

OWNER

Line Heater H-101

Calculation



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1. OBJECTIVE

This calculation sizes line heater H-101, an indirect-fired water-bath heater built to API Specification 12K. It sets the absorbed duty for each operating case, the firebox rating and efficiency, the bath temperature, the process coil (size, number of parallel paths and passes, area and heat transfer coefficient) and the coil pressure drop, and the fuel consumption. It confirms or revises the nominal 5.0 MMBtu/h firebox of the Basis of Design.

2. METHODOLOGY

The heater must raise the gas temperature enough that, after the pressure cut at the flow control valves, the gas leaves at the setpoint established in PRO-CAL-003. For each case TORUS solved the heater outlet temperature that meets that setpoint with the station hydraulic model, and took the absorbed duty as the enthalpy rise of the gas from the GERG-2008 equation of state. The design duty is the governing case plus a 10 % margin for coil fouling and for the uncertainty in the hydrate estimate.

Efficiency was calculated from a combustion balance of the design gas at the stated excess air and stack temperature, including the latent heat of the product water because the rating is on the higher heating value, plus a casing loss. The firebox rating was then rounded up to the next standard size.

The coil was sized for heat transfer from an isothermal glycol-water bath. The gas-side film coefficient follows the Gnielinski correlation. The bath-side coefficient follows the Churchill-Chu correlation for natural convection from a horizontal cylinder, reduced by a bundle factor, with the wall temperature iterated so both films carry the same heat flux. Fouling and wall resistances were added in series to give an overall coefficient on the outside area. Six coil arrangements were screened against three requirements: enough area for the design duty, a pressure drop not above the 10 psi allowance of the Basis of Design, and a gas velocity not above the lesser of 60 ft/s and the API RP 14E erosional velocity in case C5, the lowest-density case.

3. DESIGN INPUTS

The inputs in Table 3-1 govern the calculation.

Table 3-1: Design Inputs

Input	Value	Source
Required valve outlet temperature	Pressure-compensated setpoint, 43.5 to 51.1 °F	PRO-CAL-003
Heater inlet conditions by case	Station hydraulic model	PRO-CAL-002

Input	Value	Source
Design margin on absorbed duty	10 %	TORUS practice
Bath fluid	50 wt % ethylene glycol and water, freezing point about -33 °F	Selected for -5 °F minimum ambient
Bath temperature, design and high-high trip	180 °F and 200 °F	Selected; atmospheric bath boils near 220 °F
Burner excess air	25 %	Typical natural-draft burner (HOLD H-15)
Stack temperature at rated firing	600 °F	Typical firetube heater (HOLD H-15)
Casing heat loss	2 % of fired duty	Typical insulated shell
Average firetube heat flux, on fired heat release	10,000 Btu/h-ft ²	API 12K rating practice (HOLD H-15)
Fouling, gas side and bath side	0.0005 and 0.001 h-ft ² ·°F/Btu	Clean dry gas; glycol bath
Natural convection bundle factor	0.85	TORUS practice
Straight length per coil pass	22 ft	Fits the 96 in x 29 ft shell of MEC-DS-003
Design gas heating value	1,103.7 Btu/scf higher, 997.3 Btu/scf lower	 GEN-DB-001

4. ASSUMPTIONS

- Efficiency, stack temperature, excess air, firetube flux and pilot gas rate are typical values.
Verification required against the selected vendor's data (HOLD H-15).
- The heater is sized on the design gas. The rich gas of case C7 needs 1.52 MMBtu/h, well within the rating.
- Bath heat loss is included in the 2 % casing loss.
- The coil area excludes the return bends, which adds a small margin.
- The overall coefficient is calculated for a clean coil; fouling is carried in the resistances and in the 10 % duty margin.

5. REFERENCES

- API Specification 12K, 9th Edition (2021), Indirect-type Oil-field Heaters.
- API Recommended Practice 14E, 5th Edition (1991, reaffirmed 2013), Design and Installation of Offshore Production Platform Piping Systems (erosional velocity).

3. ASME Boiler and Pressure Vessel Code, Section VIII Division 1 (2023), for the coil manifolds.
4. Churchill, S.W. and Chu, H.H.S., Correlating Equations for Laminar and Turbulent Free Convection from a Horizontal Cylinder, Int. J. Heat Mass Transfer 18 (1975).
5. Gnielinski, V., New Equations for Heat and Mass Transfer in Turbulent Pipe and Channel Flow, Int. Chem. Eng. 16 (1976).
6. Crane Technical Paper 410, Flow of Fluids through Valves, Fittings and Pipe (2018).
7. GPA 2145-16, Table of Physical Properties for Hydrocarbons.
8. GEN-DB-001, Basis of Design.
9. PRO-CAL-002, Line Sizing and Station Hydraulics; PRO-CAL-003, Joule-Thomson Cooling, Hydrate and Dewpoint; PRO-CAL-010, Fuel Gas System.

6. CALCULATION

6.1. ABSORBED DUTY

Case C1, the winter design maximum, governs. The heater receives 244,465 lb/h at 1,146 psig and 44.7 °F. To deliver 43.6 °F at the valve outlet (752 psig), where the setpoint is 43.6 °F, the gas must leave the heater at 67.4 °F. The enthalpies are 297.68 and 313.87 Btu/lb:

GERG-2008 enthalpies

$$Q_{abs} = \dot{m} (h_{out} - h_{in}) = 244,465 (313.87 - 297.68) = 3.96 \times 10^6 \text{ Btu/h}$$

$$Q_{design} = 1.10 Q_{abs} = 4.35 \text{ MMBtu/h}$$

Table 6-1 gives the duty for each case that uses the heater. C6 is C1 with the heater unavailable, so it needs the same duty. Winter normal operation is case C2 flow and pressures with a 45 °F inlet; it sets the average fuel use.

Table 6-1: Absorbed Duty by Case

Case	Flow, MMSCFD	Heater inlet, psig	Heater inlet, °F	Heater outlet, °F	Valve outlet, °F	Setpoint, °F	Absorbed, MMBtu/h
C1	120	1,146	44.7	67.4	43.6	43.6	3.96
C5	120	894	59.6	59.6	50.8	43.6	0.03
C7 (rich gas)	120	1,095	59.7	67.8	52.1	52.1	1.52
Winter normal	90	1,047	44.8	53.6	47.8	47.8	1.13

6.2. EFFICIENCY AND FIREBOX RATING

Per lbmol of design fuel gas, the combustion balance gives the flue gas in Table 6-2.



Table 6-2: Combustion Balance per lbmol of Fuel

Quantity	lbmol per lbmol fuel
O2, stoichiometric	2.176
Air supplied, 25 % excess	12.95
CO2 in flue gas	1.133
H2O in flue gas	2.103
N2 in flue gas	10.24
O2 in flue gas	0.544
Total flue gas	14.02

The flue gas carries 56,632 Btu of sensible heat from 60 to 600 °F and 40,346 Btu of latent heat in its water vapor, per lbmol of fuel with a higher heating value of 418,828 Btu/lbmol:

Combustion heat balance, higher heating value basis

$$\eta_{HHV} = 1 - \frac{Q_{sens} + Q_{lat}}{HHV} - L_{casing} = 1 - \frac{56,632 + 40,346}{418,828} - 0.02 = 0.748$$

$$Q_{fired} = \frac{Q_{design}}{\eta_{HHV}} = \frac{4.35}{0.748} = 5.82 \text{ MMBtu/h}$$

The next standard firebox size is 6.0 MMBtu/h, which absorbs 4.49 MMBtu/h. The 5.0 MMBtu/h firebox of the Basis of Design would need an efficiency of 79 % to meet the C1 duty with no margin at all, which a natural-draft firetube heater cannot be relied on to achieve, so it was not retained. Firetubes of indirect heaters are rated on heat release, so the firetube surface is set by the 6.0 MMBtu/h fired rating at an average flux of 10,000 Btu/h·ft²: at least 600 ft². Sizing on the absorbed duty would give only 449 ft² and would overload the firetube at full firing. Table 6-3 shows how the efficiency moves with stack temperature and excess air; a vendor reporting a stack temperature above 700 °F at rated firing would need a larger firebox.

Table 6-3: Efficiency Sensitivity

Stack temperature, °F	Excess air, %	Efficiency, % HHV	Efficiency, % LHV
500	15	78.2	86.5
500	25	77.4	85.7
500	40	76.3	84.4
600	15	75.8	83.9
600	25	74.8	82.8
600	40	73.4	81.3
700	15	73.4	81.2
700	25	72.2	79.9
700	40	70.5	78.1

H-101 requires 5.82 MMBtu/h fired. A 6.0 MMBtu/h firebox is selected, in place of the nominal 5.0 MMBtu/h of the Basis of Design.

6.3. PROCESS COIL

Table 6-4 compares the six coil arrangements for case C1 area and U value, the larger of the C1 and C5 pressure drops, and the C5 velocity against its erosional limit. A single NPS 6 path, the arrangement implied by the Basis of Design, fails: at 120 MMSCFD it runs at 105 ft/s against an erosional limit of 53 ft/s and loses 54.5 psi. Option D is the first to meet all three requirements. The NPS 8 options have less area per foot of shell and would need more passes than the shell holds.

Table 6-4: Coil Options

Option	Coil	Area, ft ²	Area required, ft ²	U, Btu/h·ft ² ·°F	Pressure drop, psi	C5 velocity / limit, ft/s	Result
A	NPS 6, 1 x 12	458	467	75.4	54.5	105 / 53	Fails
B	NPS 6, 2 x 6	458	508	69.4	7.3	53 / 53	Fails
C	NPS 6, 3 x 4	458	545	64.6	2.3	35 / 53	Fails
D	NPS 6, 3 x 5	572	545	64.6	2.8	35 / 53	Meets
E	NPS 8, 2 x 4	397	578	61.0	1.4	30 / 53	Fails
F	NPS 8, 2 x 5	497	578	61.0	1.7	30 / 53	Fails

For the selected coil, NPS 6 Sch 80 (OD 6.625 in, ID 5.761 in) with 3 parallel paths of 5 passes, each path carries 22.64 lb/s. At the mean gas temperature of 56.1 °F the gas velocity is 25.8 ft/s, the Reynolds number is 6.7 million and the Prandtl number 0.978:

Gnielinski (1976)

$$Nu_i = \frac{(f/8)(Re - 1000) Pr}{1 + 12.7\sqrt{f/8} (Pr^{2/3} - 1)} = 7,072, \quad h_i = 346 \text{ Btu/h}\cdot\text{ft}^2\cdot^\circ\text{F}$$

On the bath side, at a film temperature of 144 °F and an outer surface temperature of 107.2 °F, the Rayleigh number is 8.6×10^9 and the Prandtl number 11.2:

Churchill and Chu (1975)

$$Nu_o = \left(0.60 + \frac{0.387 Ra^{1/6}}{[1 + (0.559/Pr)^{9/16}]^{8/27}} \right)^2 = 298, \quad h_o = 110.0 \text{ Btu/h}\cdot\text{ft}^2\cdot^\circ\text{F}$$

The last value includes the bundle factor of 0.85. Summing the resistances on the outside area:

$$\frac{1}{U_o} = \frac{1}{h_o} + R_{fo} + R_{fi} \frac{D_o}{D_i} + \frac{D_o}{D_i h_i} + \frac{D_o \ln(D_o/D_i)}{2k_w}$$

$$\frac{1}{U_o} = 0.00909 + 0.00100 + 0.00057 + 0.00332 + 0.00148 = 0.01548, \quad U_o = 64.6 \text{ Btu/h} \cdot \text{ft}^2 \cdot ^\circ\text{F}$$

With the bath at 180 °F the log mean temperature difference and the required area are:

$$LMTD = \frac{T_{out} - T_{in}}{\ln[(T_b - T_{in})/(T_b - T_{out})]} = \frac{67.4 - 44.7}{\ln[(180 - 44.7)/(180 - 67.4)]} = 123.6 \text{ } ^\circ\text{F}$$

$$A_{req} = \frac{Q_{design}}{U_o LMTD} = \frac{4,353,250}{64.6 \times 123.6} = 545 \text{ ft}^2$$

The coil provides $3 \times 5 \times 22 \text{ ft} \times \pi \times 6.625/12 = 572 \text{ ft}^2$, 5 % above the requirement. The pressure drop through one path (110 ft, sum of fitting coefficients 2.40, Darcy friction factor 0.0152) is 2.04 psi in case C1, against the 10 psi allowance.

The coil is NPS 6 Sch 80 in 3 parallel paths of 5 passes of 22 ft, 572 ft² outside area, with a pressure drop of 2.0 psi in C1 and 2.8 psi in C5.

6.4. PERFORMANCE BY CASE AND FUEL

Table 6-5 gives the bath temperature each case needs with a clean coil and no margin, and the fuel it burns. At C1 the bath needs 168 °F, which leaves margin to the 200 °F trip for fouling. Winter normal operation needs only about 96 °F. Table 6-6 shows the coil hydraulics.

Table 6-5: Heater Performance by Case

Case	Absorbed, MMBtu/h	U, Btu/h·ft ² ·°F	LMTD at 180 °F, °F	Bath required, °F	Fired, MMBtu/h	Fuel, scf/h
C1	3.96	64.6	123.6	168	5.29	4,791
C5	0.03	63.2	120.4	62	0.04	32
C7 (rich gas)	1.52	65.0	116.2	118	2.03	1,842
Winter normal	1.13	60.6	130.7	96	1.51	1,370

Table 6-6: Coil Hydraulics

Case	Pressure drop, psi	Velocity, ft/s	Erosional limit, ft/s	Momentum flux, lb/ft·s ²
C1	2.04	25.8	45.4	3,223
C5	2.78	35.0	52.9	4,379
C7 (rich gas)	2.27	26.8	44.8	3,578

Case	Pressure drop, psi	Velocity, ft/s	Erosional limit, ft/s	Momentum flux, lb/ft-s ²
Winter normal	1.25	21.0	47.3	1,966

At the 6.0 MMBtu/h rating the heater burns 5,436 scf/h. It burns 4,791 scf/h at C1 and 1,370 scf/h in winter normal operation, and the pilot burns 25 scf/h. With 151 days a year at winter normal duty and the pilot lit all year, the heater uses about 5.2 MMscf of fuel a year.

6.5. GAS OUTLET TEMPERATURE PROTECTION

At low flow the coil transfers far more heat than the gas can absorb. In case C3 (10 MMSCFD) the number of transfer units is 1.0, so with the bath at 180 °F the gas would leave at about 136 °F if the temperature controller failed high. The piping downstream is designed for 150 °F and the delivery maximum is 120 °F. The heater will therefore carry a high-high gas outlet temperature trip on TT-156 at 140 °F that shuts the burner down, in addition to the bath high-high trip TSHH-155 at 200 °F. The burner management system will use two diverse flame detectors, BE-153A and BE-153B.

7. RESULTS AND CONCLUSIONS

Table 7-1 summarizes the heater.

Table 7-1: H-101 Summary

Item	Value
Type	Indirect-fired water-bath heater to API 12K, natural-draft burner
Firebox rating, higher heating value	6.0 MMBtu/h
Design absorbed duty	4.35 MMBtu/h (C1 plus 10 %)
Absorbed duty at rating	4.49 MMBtu/h
Thermal efficiency, higher heating value	74.8 % (HOLD H-15)
Minimum firetube surface	600 ft ² at 10,000 Btu/h-ft ² on the fired rating
Bath	50 wt % ethylene glycol and water, 180 °F design, TSHH-155 at 200 °F, LSL-154 low level
Coil	NPS 6 Sch 80 SA-106 Grade B, 3 paths x 5 passes x 22 ft, 572 ft ²
Coil design	1,440 psig at 250 °F; nozzles and companion flanges Class 900
Coil pressure drop	2.0 psi at C1, 2.8 psi at C5
Shell	96 in x 29 ft (MEC-DS-003), about 34 ft x 9.5 ft overall
Fuel at rating / at C1 / pilot	5,436 / 4,791 / 25 scf/h
Protection	PSV-157 on the coil; TT-156 high-high trip at 140 °F; TSHH-155; LSL-154; flame detectors BE-153A and BE-153B

TORUS draws the following conclusions:

1. H-101 will have a 6.0 MMBtu/h firebox. The C1 duty at the setpoint of PRO-CAL-003 needs 5.82 MMBtu/h fired, which the nominal 5.0 MMBtu/h of the Basis of Design cannot supply. The heater remains below 10 MMBtu/h, so the air permitting assumption of the Basis of Design still holds.
2. The coil will be NPS 6 in 3 parallel paths of 5 passes. A single NPS 6 path would exceed the erosional velocity and the 10 psi coil allowance.
3. The heater will trip on high-high gas outlet temperature at 140 °F, because at low flow the gas would otherwise leave above the 150 °F design temperature of the downstream piping.
4. The fuel gas feeding PCV-161 will be preheated electrically (PRO-CAL-010), because a fuel coil in the bath gives no heat at start-up or in summer standby.

The following item remains open: efficiency, stack temperature, firetube flux, pilot rate and the final shell dimensions from the selected vendor (HOLD H-15).

