 TORUS	· Owner LINE SIZING AND STATION HYDRAULICS				Document No.	PRO-CAL-002
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PROCESS · LINE SIZING AND STATION HYDRAULICS						
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REFERENCE DOCUMENTS AND NOTES

References: GEN-DB-001, Basis of Design (cases, pressure-drop allowances); MEC-CAL-001, Pipe Wall Thickness; MEC-LST-001, Line List; MEC-DWG-001, Plot Plan, and the piping general arrangement (routed lengths and fittings); PRO-CAL-001, Heat and Material Balance; PRO-CAL-005, Filter Separator V-101; PRO-CAL-006, Control Valves; PRO-CAL-007, Pressure Relief Devices; PRO-CAL-008, Blowdown and Vent System; PRO-CAL-010, Fuel Gas System. API RP 14E, 5th Edition (1991), Section 2.5; Crane Technical Paper 410 (2013); ANSI/ISA-75.01.01 (IEC 60534-2-1); Energy Institute, Guidelines for the Avoidance of Vibration Induced Fatigue Failure in Process Pipework, 2nd Edition (2008).

- The governing case for each line is the case with the highest ratio of velocity to erosional velocity. “C1-bypass” is 120 MMSCFD in winter with H-101 bypassed, which governs the bypass line 1021.
- Criteria: velocity at or below 60 ft/s (station practice, to limit noise) and at or below the API RP 14E erosional velocity with C = 100. API RP 14E applies strictly to two-phase and solids-bearing flow; it is used here for dry gas as a conservative screen. A line with ρv^2 above 15,000 lb/ft·s² is flagged for the piping vibration screening.
- Wall thicknesses are those of MEC-CAL-001: NPS 12 STD (0.375 in), line 1042 0.500 in, NPS 10 Sch 80, NPS 8 Sch 80. Routed lengths and fittings follow the flow path in the piping layout.
- Absolute roughness 0.0018 in (new commercial steel). Fitting losses by the Crane K = n f_T method.
- Pressure drops are at the segment mean density (iterated), which is accurate because no segment loses more than 1 % of its inlet pressure.
- HOLD H-12: liquid composition and flash factor for line 1060. HOLD H-15: vendor data for the flow conditioner loss and the bypass valve trims.

OBJECTIVE AND METHOD

This calculation sizes the process lines of the and establishes the station pressure profile used by the heat and material balance and the control valve sizing. It checks each main gas line against the velocity and erosional criteria at its governing case, sets the station pressure-drop budget against the allowances of GEN-DB-001, and sizes the liquid dump line, the equalizing bypasses around the shutdown valves, and the fuel and vent lines.

TORUS calculated the pressure drop of each segment with the Darcy-Weisbach equation, the Colebrook friction factor and Crane fitting coefficients, using GERG-2008 gas properties at the segment conditions. The segments are chained into a station model that runs forward from the inlet pressure to the control valve inlet and backward from the trunk pressure to the control valve outlet; the control valve takes the remaining pressure drop.

INPUTS

Table 1 gives the fixed inputs. Flows, pressures and temperatures per case are those of PRO-CAL-001.

Table 1: Design Inputs

Symbol	Description	Value	Unit	Source
ϵ	Absolute pipe roughness	0.0018	in	Crane TP-410
v_{max}	Maximum gas velocity, station lines	60	ft/s	Station practice
C	API RP 14E constant, continuous service	100	-	API RP 14E
ρv_{flag}^2	Momentum flux flag for vibration screening	15,000	lb/ft·s ²	Energy Institute guideline
K_{FC}	Flow conditioner loss coefficient, on the 10 in bore	2.5	-	Typical perforated plate (HOLD H-15)
ΔP_{FS}	V-101 pressure drop, clean / dirty, at 120 MMSCFD and 900 psig	2 / 10	psi	GEN-DB-001
ΔP_{budget}	Station pressure drop excluding the control valve, at 120 MMSCFD	20	psi	GEN-DB-001
Q_{dump}	LCV-104 design dump rate, SG 0.85 liquid	30	gpm	PRO-CAL-005
f_{flash}	Flash gas from V-101 liquids	750	scf/bbl	Estimate (HOLD H-12)
x_T	Pressure differential ratio factor, bypass globes	0.7	-	Typical (HOLD H-15)

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LINE GEOMETRY

Table 2 gives the routed length and fittings of each line along the normal flow path.

Table 2: Line Geometry

Line	Service	OD x WT (in)	ID (in)	Length (ft)	Fittings on the flow path	Sum K
12"-G-1001-A6	IJ-101 to SDV-101 through the PR-101 station branch	12.750 x 0.375	12.000	61	1 x 3R bend, barred tee (branch), kicker tee (run), 2 FB ball (HV-101A, SDV-101), IJ-101	1.27
12"-G-1002-A6	SDV-101 to V-101 inlet	12.750 x 0.375	12.000	48	bypass tee (run), HV-103A, 3 x 90 ell	0.84
12"-G-1003-A6	V-101 outlet to meter inlet header	12.750 x 0.375	12.000	76	5 x 90 ell, 2 x 45 ell, HV-103B, bypass tee (run)	1.42
12"-G-1010-A6	Meter inlet header	12.750 x 0.375	12.000	13	inlet tee (run) + run tee (branch)	1.04
10"-G-1011-A6 / 1012	Meter run MR-110 (MR-120 identical)	10.750 x 0.594	9.562	38	2 FB ball (MOV-111/112), FC-111 K = 2.5, 12x10 reducer/expander	2.69
12"-G-1020-A6	Meter outlet header to H-101 inlet	12.750 x 0.375	12.000	133	run tee (branch), run-2 tee (run), 3 x 90 ell, bypass tee (run), HV-158A	1.89
12"-G-1021-A6	H-101 bypass	12.750 x 0.375	12.000	8	2 bypass tees (branch), HV-158C	1.60
12"-G-1022-A6	H-101 outlet to FCV inlet header	12.750 x 0.375	12.000	79	HV-158B, bypass tee (run), 90 ell, FCV-131 branch tee (branch)	1.26
12"-G-1031-A6 / 1032	FCV-131 branch (FCV-132 identical)	12.750 x 0.375	12.000	18	HV-131A/B, outlet header tee (branch); 12 x 8 reducers in the valve piping factor, NPS 12 branch	0.86
12"-G-1033-A6	FCV outlet header to SDV-102	12.750 x 0.375	12.000	30	outlet tee (branch), SDV-102	0.82
12"-G-1040-A6	SDV-102 through CKV-171 to SDV-103	12.750 x 0.375	12.000	27	CKV-171 (axial nozzle, K taken as 100 fT), SDV-103	1.34
12"-G-1041-A6	SDV-103 to IJ-102	12.750 x 0.375	12.000	72	1 x 3R bend, IJ-102	0.16
12"-G-1042-A6	IJ-102 to trunk tap, buried	12.750 x 0.500	11.750	108	2 x 3R riser bends, tap valve (FB), hot-tap tee (branch)	1.13

LINE SIZING RESULTS

Table 3 gives each line at its governing case. Every main gas line meets both criteria. The meter runs carry the highest velocity (38 ft/s at case C5); the 12 in lines stay below 31 ft/s.

Table 3: Line Sizing Results at the Governing Case

Line	Governing case	Density	Velocity	Erosional velocity	rho v2	Friction factor	Pressure drop	Drop per 100 ft	Result
		lb/ft ³	ft/s	ft/s	lb/ft·s ²	-	psi	psi	
	Note 1	GERG	Eq. 1	Eq. 4	Eq. 5	Eq. 2	Eq. 3	Eq. 3	Note 2
12"-G-1001-A6	C5	3.59	24.1	52.7	2,080	0.0131	0.47	0.76	Meets
12"-G-1002-A6	C5	3.59	24.1	52.8	2,081	0.0131	0.33	0.69	Meets
12"-G-1003-A6	C5	3.58	24.1	52.8	2,087	0.0131	0.54	0.72	Meets
12"-G-1010-A6	C5	3.58	24.1	52.8	2,087	0.0131	0.27	2.04	Meets
10"-G-1011-A6 / 1012	C5	3.58	38.1	52.9	5,185	0.0137	1.88	4.88	Meets
12"-G-1020-A6	C5	3.57	24.2	52.9	2,093	0.0131	0.82	0.62	Meets
12"-G-1021-A6	C4	3.74	23.1	51.7	2,000	0.0131	0.37	4.69	Meets
12"-G-1022-A6	C5	3.56	24.3	53.0	2,102	0.0131	0.52	0.66	Meets
12"-G-1031-A6 / 1032	C5	3.55	24.3	53.0	2,103	0.0131	0.25	1.36	Meets
12"-G-1033-A6	C5	3.01	28.7	57.6	2,482	0.0131	0.32	1.09	Meets
12"-G-1040-A6	C5	3.01	28.7	57.6	2,483	0.0131	0.45	1.68	Meets
12"-G-1041-A6	C5	3.01	28.7	57.7	2,485	0.0131	0.29	0.41	Meets
12"-G-1042-A6	C5	3.01	30.0	57.7	2,705	0.0131	0.75	0.70	Meets

Note 1: See note 1 of the notes block. Row 1 of the table gives units and row 2 the governing equation.

Note 2: “Meets” means within 60 ft/s, within the erosional velocity and below the ρv^2 flag.

The worked check below repeats the meter run 1011 result at case C5, the lowest-density case at full flow. The run inlet is at 896.4 psig and 59.8 °F, the mass flow is 67.91 lb/s and the mean density is 3.577 lb/ft³.

$$v = \frac{W}{\rho A} = \frac{67.91}{3.577 \times 0.4987} = 38.1 \text{ ft/s}$$

Eq. 1

$$\Delta P = \left(f \frac{L}{D} + \sum K\right) \frac{\rho v^2}{2g_c} = \left(0.0137 \times \frac{38.4}{0.7968} + 2.69\right) \frac{3.577 (38.1)^2}{2(32.174)(144)} = 1.88 \text{ psi}$$

Eq. 3, Crane TP-410

Meter run pressure drop is 1.88 psi at case C5, within the 3 psi allowance of GEN-DB-001.

CONTROL VALVE BRANCHES

Table 4 compares NPS 8 branch piping, sized to the valve, with NPS 12 branch piping and 12 x 8 concentric reducers at the valve flanges. NPS 8 piping would run at up to 71 ft/s at the valve outlet, above both the 60 ft/s limit and the erosional velocity, and would add noise. TORUS therefore selected NPS 12 branches for lines 1031 and 1032, with the reducers included in the valve piping geometry factor of PRO-CAL-006.

Table 4: Control Valve Branch Velocities

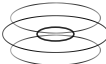
Case	Branch piping	Velocity, valve inlet (ft/s)	Velocity, valve outlet (ft/s)	Erosional velocity (ft/s)	rho v2, outlet (lb/ft·s2)	Result
C1	NPS 8, valve size	46.2	69.4	56.9	14,858	Fails
C1	NPS 12 with 12 x 8 reducers	18.7	28.0	56.9	2,422	Meets
C4	NPS 8, valve size	57.4	62.4	54.0	13,361	Fails
C4	NPS 12 with 12 x 8 reducers	23.2	25.2	54.0	2,178	Meets
C5	NPS 8, valve size	60.2	71.1	57.6	15,220	Fails
C5	NPS 12 with 12 x 8 reducers	24.3	28.7	57.6	2,481	Meets
C6	NPS 8, valve size	42.1	63.2	54.3	13,542	Fails
C6	NPS 12 with 12 x 8 reducers	17.0	25.5	54.3	2,208	Meets

STATION PRESSURE-DROP BUDGET

Table 5 sets the station losses against the 20 psi allowance, with V-101 clean and at its 10 psi change-out differential. The allowances for V-101 are scaled with ρv^2 from the 900 psig reference, so they are lower in the denser high-pressure cases. The worst case is C5: 11.7 psi with a clean filter and 19.8 psi with a dirty filter, both within the allowance. The control valve keeps at least 130 psi of pressure drop in every case at 120 MMSCFD.

Table 5: Station Pressure-Drop Budget, psi

Case, filter	Flow (MMSCFD)	Piping and valves	V-101	Meter run	H-101 coil	Total excluding FCV	Against 20 psi	FCV drop
C1, clean	120	4.08	1.41	1.32	2.04	8.86	Meets	391.1
C1, dirty	120	4.09	7.06	1.32	2.05	14.53	Meets	385.5
C2, clean	90	2.56	0.97	0.91	0.00	4.45	Meets	95.6
C2, dirty	90	2.57	4.87	0.91	0.00	8.35	Meets	91.7
C3, clean	10	0.03	0.01	0.01	0.00	0.06	Meets	49.9
C3, dirty	10	0.03	0.06	0.01	0.00	0.11	Meets	49.9
C4, clean	120	5.03	1.91	1.79	0.00	8.73	Meets	91.3

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Case, filter	Flow (MMSCFD)	Piping and valves	V-101	Meter run	H-101 coil	Total excluding FCV	Against 20 psi	FCV drop
C4, dirty	120	5.05	9.57	1.81	0.00	16.42	Meets	83.6
C5, clean	120	5.03	2.00	1.88	2.78	11.68	Meets	138.3
C5, dirty	120	5.05	10.01	1.89	2.80	19.75	Meets	130.2
C6, clean	120	4.14	1.41	1.32	0.00	6.87	Meets	393.1
C6, dirty	120	4.15	7.05	1.32	0.00	12.52	Meets	387.5
C7, clean	120	4.23	1.61	1.51	2.27	9.62	Meets	240.4
C7, dirty	120	4.24	8.06	1.52	2.28	16.10	Meets	233.9

Note 1: The meter run allowance is 3 psi and the heater coil allowance 10 psi (GEN-DB-001). With both runs in series for meter verification the meter pressure drop rises by 3.2 psi at 120 MMSCFD; verification is normally done at the case C2 rate or lower.

LIQUID LINE 1060

Downstream of LCV-104 the liquid flashes and the line carries two-phase flow. Table 6 checks the mixture velocity at the design dump rate against the API RP 14E erosional velocity. NPS 2 fails, and with the flash factor of PRO-CAL-007 NPS 3 also exceeds the erosional velocity, so TORUS sized the line NPS 4 from the LCV-104 outlet to T-101 (4”-L-1060-D1). Upstream of LCV-104 the liquid is single-phase at 3.3 ft/s and NPS 2 (2”-L-1060-A6) is adequate.

Table 6: Line 1060 Downstream of LCV-104

Line size	Liquid (lb/h)	Flash gas (lb/h)	Mixture density (lb/ft3)	Mixture velocity (ft/s)	Erosional velocity (ft/s)	Result
NPS 2 Sch 80	12,757	1,572	0.59	326.3	129.7	Fails
NPS 3 Sch 40	12,757	1,572	0.59	130.4	129.7	Fails
NPS 4 Sch 40	12,757	1,572	0.59	75.7	129.7	Meets

EQUALIZING BYPASSES AROUND SDV-101, SDV-102 AND SDV-103

Each shutdown valve has an NPS 1 Class 600 globe valve bypass to equalize pressure before the valve is opened. The bypass around SDV-103 is line 1”-G-1171-A6, and the SDV-101 and SDV-102 bypasses are lines 1”-G-1103-A6 and 1”-G-1162-A6. Table 7 gives the volume each bypass pressurizes from the 1,150 psig station side, the flow coefficient needed to do it in 20 minutes from 0 psig, and the times with the selected trims. The SDV-101 bypass pressurizes 697 ft³ and needs a C_v 5 trim; a C_v 1 trim would take more than an hour and a half. The SDV-102 and SDV-103 bypasses use C_v 1 needle trims.

Table 7: Equalizing Bypass Sizing

Bypass	Volume pressurized	Volume (ft3)	Cv for 20 min	Selected Cv	Time from 0 psig (min)	Time from 300 psig nitrogen (min)
SDV-101 bypass	S1 downstream of SDV-101 + S2 (SDV-102 closed)	697	4.91	5	20	16
SDV-102 bypass	S3 + S4 (SDV-103 open, tap valve closed)	161	1.13	1	23	19
SDV-103 bypass	S4 outlet lateral	138	0.97	1	19	16

Note 1: Sections S1 to S4 are the isolatable sections defined in PRO-CAL-008. Flow by the ISA-75.01.01 compressible flow equation (Eq. 9) with the isentropic exponent κ , packing isothermal at 60 °F (Eq. 10).

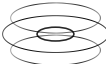
Throttling 1,150 psig gas into a depressured section cools it to about -29 °F at the start, below the -20 °F minimum design metal temperature. The section shall therefore be pre-pressurized with nitrogen, or the gas supply limited to 900 psig or less at 60 °F or warmer, and the bypass shall be used with the downstream skin temperature monitored.

FUEL GAS AND VENT LINES

Table 8 summarizes the fuel and vent line checks made in the referenced calculations.

Table 8: Fuel Gas and Vent Lines

Line	Governing condition	Result	Calculation
2”-F-1050-A6	Design fuel flow, 330 lb/h at 897 psig	Very low velocity; NPS 2 meets	PRO-CAL-010
2”-F-1051-A1	Burner fuel at 15 psig	NPS 2 meets; NPS 1 would run at about 150 ft/s and starve the burner	PRO-CAL-010
1”-F-1052-A1	G-101 fuel at 15 psig	Meets	PRO-CAL-010

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Line	Governing condition	Result	Calculation	
8"-V-1070-S1	Blowdown of all three sections at once	Maximum Mach 0.37; meets	PRO-CAL-008	
3"-V-1071-S1	PSV-101 at rated capacity	Built-up back pressure 4.9 % of set; meets	PRO-CAL-007	
4"-V-1072-S1, 4"-V-1073-S1	RO-181 and RO-182 peak flow	Mach 0.61 at the header tie-in; NPS 2 would be sonic	PRO-CAL-008	
2"-V-1074-S1, 2"-V-1075-S1	RO-183 and RO-102 peak flow	Meets	PRO-CAL-008	
2"-V-1076-S1	PSV-157 at rated capacity	Built-up back pressure 7.5 % of set; meets	PRO-CAL-007	
2"-V-1077-S1	PSV-161 at rated capacity	Built-up back pressure 5.4 % of set; meets	PRO-CAL-007	
3/8"-G-1080-T1	Analyzer sample	Sized for sample lag	MEA-CAL-004	

EQUATIONS

Eq. 1: $v = W/(\rho A)$

Eq. 2: $1/\sqrt{f} = -2\log_{10} \left[\varepsilon/(3.7D) + 2.51/(Re\sqrt{f}) \right]$, $Re = \rho v D/\mu$ (Colebrook)

Eq. 3: $\Delta P = (fL/D + \sum K) \rho v^2/(2g_c)$ (Darcy-Weisbach)

Eq. 4: $V_e = C/\sqrt{\rho_m}$, $C = 100$ (API RP 14E Eq. 2.14)

Eq. 5: momentum flux ρv^2

Eq. 6: $K = \eta f_T$ for fittings: 1.5D elbow 14, 3R bend 12, 45° elbow 8, tee run 20, tee branch 60, full-bore ball valve 3, check valve 100 (Crane TP-410)

Eq. 7: $K_2 = 0.8\sin(\theta/2)(1 - \beta^2)$ contraction, $K_2 = 2.6\sin(\theta/2)(1 - \beta^2)^2$ expansion (Crane TP-410)

Eq. 8: $\rho_m = (m_L + m_G)/(Q_L + Q_G)$, $v_m = (Q_L + Q_G)/A$

Eq. 9: $W = 63.3 C_v Y \sqrt{x P_1 \rho_1}$, $Y = 1 - x/(3 F_k x_T)$, $F_k = \kappa/1.40$, $x \leq F_k x_T$ (ISA-75.01.01)

Eq. 10: $dP/dt = W/(V \partial \rho/\partial P)$ at constant temperature

RESULTS AND CONCLUSIONS

All NPS 12 station lines, the NPS 10 meter runs and the heater bypass meet the velocity and erosional criteria in every case, and none reaches the vibration screening flag. TORUS selected NPS 12 branch piping with 12 x 8 reducers for the NPS 8 control valves, NPS 4 for line 1060 downstream of LCV-104, NPS 4 for the RO-181 and RO-182 outlet lines, and NPS 2 for the burner fuel line 1051, each for the reason given above. The station pressure drop excluding the control valve is within the 20 psi allowance in every case, with the filter clean or dirty. The equalizing bypasses are NPS 1 Class 600 globe valves, C_v 5 around SDV-101 and C_v 1 around SDV-102 and SDV-103.

The line sizes and pressure profile in this calculation feed PRO-CAL-001 and PRO-CAL-006 and the line list MEC-LST-001. They should be rechecked if the routed lengths change materially during detailed piping design, and line 1060 should be rechecked when the liquid analysis (HOLD H-12) is received.

