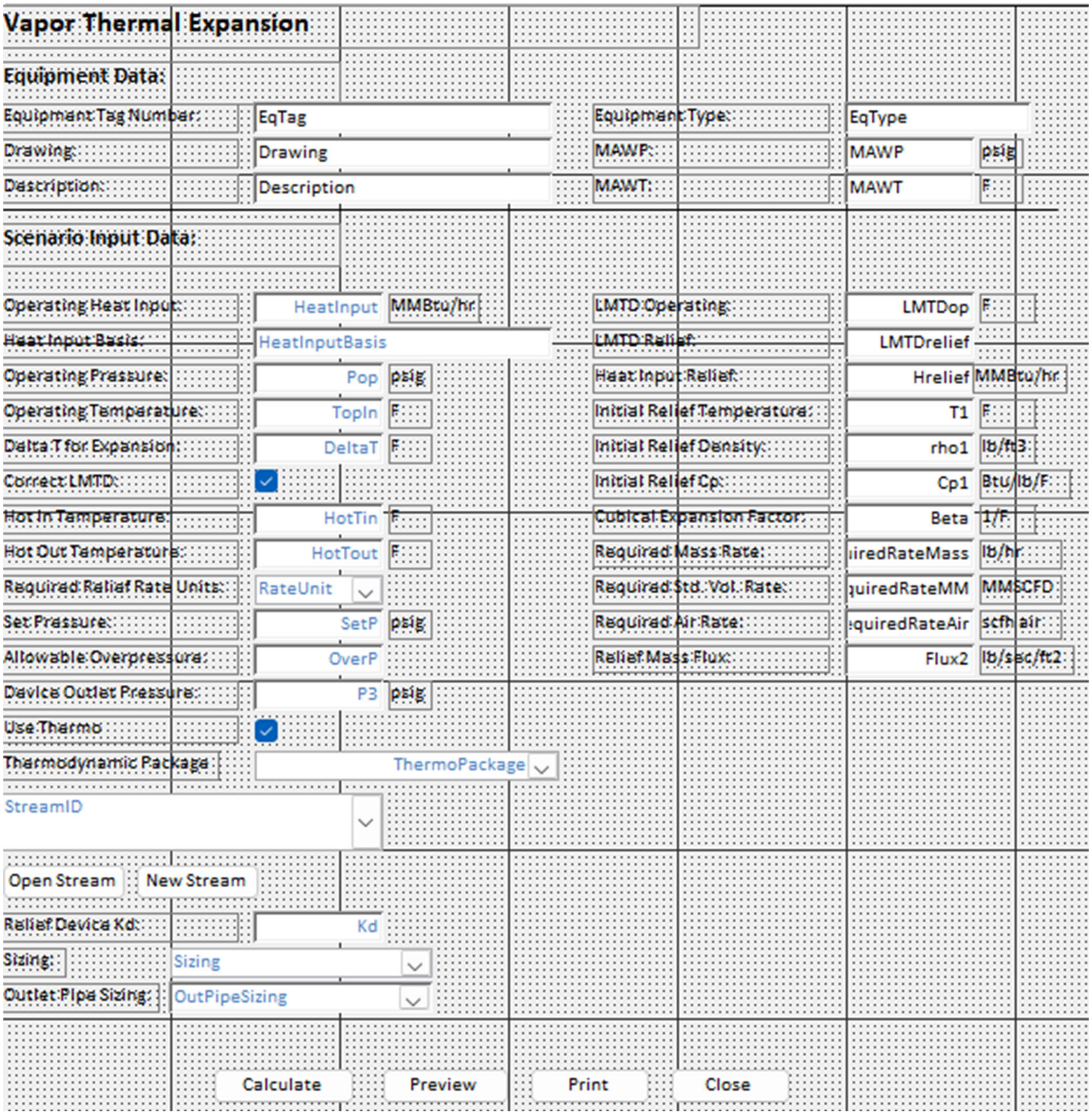
Vapor Thermal Expansion


Vapor Thermal Expansion

Equipment Data:

Equipment Tag Number: EqTag
Equipment Type: EqType
Drawing: Drawing
MAWP: MAWP psig
Description: Description
MAWT: MAWT F

Scenario Input Data:

Operating Heat Input: HeatInput MMBtu/hr
LMTD Operating: LMTDop F
Heat Input Basis: HeatInputBasis
LMTD Relief: LMTDrelief
Operating Pressure: Pop psig
Heat Input Relief: Hrelief MMBtu/hr
Operating Temperature: TopIn F
Initial Relief Temperature: T1 F
Delta T for Expansion: DeltaT F
Initial Relief Density: rho1 lb/ft3
Correct LMTD: ☑
Initial Relief Cp: Cp1 Btu/lb/F
Hot In Temperature: HotTin F
Cubical Expansion Factor: Beta 1/F
Hot Out Temperature: HotTout F
Required Mass Rate: iiredRateMass lb/hr
Required Relief Rate Units: RateUnit
Required Std. Vol. Rate: quiredRateMM MMSCFD
Set Pressure: SetP psig
Required Air Rate: equiredRateAir scfh air
Allowable Overpressure: OverP
Relief Mass Flux: Flux2 lb/sec/ft2
Device Outlet Pressure: P3 psig
Use Thermo ☑
Thermodynamic Package ThermoPackage
StreamID
Open Stream
New Stream
Relief Device Kd: Kd
Sizing: Sizing
Outlet Pipe Sizing: OutPipeSizing
Calculate
Preview
Print
Close

Equipment Data:

The six fields under Equipment Data are specified on the Overpressure Scenario Form.

Input Data:

The form fields for inputs are blue and organized under the Scenario Input column. These are described below:

HeatInput – Maximum heat input to system at operating conditions.

HeatInputBasis – Basis for heat input such as 110% of design duty, design duty or normal operating.

Pop – Operating pressure used to quantify initial density and initial relief temperature. Higher value results in higher density and lower initial relief temperature.

TopIn – Higher value results in lower density and higher initial relief temperature.

DeltaT – Temperature increase above initial relief temperature used in expansion calculation.

Correct LMTD – If yes, TopIn, HotIn and HotOut temperatures are used to determine a reduced LMTD and heat input at the relief pressure and temperature.

HotIn – Operating inlet temperature for hot side - only required for Correct LMTD

HotOut – Operating outlet temperature for hot side - only required for Correct LMTD

RateUnit – Flow units in which the required relief rate will be reported.

SetP – Set pressure that will be used along with overpressure to determine relief pressure.

OverP – Allowable overpressure typically 21% used to determine relief pressure.

P3 – Constant back pressure when PSV is closed.

Use Thermodynamics - If false, additional property inputs are required.

ThermoPackage – Thermo package used for properties. VMG (Symmetry) packages or REFPROP 10.0 from NIST

StreamID – The vapor stream contained in the vessel. A new stream can be added here. See Stream Definition Form.

Kd – Manufacturer's certified vapor Kd or 0.975 for API STD 520 default.

Sizing – PSV sizing method: API 520 Vapor or Numerical Integration (recommended when Z <= 0.8).

OutPipeSizing – Outlet pressure drop method: Adiabatic, Omega Method or Numerical Integration.

Calculation Method:

The calculation method for vapor expansion is similar to the liquid thermal expansion method utilizing the cubical expansion coefficient (α_v) determined as follows:

$$\alpha_v = \frac{rho1^2 - rho2^2}{2(T2 - T1)\ x\ rho1\ x\ rho2}$$

The heat input is generally the design duty or design duty plus some percentage over design. This operating heat input can be corrected for relief conditions using the operating and reduced LMTDs using the following formulae.

$$LMTD_{op} = \frac{[(HotTin - TopIn) - (HotTout - TopIn)]}{\log\left[\frac{(HotTin - TopIn)}{(HotTOut - TopIn)}\right]}$$

$$LMTD_{relief} = \frac{[(HotTin - T2) - (HotTout - T2)]}{\log\left[\frac{(HotTin - T2)}{(HotTOut - T2)}\right]}$$

$$Hrelief = HeatInput\ x\ \frac{LMTD_{relief}}{LMTD_{op}}$$

$$q_{relief} = \frac{Hrelief\ x\ \alpha_v}{Cp2}$$

q_{relief} is the required mass relief rate (lb/hr)

Cp2 is the mass specific heat at relief conditions (Btu/lb/°F)

Scenario Output Data:

The form fields for scenario-specific outputs are organized under the Scenario Output column. These are described below:

LMTDop – LMTD at operating conditions associated with HeatInput in °F

LMTDRelief – LMTD at relief conditions in °F

Hrelief – Heat input at relief conditions in Btu/hr accounting for reduced LMTD if specified

T1 – Temperature at initial relief conditions (start conditions for expansion)

Rho1 – Density in lb/ft^3 at initial relief conditions (start conditions for expansion)

Cp1 – Mass heat capacity in Btu/lb/°F at initial relief conditions (start conditions for expansion)

Beta – Cubical expansion coefficient at initial relief conditions 1/°F

RequiredRateMass – Required rate in lb/hr

RequiredRateMM – Required rate in MMSCFD

RequiredRateAir – Required rate converted to scfh air

Flux2 – RequiredRateMass · RequiredArea * 144 / 3600

Scenario Calculation Results:

The form fields for overall scenario results are organized in the Scenario Calculation Results Section. These outputs are typical of most of the scenario calculations and are detailed under Typical Scenario Calculation Results.

QA/QC Benchmarks:

The calculation was benchmarked against an internal RKR spreadsheet with fluid properties developed from a commercial simulator (Symmetry) using an overall heat and material balance approach based on an assumed initial gas volume of 857 ft^3. The initial relief temperature from Pressio was 417 °F versus 416.3 °F in Symmetry. In both cases the temperature increment for determining the expansion rate was

10 °F which resulted in required relief rates of 4,723 lb/hr and 4,628 lb/hr in Pressio and Symmetry (0.2% difference), respectively.

Thermal Expansion of Trapped Vapor

Vapor Thermal Expansion

Equipment Data:

Equipment Tag:	**E-6000**	Type:	Shell and Tube Exchanger
Drawing:	PID-6000	MAWP:	350 psig
Description:	Depropanizer Reboiler (Shell)	MAWT:	300 F

Scenario Description:

in the event that the shell side is free of liquid, overpressure could occur due to expansion of the vapor as a result of continued heat input from the hot oil on the tube side. The required relief rate was based on the design duty of the reboiler, the normal reboiler vapor composition at operating conditions of 270 psig @ 260 F and the relief pressure of 385 psig.

Scenario Calculation Results:

Required Rate:	4723.1	lb/hr	Device Choke Pressure:	222.6	psig
Actual Capacity:	71422.5	lb/hr	Outlet Temperature:	395.4	F
Required Area:	0.201	in2	Outlet Mass Quality:	1.000	
Actual Area:	3.043	in2	Outlet Density:	0.097	lb/ft3
Relief Pressure:	385.0	psig	Outlet Ideal Cp/Cv:	1.1	
Relief Temperature:	427.0	F	Outlet Viscosity:	0.012	cP
Relief MW:	60.37		Inlet Non-Recoverble dP:	4.6	psi
Relief Mass Quality:	1.000		Inlet dP % Set:	1.3	% Set
Relief Density:	3.15	lb/ft3	Built-Up Back Pressure:	60.1	psig
Relief SG:	2.082		Built-Up Back P % Set:	17.2	% Set
Relief Z:	0.81		Total Back Pressure:	60.1	psig
Relief Ideal Cp/Cv:	1.06		Total Back P % Set:	17.2	% Set
Relief Viscosity:	0.012	cP			

Atmospheric Dispersion Screening (Constant Back Pressure = 0 and Hydrocarbons Only):

Tail Pipe Exit Diameter:		in
Reset % Capacity:	0.0	%
Exit Minimum RE:		
Horizontal Distance (x):	0	ft
Sonic Velocity:		fps
Exit Quality Acceptable:	☐	
Lighter than Air:	☐	
Flammable::	☐	
Toxic:	☐	
Dispersion Screening Pass:		

	Actual	Reseat	
Exit RE:			
Exit Velocity:			fps
Exit/Wind Velocity:	0.0	0.0	
Minimum Exit Velocity:	0.0	0.0	fps
Horizontal Distance (x):			ft

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Description:	Depropanizer Reboiler (Shell)	MAWT:	300 F

Scenario Input Data:

Operating Heat Input:	5	MMBtu/hr
Heat Input Basis:	Design Duty	
Operating Pressure:	270	psig
Operating Temperature:	260	F
Delta T for Expansion:	10	F
Correct for Reduced LMTD:	☐	
Hot Inlet Temperature:	550	F
Hot Oulet Temperature:	450	F
Set Pressure:	350	psig
Allowable Overpressure:	10.0%	
Device Outlet Pressure:	0	psig
Thermodynamics Enabled:	☑	
Thermo Package:	Advanced_Peng-Robinson	
Relief Device Kd:	0.627	
Nozzle Sizing:	API 520 Vapor	
Outlet Pipe Sizing:	Adiabatic	

Scenario Output Data:

LMTD Operating:	236.5	F
LMTD Relief:	59.6	
Heat Input Relief:	1.26	MMBtu/hr
Initial Relief Temperature:	417.0	F
Initial Relief Density:	3.228	lb/ft3
Initial Relief Cp:	0.651	Btu/lb/F
Cubical Expansion Factor:	0.0024	1/F
Required Mass Rate:	4,723.1	lb/hr
Required Std. Vol. Rate:	0.70	MMSCFD
Required Air Rate:	55,949.2	scfh air
Relief Mass Flux:	939.9	lb/sec/ft2

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Description:	Depropanizer Reboiler (Shell)	MAWT:	300 F

Relief Stream Composition:

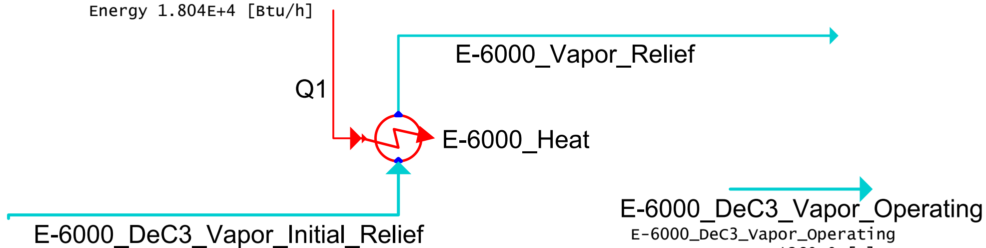
Stream Description: **Depropanizer Reboiler Vapor**

Component	Mole Fraction
methane	
ethane	
propane	0.0500
isobutane	0.2000
butane	0.5500
isopentane	0.1500
pentane	0.0400
hexane	0.0100
heptane	
octane	
nonane	
decane	
carbon dioxide	
hydrogen sulfide	
methanol	
water	

E-6000 Vapor Thermal Expansion

E-6000_Vapor_Relief		
T	*426.3	[F]
P	385.00	[psig]
Mass Flow	2766.00	[lb/h]
Mass Density	3.1553	[lb/ft3]
Cp Mass	0.6532	[Btu/lb-F]
Mass Vapor Frac	1.00	[Fraction]
Thermal Expansion Coefficient	0.0022	[1/R]

Q1		
Energy	1.804E+4	[Btu/h]



E-6000_DeC3_Vapor_Initial_Relief		
T	*416.3	[F]
P	*385.00	[psig]
Mass Flow	*2766.00	[lb/h]
Mass Density	3.2277	[lb/ft3]
Cp Mass	0.6513	[Btu/lb-F]
Thermal Expansion Coefficient	0.0023	[1/R]

E-6000_DeC3_Vapor_Operating		
T	*260.0	[F]
P	*270.00	[psig]
Mass Flow	*2766.00	[lb/h]
Volume Flow	3662.833	[bbl/d]
Mass Density	3.2280	[lb/ft3]

Heat Time = 18,040 Btu / 1,340,000 Btu/hr = 0.0135 hr = 0.81 min
Mass Released = (3.2277 lb/ft3 – 3.1553 lb/ft3) * 857 ft3 = 62.3 lb
Required Rate = 62.3 lb / 0.0135 hr = 4,628 lb/hr

Vapor Expansion due to Process Heat Input

Total Heat Input at Relief	1,340,000	Btu/hr
Trapped Volume	857.0	ft^3
Trapped Mass	2,766	lb
ΔT for Expansion	10.0	°F
Operating Temperature (T_{op})	260	°F
Operating Density (ρ_{op})	3.2277	lb/ft^3
Initial Relief Temperature (T_1)	416.3	°F
Initial Relief Density (ρ_1)	3.2280	lb/ft^3
Intial Relief Mass Heat Capacity (C_{p1})	0.6514	Btu/lb/°F
Relief Temperature (T_2)	426.30	°F
Relief Density (ρ_2)	3.1553	lb/ft^3
Relief Mass Heat Capacity (C_{p2})	0.651	Btu/lb/°F
Cubical Coefficient of Expansion (α_V)	0.0023	1/°F
Heat Required to Heat ΔT	18,040	Btu
Time Required to Heat ΔT	0.0135	hours
Mass Change Over ΔT	62.3	lb
Required Mass Relief Rate (H&M)	4,628	lb/hr
Required Mass Relief Rate (API Cubical Expansion)	4,723	lb/hr