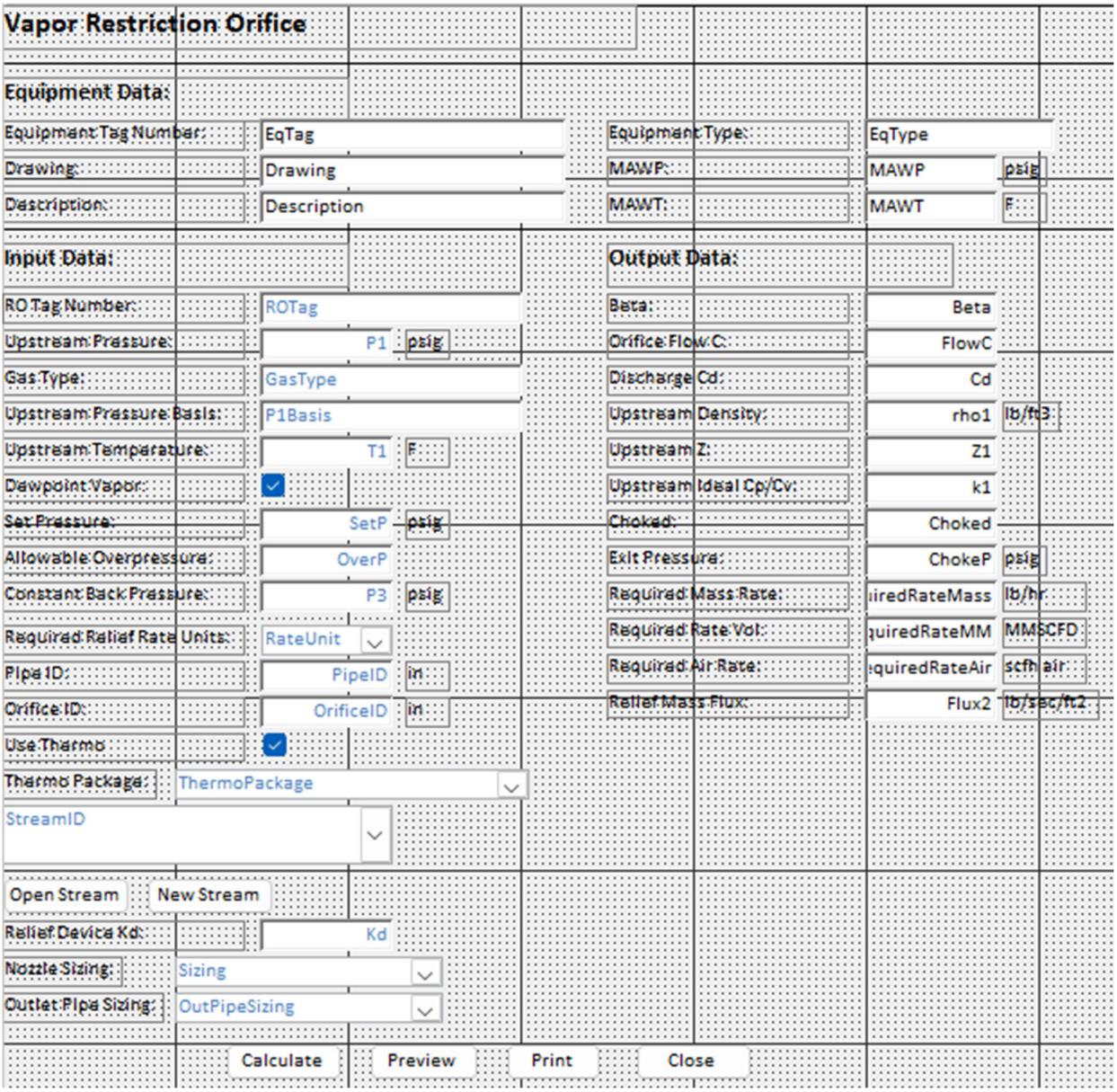
Vapor Restriction Orifice



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. The are described below:

ROTag - Restriction orifice tag number typically from P&ID.

GasType – Generic description of gas such as fuel gas or field gas.

P1 – Pressure upstream of restiriction orifice. From most to least conservative: MAWP, PSV Set, PSHH, Max Operating

P1Basis – Description for choice of P1. PSV-100 Set Pressure, PSHH Setpoint, etc.

T1 – Temperature upstream of restriiction orifice for PT Flash Only. Calculated for PQ Flash.

Dewpoint Vapor – PQ flash with Q = 1.0 if checked. Otherwise, PT Flash based on T1.

SetP – PSV set pressure used to determine relief pressure.

OverP – Allowable overpressure typically 10% used to determine relief pressure.

P3 – Constant back pressure when PSV is closed.

RateUnit – Flow units for required relief rate that is reported back to the Overpressure Scenario Form.

PipeID = Pipe inner diameter

OrificeID = Orifice inner diameter

UseThermo – Use selected ThermoPackage if checked.

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

StreamID – The stream to be used for properties. 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.

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

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

Calculation Method:

This form supports flow of a vapor through a restriction orifice under critical and sub-critical flow conditions and is based on equations found in Perry's Chemical Handbook 7th Edition.

Orifice Flow Coefficient

C, the orifice flow coefficient corrected for velocity of approach, assumes a high Reynolds number and is based on a set $C_d = 0.62$. It is calculated from C_d based on the following Crane 410 equation where β is the ratio of the orifice inner diameter to the pipe inner diameter.

$$C = \frac{C_d}{\sqrt{1-\beta^4}}$$

The critical downstream gauge pressure that results in choked flow is determined based on Equation 6-119 from Perry's Handbook.

$$P_{choked} = (P_1 + P_{atm}) \cdot \left(\frac{2}{(k_1 + 1)}\right)^{\left(\frac{k_1}{k_1 - 1}\right)} - P_{atm}$$

Where:

P1 – Pressure upstream of orifice. From most to least conservative: MAWP, PSV Set, PSHH, Max Operating

k_1 – Ideal Cp/Cv at upstream temperature

If P_{choked} is higher than the downstream relief pressure (P_2) then the flow is choked and the Mach Number (M_1) = 1.0, otherwise the flow is not choked and M_1 is determined by rearranging equation 6-115 and solving for M_1 based on the actual downstream pressure (P_2).

$$M_1 = \left(\left(\frac{(P_1 + P_{atm})}{(P_2 + P_{atm})}\right)^{\left(\frac{k_1 - 1}{k_1}\right)} - 1\right)\frac{2}{k_1 - 1}$$

P2 – Downstream relief pressure equal to SetP · (1 + OverP)

The vapor flux through the orifice is given by Equation 6-122 from Perry's Handbook with M_1 set to 1.0 if the flow is found to be choked per above.

$$G = (P_1 + P_{atm}) \cdot 144 \cdot \sqrt{\frac{k_1 MW g_c}{Z_1 R T_1}} \left(\frac{M_1}{\left(1 + \frac{k_1 - 1}{2} {M_1}^2\right)}\right)^{\left(\frac{k_1 + 1}{2(k_1 - 1)}\right)}$$

Where:

G = Mass Flux $lb_m/ft^2/sec$

MW = Vapor molecular weight

R = Universal Gas Constant 1,545 $lb_f/ft^2 \cdot ft^3/lbmole \cdot °R$

g_c= Universal Gravitational Constant 32.174 $lb_m \cdot ft/lb_f \cdot sec^2$

T1 – Temperature upstream of restriction orifice for PT Flash Only. Calculated for PQ Flash.

Z1 - Upstream compressibility

The mass flow rate can then be determined based on the orifice area and flow coefficient C.

$$W = G \cdot A \cdot C \cdot 3{,}600$$

W = Mass Flowrate lb/hr

A = Orifice Area ft^2

C = Orifice Flow Coefficient

Scenario Output Data:

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

Beta - Ratio of orifice to pipe inner diameter (OrificeID / PipeID)

FlowC – Orifice coefficient corrected for velocity of approach (set to 0.6)

Cd – Orifice flow coefficient

rho1 - Upstream density in lb/ft3 typically from thermo engine.

Z1 - Upstream compressibility typically from thermo engine.

K1 - Upstream ideal C_p/C_v typically from thermo engine.

Choked – Yes for critical flow, no for subcritical flow

ChokeP – Calculated choke pressure

RequiredRateMass - RequiredRateCv + AdditionalFlow converted to lb/hr, if necessary.

RequiredRateMM - RequiredRateCv + AdditionalFlow converted to MMSCFD, if necessary.

RequiredRateAir - RequiredRateCv + AdditionalFlow 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:

This Perry's Handbook method was benchmarked against the Orifice Numerical Integration Method. Each calculation method was also checked against an internally developed Excel spreadsheet. The calculation is based on a 0.75" RO installed in 2" Sch 80 pipe flanges. A typical residue gas composition was used with upstream conditions or 800 psig and 120 F and the downstream relief pressure of 165 psig.

Vapor Restriction Orifice

RO-1000

Equipment Data:

Equipment Tag:	**V-1000**	Type:	Pressure Vessel
Drawing:	PID-1000	MAWP:	150 psig
Description:	Slug Catcher	MAWT:	250 F

Scenario Description:

The maximum upstream pressure is 800 psig as dictated by the upstream MAWP and associated pressure relief which can exceed the design pressure of 150 psig. As such, inadvertent opening of the bypass around PCV-1000 could result in overpressure. The required relief rate is limitied by RO-1000 with a 3/4" ID and was based on the recovery residue gas compostion at 800 psig and 120 F upstream of bypass with the relief pressure of 165 psig downstream.

Scenario Results Summary:

Required Rate:	13,241	lb/hr	Device Choke Pressure:	83.8	psig
Actual Capacity:	30,665	lb/hr	Outlet Temperature:	75.9	F
Required Area:	1.232	in2	Outlet Mass Quality:	1.000	
Actual Area:	2.853	in2	Outlet Density:	0.043	lb/ft3
Relief Pressure:	165.0	psig	Outlet Ideal Cp/Cv:	1.288	
Relief Temperature:	86.2	F	Outlet Viscosity:	0.011	cP
Relief MW:	16.74		Inlet Non-Recoverable dP:	3.5	psi
Relief Mass Quality:	1.000		Inlet dP % Set:	2.3	% Set
Relief Density:	0.528	lb/ft3	Built-Up Back Pressure:	31.6	psig
Relief SG:	0.577		Built-Up Back P % Set:	21.1	% Set
Relief Z:	0.973		Total Back Pressure:	31.6	psig
Relief Ideal Cp/Cv:	1.286		Total Back P % Set:	21.1	% Set
Relief Viscosity:	0.011	cP	Reaction Force:	502	lbf

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

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

Vapor Restriction Orifice

RO-1000

Equipment Data:

Equipment Tag:	**V-1000**	Type:	Pressure Vessel
Drawing:	PID-1000	MAWP:	150 psig
Description:	Slug Catcher	MAWT:	250 F

Scenario Input Data:

RO Tag Number:	RO-1000	
Gas Type:	Residue Gas	
Upstream Pressure:	800	psig
Upstream Pressure Basis:	MAWP	
Upstream Temperature:	120	F
Dewpoint Vapor:	☐	
Set Pressure:	150	psig
Allowable Overpressure:	10.0%	
Constant Back Pressure:	0.0	psig
Pipe Inner Diameter:	1.939	in
Orifice Inner Diameter:	0.75	in
Thermodynamics Enabled:	☑	
Thermo Package:	Advanced_Peng-Robinson	
Relief Device Kd:	0.975	
Nozzle Sizing:	API 520 Vapor	
Outlet Pipe Sizing:	Adiabatic	

Scenario Output Data:

Beta:	0.387	
Orifice Flow C:	0.6	
Discharge Cd:	0.59	
Upstream Z:	0.912	
Upstream Density:	2.404	lb/ft3
Choked:	Yes	
Choke Pressure:	433	psig
Mach Number:	1	
Required Mass Rate.:	13240.9	lb/hr
Required Rate Std Vol:	7.2	MMSCFD
Required Air Rate:	233733.3	scfh air
Required Mass Flux:	429.9	lb/sec/ft2

Notes:

Vapor Restriction Orifice

RO-1000

Equipment Data:

Equipment Tag:	**V-1000**	Type:	Pressure Vessel
Drawing:	PID-1000	MAWP:	150 psig
Description:	Slug Catcher	MAWT:	250 F

Relief Stream Composition:

Stream Description: Residue Gas

Component	Mole Fraction
methane	0.9577
ethane	0.0320
propane	0.0008
butane	
isobutane	
pentane	
isopentane	
hexane	
heptane	
octane	
nonane	
decane	
carbon dioxide	0.0070
nitrogen	0.0025
methanol	
water	

Orifice Flow - Numerical Integration

Equipment Data:

Equipment Tag:	**V-1000**	Type:	Pressure Vessel
Drawing:	PID-1000	MAWP:	150 psig
Description:	Slug Catcher	MAWT:	250 F

Scenario Description:

The maximum upstream pressure is 800 psig as dictated by the upstream MAWP and associated pressure relief which can exceed the design pressure of 150 psig. As such, inadvertent opening of the bypass around PCV-1000 could result in overpressure. The required relief rate is limitied by RO-1000 with a 3/4" ID and was based on the recovery residue gas compostion at 800 psig and 120 F upstream of bypass with the relief pressure of 165 psig downstream.

Scenario Results Summary:

Required Rate:	13823.3	lb/hr	Device Choke Pressure:	82.5	psig
Actual Capacity:	30664.9	lb/hr	Outlet Temperature:	75.9	F
Required Area:	1.284	in2	Outlet Mass Quality:	1.000	
Actual Area:	2.853	in2	Outlet Density:	0.043	lb/ft3
Relief Pressure:	165.0	psig	Outlet Ideal Cp/Cv:	1.288	
Relief Temperature:	86.2	F	Outlet Viscosity:	0.011	cP
Relief Mass Quality:	1.000		Inlet Non-Recoverble dP:	3.5	psi
Relief Density:	0.53	lb/ft3	Inlet dP % Set:	2.3	% Set
Relief MW:	16.74		Built-Up Back Pressure:	31.1	psig
Relief Viscosity:	0.011	cP	Built-Up Back P % Set:	20.7	% Set
			Total Back Pressure:	31.1	psig
			Total Back P % Set:	20.7	% Set
			Reaction Force:	502	lbf

Orifice Flow - Numerical Integration

Equipment Data:

Equipment Tag:	**V-1000**	Type:	Pressure Vessel
Drawing:	PID-1000	MAWP:	150 psig
Description:	Slug Catcher	MAWT:	250 F

Input Data:

RO Tag:	RO-1000	
Gas Type:	Residue Gas	
Upstream Pressure:	800	psig
Upstream Pressure Basis:	MAWP	
Flash Type:	PT	
Upstream Mass Quality:	1.000	
Upstream Temperature:	120.0	F
Set Pressure:	150	psig
Allowable Overpressure:	10.00%	
Constant Back Pressure:	0	psig
Pressure Increment:	0.01	
Pipe ID:	1.939	in
Orifice ID:	0.75	in
Relief Device Liquid Kd:	0.650	
Relief Device Vapor Kd:	0.975	
Thermodynamic Package:	Advanced_Peng-Robinson	
Nozzle Sizing:	Numerical Integration	
Outlet Pipe Sizing:	Numerical Integration	
Notes:		

Output Data:

Beta:	0.387	
Orifice Flow C:	0.627	
Discharge Cd:	0.620	
Upstream Density:	2.40	lb/ft3
Upstream Z:	0.91	
Upstream Ideal Cp/Cv:	1.28	
Upstream Viscosity:	0.012	cP
Choked:	Yes	
Exit Pressure (P2 for Sizing):	425.4	psig
Orifice Mass Flux:	1251.6	lb/sec/ft2
Required Mass Rate:	13,823.3	lb/hr
Relief Kd:	0.975	
Relief Mass Flux:	430.6	lb/sec/ft2

Orifice Flow - Numerical Integration

Equipment Data:

Equipment Tag:	**V-1000**	Type:	Pressure Vessel
Drawing:	PID-1000	MAWP:	150 psig
Description:	Slug Catcher	MAWT:	250 F

Relief Stream Composition:

Stream Description: Residue Gas

Component	Mole Fraction
carbon dioxide	1.0000
nitrogen	
methane	
ethane	
propane	
isobutane	
butane	
isopentane	
pentane	
hexane	
heptane	
octane	
nonane	
decane	
methanol	
water	

Vapor Restriction Orifice
Perry's 7th Edition 6-118

Inputs		
Patm	14.7	psia
K_1	1.279	
MW	16.74	lb/lbmole
T_1	120	F
Z_1	0.912	
P_1	800	psig
P_2	150	psig
Orifice ID	0.75	in
C	0.6	
g_c	32.174	lb_m ft / lb_f sec^2
R	1545	lb_f ft / lbmole °R
Outputs		
Rho1	2.40	lb/ft3
P_1/P_2	4.947	
R_c	0.5496	
P_{choked}	433.0	psig
Critical Flow	Yes	
M_1	1.00	
Orifice Area	0.0031	ft^2
G	1,998	lb_m / ft^2 / sec
W	13,241	lb/hr