anchors should be located at a minimum 1/4 L = 1/4 (0.27 m) = 0.07 m from the bends. That is, relocate the vertical pipe guide established on S1038 at 0.36 m BOP down to ½ the vertical run, ½ (2 m) = 1 m BOP. Also locate the support for the solenoid valve at 0.07 m from the bend at G.

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j. Line 15-PYS-102
Chemical Feed from Polymer Day Tank to Polymer Controlled Volume Pump

The controlled volume pump has a 15 mm female taper threaded connection. The piping from the pump to the process injection point is supplied by the process unit manufacturer and is 15 mm SAE 100R7 hose. Therefore, 15-PYS-102 is selected to be identical to the process hose: 15 mm SAE 100R7 hose (thermoplastic tube, synthetic-fiber reinforcement, thermoplastic cover) with 15 mm male taper threaded end connections, built-in fittings. Minimum hose length is 3 m. Ensure that the process engineer, or the engineer that is specifying the day tanks, designs the polymer day tank with the proper discharge port - 15 mm taper threaded nozzle, female.

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k. Line XXX-FES-111
Chemical Feed from Bulk Ferrous Sulfate to Ferrous Sulfate Day Tank

Referencing Sketch C-12:

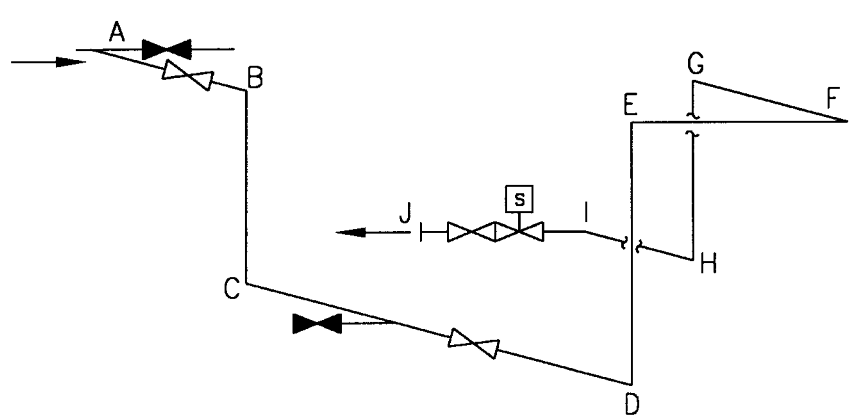
Ferrous sulfate demand = 0.757 m^3/day; therefore, assuming a 15 minute fill the maximum flow rate, Q = 5.05 x 10^{-2} m^3/min = 8.42 x 10^{-4} m^3/s

Existing run = 30.0 m
New run = 50.0 m

Maximum elevation change = -0.5 m (the elevation difference between E and A is 0.5 m down)

Existing ferrous sulfate pump head = 3.05 m (29.9 kPa)

Fittings:
- 8 x 90° elbows
- 1 x Tee, branch flow
- 1 x Tee, flow-through
- 4 x isolation ball valves



Sketch C-12

MATERIAL OF CONSTRUCTION

The existing ferrous sulfate line is 40 mm diameter, schedule 80 PVC. The ferrous sulfate is 20% solution with a specific gravity, s.g. = 1.18. Ferrous sulfate is compatible with PVC and from a site inspection there is no evidence of existing pipe erosion or breakdown. Therefore, the extension or new pipe run will also use 40 mm diameter, schedule 80 PVC with electrical heat tracing and insulation to maintain 20°C (maximum temperature differential will be 45°C).

PIPE SIZING/PRESSURE DROP

Step 1. Using the same size nominal pipe size of the existing pipe results in an actual D_i of 40 mm. Therefore, the liquid velocity is:

$$V = \frac{Q}{A} = \frac{Q}{\frac{\pi}{4} D_i^2}$$

$$= \frac{8.42 \ x \ 10^{-4} \ m^3/s}{\frac{\pi}{4} (0.040 \ m)^2} = 0.67 \ m/s$$

The actual velocity, 0.67 m/s, is somewhat slower than the acceptable range, 2.1 ± 0.9 m/s, but the pressure drop will be checked using this velocity due to the limited pump head. The line designation is amended to 40-FES-111.

Step 2. At 23.9°C, $\nu = 1.05 \times 10^{-6}$ m²/s and the Darcy-Weisbach equation is used to calculate the pressure drop through the piping.

Ref. p. 3-8.

$$h_L = \left[\left(\frac{f\ L}{D_i} + \Sigma K\right) \frac{V^2}{2\ g}\right]$$

Ref. p. 3-8.

$$R_e = \frac{D_i\ V}{\nu} = \frac{(0.040\ m)(0.67\ m/s)}{1.05\ x\ 10^{-6}\ m^2/s}$$

$$= 2.55\ x\ 10^4 - turbulent\ flow$$

$$\varepsilon = 0.0015\ mm\ from\ Table\ 3\text{-}1$$

$$\varepsilon/D_i = \frac{0.0015\ mm}{40\ mm} = 0.00004$$

Therefore, f = 0.024 from the Moody Diagram (Figure 3-1). From Sketch C-12, the sum of the minor loss coefficients from Table 3-3:

Table C-16
Minor Losses for 40-FES-111

Minor Loss	K
4 x ball valves (open)	4(4.5)
1 tee-branch flow	1.8
1 tee-flow through	0.6
8 x 90° elbows	8(0.5)
1 exit	1.0
ΣK =	25.4

$$h_L = \left(\frac{f\ L}{D_i} + \Sigma K\right) \frac{V^2}{2\ g}$$

$$= \left[\frac{(0.024)(80.0\ m)}{0.040\ m} + 25.4\right] \frac{(0.67\ m/s)^2}{2\ (9.81\ m/s^2)}$$

$$= 1.68\ m$$

The total pump head required is the sum of the piping losses, h_L, and the elevation gain of - 0.5 m. Therefore, the total pump head required is 1.98 m + (-0.5 m) = 1.48 m and the actual pump head available is 3.05 m. The pipe should not be sized smaller (even though the flow is below the desired range) unless the pump is to be replaced.

PRESSURE INTEGRITY

The design pressure is equal to the required pump head = 29.9 kPa. A pressure transients exists due to potential water hammer conditions from the solenoid valve at the tank inlet. Therefore, the transient will be minimized by having the valve be a “slow-opening” valve.

Ref. p. 3-6.

$$V_w = \left(\frac{E_s}{n_1\ \rho}\right)^{0.5}$$

$$= \left(\frac{2{,}180\ MPa}{(10^{-6} MPa/Pa)(1{,}178\ kg/m^3)}\right)^{0.5} = 1{,}360\ m/s$$

and

$$t_c = \frac{2\ L}{V_w} = \frac{2\ (80\ m)}{1{,}360\ m/s} = 0.12\ s$$

A gradual valve closure, t_v, of 2 s is to be provided. Therefore, the pressure rise is determined.

Ref. p. 3-6.

$$P_i' = \frac{2\ \rho\ L\ V\ n_1}{t_v} =$$

$$\frac{2\ (1{,}178\ kg/m^3)(80\ m)(0.67\ m/s)(10^{-3} kPa/Pa)}{2\ s}$$

$$= 63.1\ kPa$$

Because the pressure transient is significant (>10% of the operating pressure), it must be included as part of the design pressure.

$$P = 29.9\ kPa + 63.1\ kPa = 93\ kPa$$

From ASME B31.3, the minimum wall thickness, t_m, for thermoplastic pipe is:

$$t_m = \frac{P\ D_o}{(2\ S + P)}$$

S = hydrostatic design stress = 13.8 MPa (reference ASME B31.3, Table B-1)

$$t_m = \frac{(0.093\ MPa)(40\ mm)}{[2\ (13.8\ MPa) + (0.093\ MPa)]}$$

$$= 0.134\ mm$$

Nominal 40 mm, schedule 80 pipe has a thickness of 5.1 mm; therefore, the 40 mm pipe section satisfies pressure integrity.

LOADS

Step 1. Pressure - See the pressure integrity calculations for the design pressure.

Step 2. Weight - The 40-FES-111 dead weight is the piping and the insulation. Because the piping section will be continuously full, the weight of the fluid will be determined as part of the dead weight.

The insulation for the piping was selected pursuant to GS 15250 to be flexible cellular (elastomeric) foam, 9.525 mm thick and with a specific weight of approximately 314 N/m^3.

$$W = W_P + W_i + W_L$$

$$= A_P\ \gamma_{PVC} + \pi\ \gamma_I\ T_i\ (D_o + T_i) + \frac{\pi}{4}\ D_i^2\ \gamma_L$$

$$W = (6.89\ x\ 10^{-4} m^2)\ (13{,}517\ N/m^3)$$
$$+ \pi\ (314\ N/m^3)(9.525\ mm)\ x$$
$$(50\ mm + 9.525\ mm)(10^{-6} m^2/mm^2)$$
$$+ \frac{\pi}{4}\ (40\ mm)^2(11{,}560\ N/m^3)(10^{-6}\ m^2/mm^2)$$
$$= 24.4\ N/m;\ uniformly\ distributed$$

Step 3. Wind - From TI 809-01, the basic wind speed is 40.2 m/s. The plant is located in an area with exposure C (open terrain with scattered obstructions having heights less than 10 m) so a gust factor of 33% is added to the basic wind speed to determine the design wind speed, V_{dw}.

$$V_{dw} = (40.2\ m/s)\ (1.33) = 53.5\ m/s$$
$$(or\ 192.6\ km/hr, > minimum\ of\ 161\ km/hr)$$

Ref. p. 2-7.

$$R_e = C_{W2}\ V_W\ D_o$$
$$= (6.87)(53.5\ m/s)[50\ mm + 2\ (9.525\ mm)]$$
$$= 2.54\ x\ 10^4$$

Using the R_e value in the ASCE 7 drag coefficient chart and assuming an infinite circular cylinder (i.e., L:D > 5:1), C_D = 1.21.

Ref. p. 2-7.

$$F_W = C_{W1}\ V_W^2\ C_D\ D_o$$
$$= (2.543\ x\ 10^{-6})(53.5\ m/s)^2(1.21)\ x$$
$$[50\ mm + 2\ (9.525\ mm)] = 0.61\ N/m$$

The design wind loads are uniformly distributed horizontally (i.e., perpendicular to the weight load).

Step 4. Snow - From TI 809-01, the basic snow load is 239 kPa.

Ref. p. 2-8.

$$W_s = ½\ n\ D_o\ S_L =$$
$$½\ (10^{-3} m/mm)[50\ mm + 2(9.525\ mm)](239\ kPa)$$
$$= 8.25\ N/m$$

The design snow loads are uniformly distributed and additive to the weight.

Step 5. Ice - No data is readily available; therefore, assume a maximum buildup of 12.5 mm.

Ref. p. 2-8.

$$W_I = \pi\ n_3\ S_I\ t_I\ (D_o + t_I)$$
$$= \pi\ (10^{-6} m^2/mm^2)(8{,}820\ N/m^3)(12.5\ mm)\ x$$
$$[50\ mm + 2(9.525\ mm) + 12.5\ mm] = 28.2\ N/m$$

The design ice loads are uniformly distributed and additive to the weight.

Step 6. Seismic - From TM 5-809-10, the facility is located in a seismic zone 0; therefore, the seismic loading is not applicable.

Step 7. Thermal - Thermal loads will be examined under the stress analysis. The coefficient of thermal expansion = (54 x 10^{-6} mm/mm-°C) (45°C) = 2.43 x 10^{-3} mm/mm.

STRESS ANALYSIS

Step 1. Internal Stresses - 40-FES-111 meets the pressure integrity requirements; therefore, the limits of stress due to internal pressure are satisfied.

Step 2. External Stresses - In accordance with ASME B31.3, for thermoplastic piping the sum of the external stresses resulting from loads must be less than 1.33 S_h:

Ref. p. 3-17.

$$\Sigma S_L \leq 1.33\ S_h$$

From ASME B31.3, Table A-1, S_h = 13.8 MPa.

$$1.33 S_h = 1.33\ (13.8\ MPa) = 18.4\ MPa$$

To determine the longitudinal stress due to uniformly distributed loads such as weight, the support spans and spacing must first be determined. Referring to Figure C-3, Piping Layout Plan, all three chemical feed lines will be run parallel and will be supported on a pipe rack. As the smallest diameter pipe of the three chemical feed lines, 40-FES-111 will control the support spacing. From manufacturer's data (see Table 5-4), the maximum support spacing, L, for 40 mm PVC pipe is 1.7 m; see Figure C-4, Piping Layout Plan with Support Locations.

Ref. p. 3-17.

$$\Sigma S_L = 0.1\ \frac{W\ L^2}{n\ Z}$$

Ref. p. 3-25.

$$Z = \frac{\pi}{32}\ \frac{D_o^4 - D_i^4}{D_o}$$

$$= \frac{\pi}{32}\ \frac{(50\ mm)^4 - (40\ mm)^4}{(50\ mm)} = 7{,}245\ mm^3$$

It is assumed that snow and ice will not occur concurrently and since the ice loading is greater than the snow loading, the sustained loads are equal to the weight of the piping system and the ice.

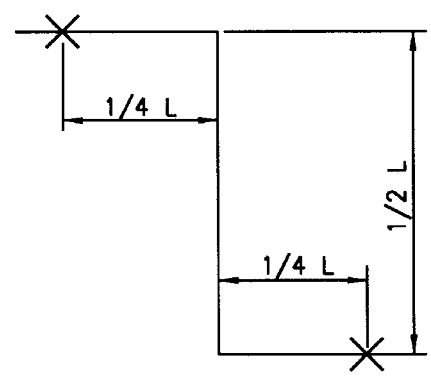
Ref. p. 3-17.

$$\Sigma S_L = (0.1)\frac{[27.4\ N/m + 28.2\ N/m](1.7\ m)^2}{(10^{-3}\ m/mm)(7{,}245\ mm^3)}$$

$$= 2.26\ MPa$$

For 40-FES-111, $\Sigma S_L \leq 1.33 S_h$; therefore, the system is acceptable for the design stress loading.

Step 3. Stresses are imposed upon the piping system due to thermal expansion and contraction. To ensure that thermoplastic piping systems have sufficient flexibility to prevent these failures, a minimum offset is required between a bend and a restrained anchor. For 40-FES-111, there are a series of Z-shaped arrangements: A-B-C-D, C-D-E-F, E-F-G-H, and G-H-I-J; see Sketch C-12.



Sketch C-13

Referencing Sketch C-13, for Z-shapes:

$$L = \frac{1\ m}{1{,}000\ mm}\left(\frac{3\ E\ D_o\ \alpha}{S}\right)^{0.5}$$

where:
L = offset pipe length, m
E = modulus of elasticity = 2,895 MPa
S = allowable stress = 13.8 MPa
D_o = outer pipe diameter = 32 mm
α = thermal expansion coefficient = 2.43 x 10^{-3} mm/mm

For pipe section A-B-C-D with a length of approximately 3 m:

$$L_{ABCD} = \frac{1\ m}{1{,}000\ mm}\ x \left(\frac{3(2{,}895 MPa)(50 mm)[(2.43 x10^{-3} \frac{mm}{mm})(3{,}500 mm)]}{13.8 MPa}\right)^{0.5}$$

$$= 0.52\ m,\ minimum.$$

Since ½ (B-C) = ½ (3.5 m) > L_{ABCD}, the flexibility of the piping segment is acceptable. The restraints (anchors) should be located at a minimum 1/4 L = 1/4 (0.52 m) = 0.13 m from the bends.

For pipe section C-D-E-F with a length of approximately 3 m:

$$L_{CDEF} = \frac{1\ m}{1{,}000\ mm}\ x \left(\frac{3(2{,}895 MPa)(50 mm)[(2.43 x10^{-3} \frac{mm}{mm})(3{,}000 mm)]}{13.8 MPa}\right)^{0.5}$$

$$= 0.34\ m,\ minimum.$$

Since ½ (D-E) = ½ (3 m) > L_{CDEF}, the flexibility of the piping segment is acceptable. The anchors should be located at a minimum 1/4 L = 1/4 (0.34 m) = 0.08 m from the bends. That is, a pipe guide should be located at support no. S1006 and another within the existing pipe trench.

For pipe section E-F-G-H with a length of approximately 7.5 m:

$$L_{EFGH} = \frac{1\ m}{1{,}000\ mm}\ x \left(\frac{3(2{,}895 MPa)(50 mm)[(2.43 x10^{-3} \frac{mm}{mm})(7{,}500 mm)]}{13.8 MPa}\right)^{0.5}$$

$$= 0.75\ m,\ minimum.$$

Since ½ (F-G) = ½ (7.5 m) > L_{EFGH}, the flexibility of the piping segment is acceptable. The anchors should be located at a minimum 1/4 L = 1/4 (0.75 m) = 0.19 m from the bends. That is, a pipe guide should be located at support no. 1016 and a vertical pipe guide established at 0.2 m from BOP on support no. S1036.

For pipe section G-H-I-J with a length of approximately 1.5 m:

$$L_{GHIJ} = \frac{1\ m}{1{,}000\ mm}\ x \left(\frac{3(2{,}895 MPa)(50 mm)[(2.43 x10^{-3} \frac{mm}{mm})(1{,}500 mm)]}{13.8 MPa}\right)^{0.5}$$

$$= 0.24\ m,\ minimum.$$

Since ½ (H-I) = ½ (1.5 m) > L_{GHIJ}, the flexibility of the piping segment is acceptable. The anchors should be located at a minimum 1/4 L = 1/4 (0.24 m) = 0.06 m from the bends. That is, relocate the vertical pipe guide established on S1036 at 0.20 m BOP down to ½ the vertical run, ½ (2 m) = 1 m BOP. Also locate the support for the solenoid valve at 0.06 m from the bend at I.

l. Line 20-FES-112
Chemical Feed from Ferrous Sulfate Day Tank to Ferrous Sulfate Controlled Volume Pump

The controlled volume pump has a 20 mm female taper threaded connection. The piping from the pump to the process injection point is supplied by the process unit manufacturer and is 20 mm SAE 100R7 hose. Therefore, 20-FES-112 is selected to be identical to the process hose: 20 mm SAE 100R7 hose (thermoplastic tube, synthetic-fiber reinforcement, thermoplastic cover) with 20 mm male taper threaded end connections, built-in fittings. Minimum hose length is 2 m.

Ensure that the process engineer, or the engineer that is specifying the day tanks, designs the ferrous sulfate day tank with the proper discharge port - 20 mm taper threaded nozzle, female.