TORUS	· Owner HEAT AND MATERIAL BALANCE				Document No.	PRO-CAL-001
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PROCESS · HEAT AND MATERIAL BALANCE						
Rev.	Date	Revision description	Prepared	Reviewed	Approved	
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REFERENCE DOCUMENTS AND NOTES

References: GEN-DB-001, Basis of Design (compositions, cases, equipment); PRO-DWG-001 and PRO-DWG-002, Process Flow Diagram (stream numbers); PRO-CAL-002, Line Sizing and Station Hydraulics (pressure profile); PRO-CAL-003, Joule-Thomson, Hydrate and Dewpoint (control valve outlet temperature); PRO-CAL-004, Line Heater H-101; PRO-CAL-005, Filter Separator V-101 (liquids); PRO-CAL-007, Pressure Relief Devices and Tank Venting; PRO-CAL-008, Blowdown and Vent System; PRO-CAL-010, Fuel Gas System. AGA Report No. 8 Part 2 (GERG-2008); GPA 2145-16 and GPA 2172-19 (heating value).

- The case flow is the custody flow measured and delivered to the trunk. Station inlet flow is the custody flow plus the fuel gas drawn at stream 10, upstream of the meters.
- Pressures come from the station hydraulic model of PRO-CAL-002 with the filter separator clean: forward from the inlet pressure through V-101, the meter run and H-101 (or its bypass), and backward from the trunk pressure to the control valve outlet. The control valve takes the difference.
- Vapor fraction 1.00 means the GERG-2008 flash finds single-phase gas at the stream state.
- Viscosity is from the CoolProp extended corresponding-states model; where that model does not converge at low temperature the Lee-Gonzalez-Eakin correlation is used at the GERG-2008 density.
- Heating value is the real-gas gross value at 14.73 psia and 60 °F, dry, per GPA 2172.
- Piping is adiabatic. Heat exchange with ambient over the short station runs is neglected, which is conservative for the winter outlet temperature.
- HOLD H-12: extended gas analysis. HOLD H-13: receiving pipeline gas quality specification. HOLD H-15: heater efficiency from vendor data. HOLD H-20: V-101 liquids rate.

OBJECTIVE AND METHOD

This calculation gives the heat and material balance of the for the seven design cases of GEN-DB-001. It defines the numbered streams on the Process Flow Diagram and reports, for each stream, the pressure, temperature, flows and the physical properties that the equipment and line sizing calculations use.

TORUS solved the station pressure profile with the hydraulic model of PRO-CAL-002 and took every temperature as isenthalpic from the station inlet, because the piping is adiabatic and the only heat input is the line heater. With H-101 in service, its outlet temperature was solved so that the control valve outlet (stream 7) meets the required temperature of PRO-CAL-003: the larger of 40 °F, the hydrate dewpoint of gas at 7 lb/MMscf plus 10 °F, and the hydrocarbon dewpoint plus 10 °F. All properties are from the GERG-2008 equation of state (AGA Report No. 8 Part 2), evaluated with CoolProp 8.0. The isentropic exponent κ is reported because the valve and orifice flow calculations of this package use it in place of the real-gas c_p/c_v .

INPUTS

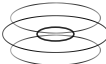
The design cases in Table 1 are those of GEN-DB-001 Section 6. Table 2 lists the remaining inputs.

Table 1: Design Cases

Case	Description	Custody flow (MMSCFD)	Inlet P (psig)	Inlet T (°F)	Trunk P (psig)	Gas	H-101
C1	Design max, winter, max pressure cut	120	1,150	45	750	Design	In service
C2	Normal operation	90	1,050	70	950	Design	Bypassed
C3	Minimum flow (turndown)	10	1,000	60	950	Design	Bypassed
C4	Summer max temperature	120	1,100	120	1,000	Design	Bypassed
C5	Min metering pressure, max flow	120	900	60	750	Design	In service
C6	Heater-out winter upset	120	1,150	45	750	Design	Bypassed
C7	Rich gas, design max	120	1,100	60	850	Rich	In service

Table 2: Design Inputs

Symbol	Description	Value	Unit	Source
P_{atm}	Local atmospheric pressure	14.10	psia	GEN-DB-001

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Symbol	Description	Value	Unit	Source
P_b , T_b	Standard conditions	14.73, 60	psia, °F	GEN-DB-001
ρ_b	Base density, design gas	0.04889	lb/scf	GERG-2008
η	H-101 thermal efficiency, HHV	74.8	%	PRO-CAL-004 (HOLD H-15)
T_{E161}	E-161 outlet setpoint	105	°F	PRO-CAL-010
P_{161} , P_{162}	PCV-161 and PCV-162 set pressures	150, 15	psig	PRO-CAL-010
Q_{pilot}	H-101 pilot gas	25	scf/h	PRO-CAL-004 (HOLD H-15)
-	Filter separator condition	Clean, 2 psi at 120 MMSCFD and 900 psig	-	GEN-DB-001

The compositions in Table 3 are those of GEN-DB-001 Section 5.1 (HOLD H-12); Table 4 gives the resulting base properties.

Table 3: Gas Compositions, mol %

Component	Lean	Design	Rich
Methane	94.00	88.50	83.60
Ethane	3.00	6.00	8.50
Propane	0.60	2.20	3.60
i-Butane	0.10	0.40	0.70
n-Butane	0.10	0.50	0.90
i-Pentane	0.03	0.12	0.25
n-Pentane	0.02	0.10	0.20
n-Hexane	0.02	0.10	0.15
Nitrogen	1.20	1.20	1.10
Carbon dioxide	0.93	0.88	1.00

Table 4: Base Properties at 14.73 psia and 60 °F

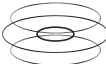
Composition	MW	Specific gravity	Base Z	HHV (Btu/scf)	LHV (Btu/scf)	Base density (lb/scf)
Lean	17.162	0.5926	0.99782	1,031.7	930.2	0.04543
Design	18.464	0.6375	0.99743	1,103.7	997.3	0.04889
Rich	19.687	0.6798	0.99703	1,168.8	1,058.2	0.05215

STREAM LIST

Table 5 lists the streams shown on PRO-DWG-001 and PRO-DWG-002.

Table 5: Stream List

Stream	Description	Line
1	Station inlet at IJ-101	12"-G-1001-A6
2	V-101 inlet, downstream of SDV-101	12"-G-1002-A6
3	V-101 gas outlet	12"-G-1003-A6
4	Meter inlet header (custody gas)	12"-G-1010-A6
5	Meter outlet header, H-101 inlet	12"-G-1020-A6
6	H-101 outlet or bypass, FCV inlet	12"-G-1022-A6

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Stream	Description		Line	
	7	FCV outlet header	12"-G-1033-A6	
	8	Station outlet at the trunk tap	12"-G-1042-A6	
	10	Fuel take-off from V-101 outlet	2"-F-1050-A6	
	11	E-161 outlet, fuel preheated	2"-F-1050-A6	
	12	PCV-161 outlet, first cut	FG-101 internal	
	13	PCV-162 outlet to H-101 burner and pilot	2"-F-1051-A1	
	14	PCV-162 outlet to G-101 (standby)	1"-F-1052-A1	
	20	V-101 liquids through LCV-104 to T-101	2"-L-1060-A6 / 4"-L-1060-D1	
	21	PR-101 barrel drain to T-101 (batch)	2"-L-1061-A6/D1	
	22	T-101 truck-out (batch)	Truck loadout	
	30	Vent header to VS-101 (intermittent)	8"-V-1070-S1	
	31	T-101 vapor through PVRV-193 and FA-193	Tank vent	

BALANCE SUMMARY

Table 6 shows that the mass balance closes in every case: stream 1 equals stream 8 plus the fuel drawn at stream 10. Table 7 gives the heat input. The difference $h_6 - h_7$ is zero, which confirms that the control valve and downstream piping are modeled as isenthalpic.

Table 6: Mass Balance Closure

Case	Stream 1 (lb/h)	Stream 4 (lb/h)	Stream 10 (lb/h)	Streams 8 + 10 (lb/h)	Difference (lb/h)	Stream 1 (MMSCFD)	Stream 8 (MMSCFD)
C1	244,700	244,465	235.5	244,700	0.0	120.116	120.000
C2	183,350	183,349	1.2	183,350	0.0	90.001	90.000
C3	20,373	20,372	1.2	20,373	0.0	10.001	10.000
C4	244,466	244,465	1.2	244,466	0.0	120.001	120.000
C5	244,468	244,465	2.8	244,468	0.0	120.001	120.000
C6	244,466	244,465	1.2	244,466	0.0	120.001	120.000
C7	260,863	260,771	92.0	260,863	0.0	120.042	120.000

Table 7: Energy Summary

Case	H-101	Absorbed (MMBtu/h)	Fired, HHV (MMBtu/h)	E-161 (kW)	h6 minus h7 (Btu/lb)	Stream 7 T (°F)	Required stream 7 T (°F)
C1	In service	3.96	5.29	2.84	0.000	43.6	43.6
C2	Bypassed	0.00	0.00	0.01	0.000	64.3	-
C3	Bypassed	0.00	0.00	0.01	0.000	57.0	-
C4	Bypassed	0.00	0.00	0.00	0.000	115.5	-
C5	In service	0.03	0.04	0.02	0.000	50.8	43.6
C6	Bypassed	0.00	0.00	0.01	0.000	18.2	-
C7	In service	1.52	2.03	0.83	0.000	52.1	52.1

Note 1: Fired duty is absorbed duty divided by the 74.8 % efficiency of PRO-CAL-004. E-161 duty is at the actual fuel draw of the case; its design duty at the full fuel design flow is in PRO-CAL-010.

CASE C1: DESIGN MAX, WINTER, MAX PRESSURE CUT

Table 8 gives the main gas streams for case C1 (120 MMSCFD custody flow, design gas, H-101 in service) and Table 9 the fuel gas streams.

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Table 8: Case C1, Main Gas Streams

Property, unit	Eq.	S1	S2	S3	S4	S5	S6	S7	S8
Pressure, psig	Note 2	1,150	1,149	1,148	1,147	1,146	1,144	751.8	750.0
Temperature, °F	Eq. 3	45.0	45.0	44.9	44.8	44.8	67.4	43.6	43.4
Vapor fraction	Note 3	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Mass flow, lb/h	Eq. 1	244,700	244,700	244,700	244,465	244,465	244,465	244,465	244,465
Standard flow, MMSCFD	Eq. 1	120.12	120.12	120.12	120.00	120.00	120.00	120.00	120.00
Actual flow, acfm	Eq. 2	799.0	799.4	800.3	799.9	800.8	879.1	1,320	1,323
Molecular weight, lb/lbmol	GERG	18.46	18.46	18.46	18.46	18.46	18.46	18.46	18.46
Compressibility Z	GERG	0.7775	0.7775	0.7776	0.7776	0.7777	0.8153	0.8484	0.8486
Density, lb/ft³	GERG	5.104	5.102	5.096	5.094	5.088	4.635	3.086	3.079
Viscosity, cP	Note 4	0.0134	0.0134	0.0134	0.0134	0.0134	0.0134	0.0119	0.0119
Heat capacity C_p , Btu/lb·°F	GERG	0.735	0.735	0.735	0.735	0.734	0.689	0.624	0.624
Ratio C_p/C_v (real)	GERG	1.787	1.787	1.787	1.787	1.786	1.672	1.564	1.563
Ratio k (ideal gas)	GERG	1.285	1.285	1.285	1.285	1.285	1.279	1.285	1.285
Isentropic exponent κ	Eq. 7	1.429	1.429	1.429	1.428	1.428	1.401	1.329	1.329
Speed of sound, ft/s	GERG	1,229	1,229	1,229	1,228	1,228	1,273	1,236	1,236
Gross heating value, Btu/scf	Note 5	1,103.7	1,103.7	1,103.7	1,103.7	1,103.7	1,103.7	1,103.7	1,103.7

Table 9: Case C1, Fuel Gas Streams

Property, unit	Eq.	S10	S11	S12	S13	S14
Pressure, psig	Note 2	1,148	1,148	150.0	15.0	15.0
Temperature, °F	Eq. 3	44.9	105.0	45.9	36.0	36.0
Vapor fraction	Note 3	1.00	1.00	1.00	1.00	1.00
Mass flow, lb/h	Eq. 1	235	235	235	235	0.0
Standard flow, MMSCFD	Eq. 1	0.1156	0.1156	0.1156	0.1156	0.0000
Actual flow, acfm	Eq. 2	0.8	1.0	6.8	38.6	0
Molecular weight, lb/lbmol	GERG	18.46	18.46	18.46	18.46	18.46
Compressibility Z	GERG	0.7776	0.8611	0.9683	0.9940	0.9940
Density, lb/ft³	GERG	5.096	4.112	0.577	0.102	0.102
Viscosity, cP	Note 4	0.0134	0.0137	0.0106	0.0103	0.0103
Heat capacity C_p , Btu/lb·°F	GERG	0.735	0.650	0.507	0.486	0.486
Ratio C_p/C_v (real)	GERG	1.787	1.553	1.327	1.294	1.294
Ratio k (ideal gas)	GERG	1.285	1.270	1.285	1.287	1.287
Isentropic exponent κ	Eq. 7	1.429	1.371	1.285	1.287	1.287
Speed of sound, ft/s	GERG	1,229	1,340	1,301	1,306	1,306
Gross heating value, Btu/scf	Note 5	1,103.7	1,103.7	1,103.7	1,103.7	1,103.7

Note 1: Stream 14 carries no flow in normal operation. G-101 is a standby generator; its design flow is 680 scf/h at the stream 13 state.

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CASE C2: NORMAL OPERATION

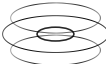
Table 10 gives the main gas streams for case C2 (90 MMSCFD custody flow, design gas, H-101 bypassed) and Table 11 the fuel gas streams.

Table 10: Case C2, Main Gas Streams

Property, unit	Eq.	S1	S2	S3	S4	S5	S6	S7	S8
Pressure, psig	Note 2	1,050	1,050	1,049	1,048	1,047	1,047	950.8	950.0
Temperature, °F	Eq. 3	70.0	70.0	69.9	69.9	69.9	69.8	64.3	64.3
Vapor fraction	Note 3	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Mass flow, lb/h	Eq. 1	183,350	183,350	183,350	183,349	183,349	183,349	183,349	183,349
Standard flow, MMSCFD	Eq. 1	90.00	90.00	90.00	90.00	90.00	90.00	90.00	90.00
Actual flow, acfm	Eq. 2	735.4	735.7	736.3	736.6	737.2	737.6	809.4	810.0
Molecular weight, lb/lbmol	GERG	18.46	18.46	18.46	18.46	18.46	18.46	18.46	18.46
Compressibility Z	GERG	0.8318	0.8319	0.8319	0.8320	0.8320	0.8321	0.8392	0.8392
Density, lb/ft³	GERG	4.155	4.154	4.150	4.148	4.145	4.143	3.776	3.772
Viscosity, cP	Note 4	0.0131	0.0131	0.0131	0.0131	0.0131	0.0131	0.0127	0.0127
Heat capacity c_p , Btu/lb·°F	GERG	0.665	0.665	0.665	0.665	0.665	0.665	0.650	0.650
Ratio c_p/c_v (real)	GERG	1.621	1.621	1.621	1.621	1.620	1.620	1.596	1.596
Ratio k (ideal gas)	GERG	1.279	1.279	1.279	1.279	1.279	1.279	1.280	1.280
Isentropic exponent κ	Eq. 7	1.374	1.374	1.374	1.374	1.374	1.374	1.356	1.356
Speed of sound, ft/s	GERG	1,277	1,277	1,277	1,277	1,277	1,277	1,267	1,267
Gross heating value, Btu/scf	Note 5	1,103.7	1,103.7	1,103.7	1,103.7	1,103.7	1,103.7	1,103.7	1,103.7

Table 11: Case C2, Fuel Gas Streams

Property, unit	Eq.	S10	S11	S12	S13	S14
Pressure, psig	Note 2	1,049	1,049	150.0	15.0	15.0
Temperature, °F	Eq. 3	69.9	105.0	51.9	42.2	42.2
Vapor fraction	Note 3	1.00	1.00	1.00	1.00	1.00
Mass flow, lb/h	Eq. 1	1.2	1.2	1.2	1.2	0.0
Standard flow, MMSCFD	Eq. 1	0.0006	0.0006	0.0006	0.0006	0.0000
Actual flow, acfm	Eq. 2	0.0	0.0	0.0	0.2	0
Molecular weight, lb/lbmol	GERG	18.46	18.46	18.46	18.46	18.46
Compressibility Z	GERG	0.8319	0.8712	0.9696	0.9943	0.9943
Density, lb/ft³	GERG	4.150	3.717	0.569	0.100	0.100
Viscosity, cP	Note 4	0.0131	0.0135	0.0107	0.0104	0.0104
Heat capacity c_p , Btu/lb·°F	GERG	0.665	0.635	0.508	0.488	0.488
Ratio c_p/c_v (real)	GERG	1.621	1.523	1.324	1.293	1.293
Ratio k (ideal gas)	GERG	1.279	1.270	1.283	1.285	1.285
Isentropic exponent κ	Eq. 7	1.374	1.352	1.284	1.285	1.285

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Property, unit		Eq.	S10	S11	S12	S13	S14
Speed of sound, ft/s		GERG	1,277	1,338	1,309	1,314	1,314
Gross heating value, Btu/scf		Note 5	1,103.7	1,103.7	1,103.7	1,103.7	1,103.7

Note 1: Stream 14 carries no flow in normal operation. G-101 is a standby generator; its design flow is 680 scf/h at the stream 13 state.

CASE C3: MINIMUM FLOW (TURNDOWN)

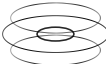
Table 12 gives the main gas streams for case C3 (10 MMSCFD custody flow, design gas, H-101 bypassed) and Table 13 the fuel gas streams.

Table 12: Case C3, Main Gas Streams

Property, unit	Eq.	S1	S2	S3	S4	S5	S6	S7	S8
Pressure, psig	Note 2	1,000	1,000.0	1,000.0	1,000.0	1,000.0	1,000.0	950.0	950.0
Temperature, °F	Eq. 3	60.0	60.0	60.0	60.0	60.0	60.0	57.0	57.0
Vapor fraction	Note 3	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Mass flow, lb/h	Eq. 1	20,373	20,373	20,373	20,372	20,372	20,372	20,372	20,372
Standard flow, MMSCFD	Eq. 1	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00
Actual flow, acfm	Eq. 2	83.5	83.5	83.5	83.5	83.5	83.5	87.8	87.8
Molecular weight, lb/lbmol	GERG	18.46	18.46	18.46	18.46	18.46	18.46	18.46	18.46
Compressibility Z	GERG	0.8259	0.8259	0.8259	0.8259	0.8259	0.8259	0.8298	0.8298
Density, lb/ft³	GERG	4.065	4.065	4.065	4.065	4.065	4.065	3.869	3.869
Viscosity, cP	Note 4	0.0129	0.0129	0.0129	0.0129	0.0129	0.0129	0.0127	0.0127
Heat capacity c_p , Btu/lb·°F	GERG	0.667	0.667	0.667	0.667	0.667	0.667	0.659	0.659
Ratio c_p/c_v (real)	GERG	1.634	1.634	1.634	1.634	1.634	1.634	1.620	1.620
Ratio k (ideal gas)	GERG	1.281	1.281	1.281	1.281	1.281	1.281	1.282	1.282
Isentropic exponent κ	Eq. 7	1.370	1.370	1.370	1.370	1.370	1.370	1.361	1.361
Speed of sound, ft/s	GERG	1,258	1,258	1,258	1,258	1,258	1,258	1,253	1,253
Gross heating value, Btu/scf	Note 5	1,103.7	1,103.7	1,103.7	1,103.7	1,103.7	1,103.7	1,103.7	1,103.7

Table 13: Case C3, Fuel Gas Streams

Property, unit	Eq.	S10	S11	S12	S13	S14
Pressure, psig	Note 2	1,000.0	1,000.0	150.0	15.0	15.0
Temperature, °F	Eq. 3	60.0	105.0	54.8	45.3	45.3
Vapor fraction	Note 3	1.00	1.00	1.00	1.00	1.00
Mass flow, lb/h	Eq. 1	1.2	1.2	1.2	1.2	0.0
Standard flow, MMSCFD	Eq. 1	0.0006	0.0006	0.0006	0.0006	0.0000
Actual flow, acfm	Eq. 2	0.0	0.0	0.0	0.2	0
Molecular weight, lb/lbmol	GERG	18.46	18.46	18.46	18.46	18.46
Compressibility Z	GERG	0.8259	0.8763	0.9702	0.9944	0.9944
Density, lb/ft³	GERG	4.065	3.526	0.566	0.100	0.100
Viscosity, cP	Note 4	0.0129	0.0133	0.0108	0.0105	0.0105
Heat capacity c_p , Btu/lb·°F	GERG	0.667	0.628	0.509	0.489	0.489

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Property, unit		Eq.	S10	S11	S12	S13	S14
Ratio c_p/c_v (real)		GERG	1.634	1.509	1.323	1.292	1.292
Ratio k (ideal gas)		GERG	1.281	1.270	1.282	1.285	1.285
Isentropic exponent κ		Eq. 7	1.370	1.344	1.283	1.284	1.284
Speed of sound, ft/s		GERG	1,258	1,338	1,313	1,318	1,318
Gross heating value, Btu/scf		Note 5	1,103.7	1,103.7	1,103.7	1,103.7	1,103.7

Note 1: Stream 14 carries no flow in normal operation. G-101 is a standby generator; its design flow is 680 scf/h at the stream 13 state.

CASE C4: SUMMER MAX TEMPERATURE

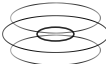
Table 14 gives the main gas streams for case C4 (120 MMSCFD custody flow, design gas, H-101 bypassed) and Table 15 the fuel gas streams.

Table 14: Case C4, Main Gas Streams

Property, unit	Eq.	S1	S2	S3	S4	S5	S6	S7	S8
Pressure, psig	Note 2	1,100	1,099	1,097	1,097	1,095	1,094	1,002	1,000
Temperature, °F	Eq. 3	120.0	120.0	119.9	119.8	119.8	119.7	115.5	115.4
Vapor fraction	Note 3	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Mass flow, lb/h	Eq. 1	244,466	244,466	244,466	244,465	244,465	244,465	244,465	244,465
Standard flow, MMSCFD	Eq. 1	120.00	120.00	120.00	120.00	120.00	120.00	120.00	120.00
Actual flow, acfm	Eq. 2	1,084	1,085	1,087	1,088	1,089	1,090	1,187	1,189
Molecular weight, lb/lbmol	GERG	18.46	18.46	18.46	18.46	18.46	18.46	18.46	18.46
Compressibility Z	GERG	0.8800	0.8801	0.8802	0.8802	0.8803	0.8804	0.8853	0.8854
Density, lb/ft³	GERG	3.757	3.755	3.749	3.746	3.740	3.736	3.432	3.427
Viscosity, cP	Note 4	0.0138	0.0138	0.0137	0.0137	0.0137	0.0137	0.0134	0.0134
Heat capacity c_p , Btu/lb·°F	GERG	0.635	0.635	0.635	0.634	0.634	0.634	0.624	0.624
Ratio c_p/c_v (real)	GERG	1.505	1.505	1.505	1.505	1.504	1.504	1.488	1.488
Ratio k (ideal gas)	GERG	1.266	1.266	1.266	1.266	1.266	1.266	1.267	1.267
Isentropic exponent κ	Eq. 7	1.352	1.352	1.352	1.352	1.352	1.352	1.339	1.339
Speed of sound, ft/s	GERG	1,363	1,363	1,363	1,363	1,363	1,362	1,355	1,355
Gross heating value, Btu/scf	Note 5	1,103.7	1,103.7	1,103.7	1,103.7	1,103.7	1,103.7	1,103.7	1,103.7

Table 15: Case C4, Fuel Gas Streams

Property, unit	Eq.	S10	S11	S12	S13	S14
Pressure, psig	Note 2	1,097	1,097	150.0	15.0	15.0
Temperature, °F	Eq. 3	119.9	119.9	67.6	58.6	58.6
Vapor fraction	Note 3	1.00	1.00	1.00	1.00	1.00
Mass flow, lb/h	Eq. 1	1.2	1.2	1.2	1.2	0.0
Standard flow, MMSCFD	Eq. 1	0.0006	0.0006	0.0006	0.0006	0.0000
Actual flow, acfm	Eq. 2	0.0	0.0	0.0	0.2	0
Molecular weight, lb/lbmol	GERG	18.46	18.46	18.46	18.46	18.46

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Property, unit		Eq.	S10	S11	S12	S13	S14
Compressibility Z		GERG	0.8802	0.8802	0.9727	0.9949	0.9949
Density, lb/ft³		GERG	3.749	3.749	0.551	0.097	0.097
Viscosity, cP		Note 4	0.0137	0.0137	0.0110	0.0107	0.0107
Heat capacity c_p , Btu/lb·°F		GERG	0.635	0.635	0.512	0.493	0.493
Ratio c_p/c_v (real)		GERG	1.505	1.505	1.317	1.288	1.288
Ratio k (ideal gas)		GERG	1.266	1.266	1.279	1.282	1.282
Isentropic exponent κ		Eq. 7	1.352	1.352	1.281	1.281	1.281
Speed of sound, ft/s		GERG	1,363	1,363	1,330	1,334	1,334
Gross heating value, Btu/scf		Note 5	1,103.7	1,103.7	1,103.7	1,103.7	1,103.7

Note 1: Stream 14 carries no flow in normal operation. G-101 is a standby generator; its design flow is 680 scf/h at the stream 13 state.

CASE C5: MIN METERING PRESSURE, MAX FLOW

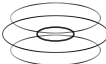
Table 16 gives the main gas streams for case C5 (120 MMSCFD custody flow, design gas, H-101 in service) and Table 17 the fuel gas streams.

Table 16: Case C5, Main Gas Streams

Property, unit	Eq.	S1	S2	S3	S4	S5	S6	S7	S8
Pressure, psig	Note 2	900.0	899.2	897.2	896.4	894.5	890.9	751.8	750.0
Temperature, °F	Eq. 3	60.0	60.0	59.8	59.8	59.7	59.6	50.8	50.7
Vapor fraction	Note 3	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Mass flow, lb/h	Eq. 1	244,468	244,468	244,468	244,465	244,465	244,465	244,465	244,465
Standard flow, MMSCFD	Eq. 1	120.00	120.00	120.00	120.00	120.00	120.00	120.00	120.00
Actual flow, acfm	Eq. 2	1,133	1,134	1,137	1,138	1,140	1,145	1,352	1,356
Molecular weight, lb/lbmol	GERG	18.46	18.46	18.46	18.46	18.46	18.46	18.46	18.46
Compressibility Z	GERG	0.8418	0.8419	0.8421	0.8422	0.8423	0.8428	0.8567	0.8569
Density, lb/ft ³	GERG	3.595	3.592	3.584	3.581	3.574	3.558	3.013	3.006
Viscosity, cP	Note 4	0.0125	0.0125	0.0125	0.0125	0.0125	0.0125	0.0120	0.0120
Heat capacity c_p , Btu/lb·°F	GERG	0.643	0.643	0.643	0.643	0.642	0.642	0.618	0.618
Ratio c_p/c_v (real)	GERG	1.587	1.586	1.586	1.586	1.585	1.584	1.544	1.543
Ratio k (ideal gas)	GERG	1.281	1.281	1.281	1.281	1.281	1.281	1.283	1.283
Isentropic exponent κ	Eq. 7	1.349	1.349	1.348	1.348	1.348	1.347	1.327	1.327
Speed of sound, ft/s	GERG	1,260	1,260	1,260	1,260	1,260	1,260	1,250	1,250
Gross heating value, Btu/scf	Note 5	1,103.7	1,103.7	1,103.7	1,103.7	1,103.7	1,103.7	1,103.7	1,103.7

Table 17: Case C5, Fuel Gas Streams

Property, unit	Eq.	S10	S11	S12	S13	S14
Pressure, psig	Note 2	897.2	897.2	150.0	15.0	15.0
Temperature, °F	Eq. 3	59.8	105.0	61.1	51.8	51.8
Vapor fraction	Note 3	1.00	1.00	1.00	1.00	1.00

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Property, unit	Eq.	S10	S11	S12	S13	S14	
Mass flow, lb/h	Eq. 1	2.8	2.8	2.8	2.8	0.0	
Standard flow, MMSCFD	Eq. 1	0.0014	0.0014	0.0014	0.0014	0.0000	
Actual flow, acfm	Eq. 2	0.0	0.0	0.1	0.5	0	
Molecular weight, lb/lbmol	GERG	18.46	18.46	18.46	18.46	18.46	
Compressibility Z	GERG	0.8421	0.8875	0.9714	0.9946	0.9946	
Density, lb/ft³	GERG	3.584	3.129	0.558	0.098	0.098	
Viscosity, cP	Note 4	0.0125	0.0131	0.0109	0.0106	0.0106	
Heat capacity c_p , Btu/lb·°F	GERG	0.643	0.613	0.510	0.491	0.491	
Ratio c_p/c_v (real)	GERG	1.586	1.479	1.320	1.290	1.290	
Ratio k (ideal gas)	GERG	1.281	1.270	1.281	1.283	1.283	
Isentropic exponent κ	Eq. 7	1.348	1.328	1.282	1.283	1.283	
Speed of sound, ft/s	GERG	1,260	1,339	1,321	1,326	1,326	
Gross heating value, Btu/scf	Note 5	1,103.7	1,103.7	1,103.7	1,103.7	1,103.7	

Note 1: Stream 14 carries no flow in normal operation. G-101 is a standby generator; its design flow is 680 scf/h at the stream 13 state.

CASE C6: HEATER-OUT WINTER UPSET

Table 18 gives the main gas streams for case C6 (120 MMSCFD custody flow, design gas, H-101 bypassed) and Table 19 the fuel gas streams.

Table 18: Case C6, Main Gas Streams

Property, unit	Eq.	S1	S2	S3	S4	S5	S6	S7	S8
Pressure, psig	Note 2	1,150	1,149	1,148	1,147	1,146	1,145	751.6	750.0
Temperature, °F	Eq. 3	45.0	45.0	44.9	44.8	44.8	44.7	18.2	18.1
Vapor fraction	Note 3	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Mass flow, lb/h	Eq. 1	244,466	244,466	244,466	244,465	244,465	244,465	244,465	244,465
Standard flow, MMSCFD	Eq. 1	120.00	120.00	120.00	120.00	120.00	120.00	120.00	120.00
Actual flow, acfm	Eq. 2	798.2	798.6	799.5	799.9	800.8	801.3	1,203	1,206
Molecular weight, lb/lbmol	GERG	18.46	18.46	18.46	18.46	18.46	18.46	18.46	18.46
Compressibility Z	GERG	0.7775	0.7775	0.7776	0.7776	0.7777	0.7778	0.8141	0.8143
Density, lb/ft ³	GERG	5.104	5.102	5.096	5.094	5.088	5.085	3.386	3.379
Viscosity, cP	Note 4	0.0134	0.0134	0.0134	0.0134	0.0134	0.0134	0.0116	0.0116
Heat capacity c_p , Btu/lb·°F	GERG	0.735	0.735	0.735	0.735	0.734	0.734	0.657	0.657
Ratio c_p/c_v (real)	GERG	1.787	1.787	1.787	1.787	1.786	1.786	1.651	1.651
Ratio k (ideal gas)	GERG	1.285	1.285	1.285	1.285	1.285	1.285	1.291	1.291
Isentropic exponent κ	Eq. 7	1.429	1.429	1.429	1.428	1.428	1.428	1.339	1.338
Speed of sound, ft/s	GERG	1,229	1,229	1,229	1,228	1,228	1,228	1,184	1,184
Gross heating value, Btu/scf	Note 5	1,103.7	1,103.7	1,103.7	1,103.7	1,103.7	1,103.7	1,103.7	1,103.7

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Table 19: Case C6, Fuel Gas Streams

Property, unit	Eq.	S10	S11	S12	S13	S14
Pressure, psig	Note 2	1,148	1,148	150.0	15.0	15.0
Temperature, °F	Eq. 3	44.9	105.0	45.9	36.0	36.0
Vapor fraction	Note 3	1.00	1.00	1.00	1.00	1.00
Mass flow, lb/h	Eq. 1	1.2	1.2	1.2	1.2	0.0
Standard flow, MMSCFD	Eq. 1	0.0006	0.0006	0.0006	0.0006	0.0000
Actual flow, acfm	Eq. 2	0.0	0.0	0.0	0.2	0
Molecular weight, lb/lbmol	GERG	18.46	18.46	18.46	18.46	18.46
Compressibility Z	GERG	0.7776	0.8611	0.9683	0.9940	0.9940
Density, lb/ft³	GERG	5.096	4.112	0.577	0.102	0.102
Viscosity, cP	Note 4	0.0134	0.0137	0.0106	0.0103	0.0103
Heat capacity C_p , Btu/lb·°F	GERG	0.735	0.650	0.507	0.486	0.486
Ratio C_p/C_v (real)	GERG	1.787	1.553	1.327	1.294	1.294
Ratio k (ideal gas)	GERG	1.285	1.270	1.285	1.287	1.287
Isentropic exponent κ	Eq. 7	1.429	1.371	1.285	1.287	1.287
Speed of sound, ft/s	GERG	1,229	1,340	1,301	1,306	1,306
Gross heating value, Btu/scf	Note 5	1,103.7	1,103.7	1,103.7	1,103.7	1,103.7

Note 1: Stream 14 carries no flow in normal operation. G-101 is a standby generator; its design flow is 680 scf/h at the stream 13 state.

CASE C7: RICH GAS, DESIGN MAX

Table 20 gives the main gas streams for case C7 (120 MMSCFD custody flow, rich gas, H-101 in service) and Table 21 the fuel gas streams.

Table 20: Case C7, Main Gas Streams

Property, unit	Eq.	S1	S2	S3	S4	S5	S6	S7	S8
Pressure, psig	Note 2	1,100	1,099	1,098	1,097	1,096	1,093	851.6	850.0
Temperature, °F	Eq. 3	60.0	60.0	59.9	59.8	59.7	67.8	52.1	51.9
Vapor fraction	Note 3	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Mass flow, lb/h	Eq. 1	260,863	260,863	260,863	260,771	260,771	260,771	260,771	260,771
Standard flow, MMSCFD	Eq. 1	120.04	120.04	120.04	120.00	120.00	120.00	120.00	120.00
Actual flow, acfm	Eq. 2	855.8	856.2	857.4	857.6	858.7	890.8	1,135	1,137
Molecular weight, lb/lbmol	GERG	19.69	19.69	19.69	19.69	19.69	19.69	19.69	19.69
Compressibility Z	GERG	0.7741	0.7742	0.7743	0.7743	0.7744	0.7890	0.8103	0.8105
Density, lb/ft³	GERG	5.081	5.078	5.071	5.068	5.061	4.879	3.830	3.823
Viscosity, cP	Note 4	0.0136	0.0136	0.0136	0.0136	0.0136	0.0136	0.0125	0.0125
Heat capacity C_p , Btu/lb·°F	GERG	0.719	0.719	0.718	0.718	0.718	0.700	0.656	0.656
Ratio C_p/C_v (real)	GERG	1.746	1.746	1.745	1.745	1.744	1.700	1.627	1.627
Ratio k (ideal gas)	GERG	1.267	1.267	1.267	1.267	1.267	1.265	1.269	1.269

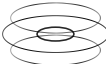
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Property, unit	Eq.	S1	S2	S3	S4	S5	S6	S7	S8	
Isentropic exponent κ	Eq. 7	1.384	1.384	1.383	1.383	1.383	1.373	1.323	1.323	
Speed of sound, ft/s	GERG	1,186	1,186	1,185	1,185	1,185	1,201	1,177	1,177	
Gross heating value, Btu/scf	Note 5	1,168.8	1,168.8	1,168.8	1,168.8	1,168.8	1,168.8	1,168.8	1,168.8	

Table 21: Case C7, Fuel Gas Streams

Property, unit	Eq.	S10	S11	S12	S13	S14
Pressure, psig	Note 2	1,098	1,098	150.0	15.0	15.0
Temperature, °F	Eq. 3	59.9	105.0	42.5	31.5	31.5
Vapor fraction	Note 3	1.00	1.00	1.00	1.00	1.00
Mass flow, lb/h	Eq. 1	92.0	92.0	92.0	92.0	0.0
Standard flow, MMSCFD	Eq. 1	0.0424	0.0424	0.0424	0.0424	0.0000
Actual flow, acfm	Eq. 2	0.3	0.4	2.5	14.0	0
Molecular weight, lb/lbmol	GERG	19.69	19.69	19.69	19.69	19.69
Compressibility Z	GERG	0.7743	0.8405	0.9624	0.9929	0.9929
Density, lb/ft³	GERG	5.071	4.297	0.623	0.109	0.109
Viscosity, cP	Note 4	0.0136	0.0138	0.0104	0.0101	0.0101
Heat capacity c_p , Btu/lb·°F	GERG	0.718	0.652	0.497	0.473	0.473
Ratio c_p/c_v (real)	GERG	1.745	1.561	1.319	1.282	1.282
Ratio k (ideal gas)	GERG	1.267	1.256	1.271	1.274	1.274
Isentropic exponent κ	Eq. 7	1.383	1.343	1.268	1.273	1.273
Speed of sound, ft/s	GERG	1,185	1,269	1,244	1,252	1,252
Gross heating value, Btu/scf	Note 5	1,168.8	1,168.8	1,168.8	1,168.8	1,168.8

Note 1: Stream 14 carries no flow in normal operation. G-101 is a standby generator; its design flow is 680 scf/h at the stream 13 state.

LIQUID, VENT AND STANDBY STREAMS

The streams in Table 22 are intermittent or design allowances and are the same in every case.

Table 22: Liquid, Vent and Standby Streams

Stream	Service	Flow	Composition	Pressure	Temperature	Source or note
20	V-101 liquids through LCV-104	2 bbl/d average (HOLD H-20); 30 gpm while dumping; design pig slug 5 bbl	Condensate, water and compressor oil, SG about 0.85 (HOLD H-12)	V-101 pressure to about 5 psig	About 30 to 60 °F after flashing across LCV-104	Flash gas about 750 scf per bbl dumped
21	PR-101 barrel drain	Batch, design 5 bbl per pig receipt	As stream 20	Atmospheric; barrel vented first	Ambient	Gravity drain
22	T-101 truck-out	Batch, vacuum truck at up to 400 gpm	As stream 20	Atmospheric	Ambient	About two loads a year at the normal liquids rate plus pig receipts
30	Vent header to VS-101	Intermittent: 16,859 lb/h peak blowdown of the inlet section; 15,793 lb/h PSV-101 in fire	Design gas	Atmospheric at the tip	Down to -64 °F in winter blowdown; 302 °F in fire relief	PRO-CAL-007, PRO-CAL-008
31	T-101 vent	Up to 30,863 SCFH air equivalent during a pig-slug dump	Flash gas with air and liquid vapor	Tank set 8 oz/in²	Ambient	PRO-CAL-007

EQUATIONS

Eq. 1: $W = Q \times 10^6 / 24 \times \rho_b$, with W in lb/h, Q in MMSCFD and ρ_b in lb/scf

Eq. 2: $Q_{act} = W / (60 \rho)$, in acfm

Eq. 3: $h(P_2, T_2) = h(P_1, T_1)$ through piping, valves and regulators (isenthalpic)

Eq. 4: $Q_{abs} = W(h_6 - h_5)$, heater absorbed duty

Eq. 5: $Q_{fired} = Q_{abs} / \eta$

Eq. 6: $Q_{E161} = W_{fuel}(h_{11} - h_{10})$

Eq. 7: $\kappa = \rho c^2 / p$, isentropic exponent from the real-gas speed of sound

RESULTS AND CONCLUSIONS

Every gas stream is single-phase in every case. The coldest process stream is the control valve outlet in case C6, the heater-out winter upset, at 18.2 °F. It stays above the -20 °F minimum design metal temperature and above the hydrocarbon dewpoint of the design gas, but it is below the hydrate criterion of PRO-CAL-003, which is why C6 is treated as an upset to be corrected and not as an operating case.

Case C1 governs the heater. H-101 absorbs 3.96 MMBtu/h and raises the gas from 44.8 °F to 67.4 °F so that the control valve outlet is 43.6 °F at 752 psig. Case C7, the rich-gas upset, needs 1.52 MMBtu/h to hold 52.1 °F, a margin of 10 °F above its hydrocarbon dewpoint at the outlet pressure. Station inlet flow exceeds custody flow only by the fuel draw, at most 235 lb/h in C1, about 0.1 %.

The stream values in this calculation are the ones shown on PRO-DWG-001 (cases C1 and C2) and PRO-DWG-002 (cases C3 to C7), and they are the inputs to the equipment and line sizing calculations listed in the references. The balance should be rerun when the extended gas analysis (HOLD H-12) and the heater vendor's efficiency (HOLD H-15) are received.