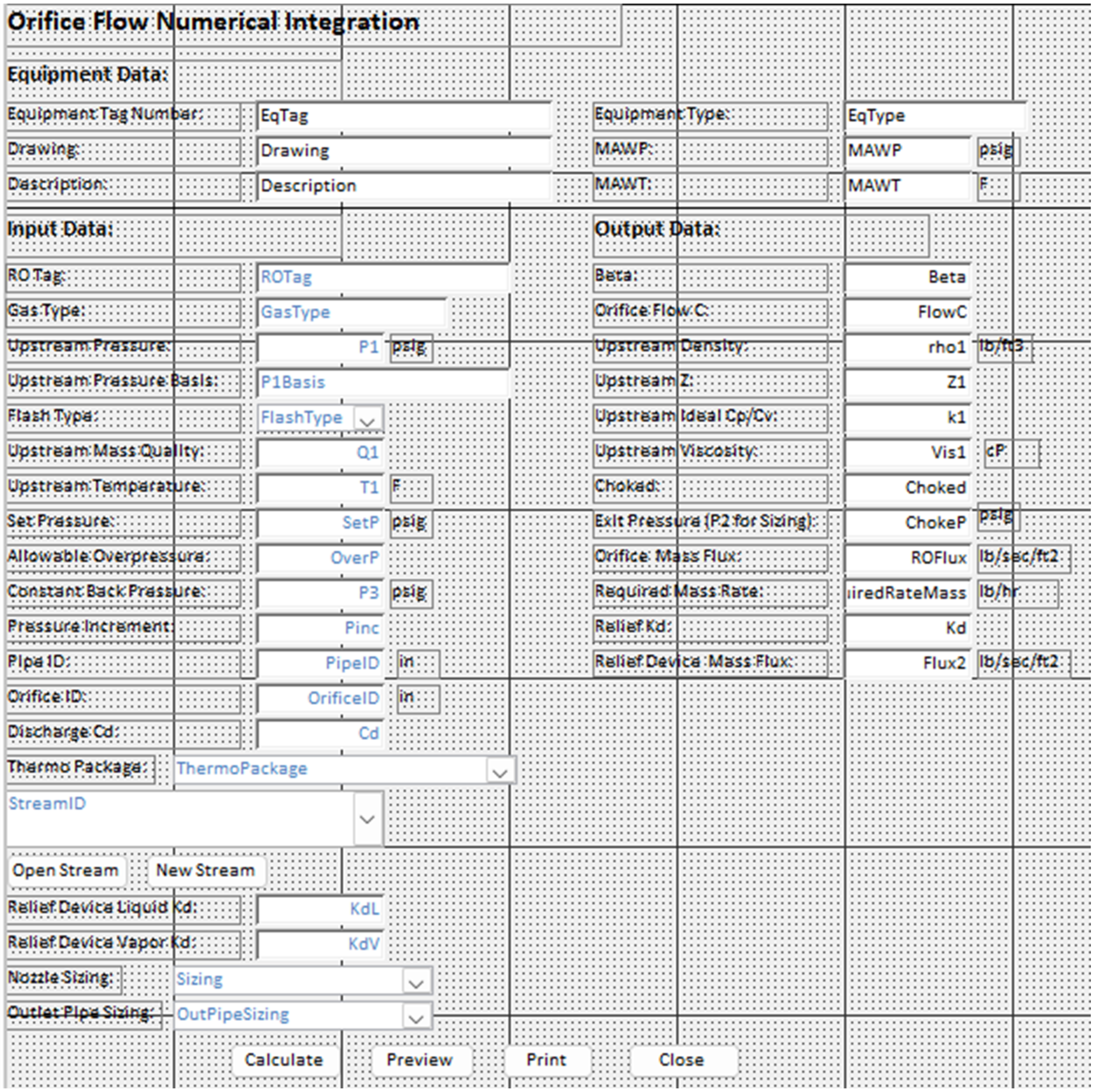
Orifice – Numerical Integration



Orifice Flow Numerical Integration

Equipment Data:

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

Input Data:		Output Data:	
RO Tag:	ROTag	Beta:	Beta
Gas Type:	GasType	Orifice Flow C:	FlowC
Upstream Pressure:	P1 psig	Upstream Density:	rho1 lb/ft3
Upstream Pressure Basis:	P1Basis	Upstream Z:	Z1
Flash Type:	FlashType	Upstream Ideal Cp/Cv:	k1
Upstream Mass Quality:	Q1	Upstream Viscosity:	Vis1 cP
Upstream Temperature:	T1 F	Choked:	Choked
Set Pressure:	SetP psig	Exit Pressure (P2 for Sizing):	ChokeP psig
Allowable Overpressure:	OverP	Orifice Mass Flux:	ROFlux lb/sec/ft2
Constant Back Pressure:	P3 psig	Required Mass Rate:	iiredRateMass lb/hr
Pressure Increment:	Pinc	Relief Kd:	Kd
Pipe ID:	PipeID in	Relief Device Mass Flux:	Flux2 lb/sec/ft2
Orifice ID:	OrificeID in		
Discharge Cd:	Cd		
Thermo Package:	ThermoPackage		

StreamID

Open Stream | New Stream

Relief Device Liquid Kd:	KdL
Relief Device Vapor Kd:	KdV
Nozzle Sizing:	Sizing
Outlet Pipe Sizing:	OutPipeSizing

Calculate | Preview | Print | Close

Note: Thermodynamics are required for this form.

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 restriction 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.

Flash Type – PT or PQ flash.

Q1 – Quality upstream of restriction orifice for PQ Flash Only. Calculated for PT Flash.

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

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.

Pinc - Number of pressure increments to be analyzed. (P1 - P2) / Pincrements = Pressure Step

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

PipeID = Pipe inner diameter

Cd = Orifice discharge coefficient defaulted to 0.62.

OrificeID = Orifice inner diameter

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.

KdL – Manufacturer's certified liquid Kd or 0.65 for API STD 520 default.

KdV – 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:

This form supports flow of a vapor or two phase flow through a restriction orifice under critical and sub-critical flow conditions and is based on Numerical Integration equations from API RP 520.

Orifice Flow Coefficient

C_d, the orifice discharge coefficient corrected for velocity of approach, assumes a high Reynolds number and is set at 0.62. C, the orifice flow coefficient corrected for velocity of approach 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 ideal mass flux is given by the following equation that will then be corrected based on C.

$$G^2 = (\rho_t^2) \times \left(-9266.1 \times \int_{P_o}^{P_t} \frac{dP}{\rho} \right)$$

Where:

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

$_t$ – Conditions at the throat of the orifice

The integral is evaluated based on pressure steps unit either a maximum is reached (choked flow) or the downstream pressure (P2) is reached.

$$\int_{P_0}^{P_t} \frac{dP}{\rho} \approx \sum_{i=0}^{t} 2 \times \left(\frac{P_{i+1} - P_i}{\rho_{i+1} + \rho_i} \right)$$

The pressure step which is equal to $P_{i+1} - P_i$ is determined based on the actual dP equal to P1 – P2 multiplied by P_{inc} following equation. The default value of P_{inc} 1.0% (entered as 0.01) if a value is not entered. The densities for each step are determined based on successive isentropic flashes. Once the ideal G has been determined it is converted to mass flow using the following equation.

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

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

Kinlet - Inlet pipe resistance factor

Koutlet - Outlet pipe resistance factor

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

ROFlux – Calculated actual mass flux in lb/ft^2/sec across orifice (ideal G reduce by Flow C)

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

Kd – Overall relief valve Kd based on volumetric average of liquid and vapor values if two phase

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 orifice flow numerical integration calculation was benchmarked against Example Problem B.1.3 from the 8th Edition of API STD 520 by comparing the calculated ideal mass fluxes. The API example determined an ideal mass flux of 3,201 lb/ft^2/sec with a choke pressure of 454 psig versus 3,225 lb/ft^2/sec (Orifice Mass Flux / Orifice Flow C) with a choke pressure of 478 psig with Pressio.

Orifice Flow - Numerical Integration

PCV-2000 Bypass Open with RO-2000 Help Case

Equipment Data:

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

Scenario Description:

Based on the API STD 520 8th Edition Annex B.1.3 Example. The maximum upstream pressure is 783 psig which can exceed the design pressure. As such, inadvertent opening of the bypass around PCV-2000 could result in overpressure. The required relief rate is limited by RO-2000 with a 1/2" ID and was based on the properties of pure ethylene at 783 psig and 80 F upstream of bypass with a nominal back pressure of 5 psig.

Scenario Results Summary:

Required Rate:	9830.8	lb/hr	Device Choke Pressure:	66.0	psig
Actual Capacity:	30296.7	lb/hr	Outlet Temperature:	-77.4	F
Required Area:	0.598	in2	Outlet Mass Quality:	1.000	
Actual Area:	1.838	in2	Outlet Density:	0.102	lb/ft3
Relief Pressure:	165.0	psig	Outlet Ideal Cp/Cv:	1.297	
Relief Temperature:	-36.8	F	Outlet Viscosity:	0.008	cP
Relief Mass Quality:	1.000		Inlet Non-Recoverble dP:	1.3	psi
Relief Density:	1.33	lb/ft3	Inlet dP % Set:	0.9	% Set
Relief MW:	28.05		Built-Up Back Pressure:	10.9	psig
Relief Viscosity:	0.009	cP	Built-Up Back P % Set:	7.3	% Set
			Total Back Pressure:	10.9	psig
			Total Back P % Set:	7.3	% Set
			Reaction Force:	257	lbf

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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-2000	
Gas Type:	Pure Ethylene	
Upstream Pressure:	783	psig
Upstream Pressure Basis:	Maximum Operating Pressure	
Flash Type:	PT	
Upstream Mass Quality:	1.000	
Upstream Temperature:	80.0	F
Set Pressure:	150	psig
Allowable Overpressure:	10.00%	
Constant Back Pressure:	0	psig
Pressure Increment:	10	
Pipe ID:	1.939	in
Orifice ID:	0.5	in
Relief Device Liquid Kd:	0.650	
Relief Device Vapor Kd:	0.975	
Thermodynamic Package:	PSRK	
Nozzle Sizing:	Numerical Integration	
Outlet Pipe Sizing:	Omega Method	
Notes:		

Output Data:

Beta:	0.258	
Orifice Flow C:	0.621	
Discharge Cd:	0.620	
Upstream Density:	6.64	lb/ft3
Upstream Z:	0.58	
Upstream Ideal Cp/Cv:	1.24	
Upstream Viscosity:	0.014	cP
Choked:	Yes	
Exit Pressure (P2 for Sizing):	412.2	psig
Orifice Mass Flux:	2002.7	lb/sec/ft2
Required Mass Rate:	9,830.8	lb/hr
Relief Kd:	0.975	
Relief Mass Flux:	657.6	lb/sec/ft2

Orifice Flow - Numerical Integration

PCV-2000 Bypass Open with RO-2000 Help Case

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: **Ethylene**

Component	Mole Fraction
ethylene	1.0000

Orifice or Nozzle Flow
Numerical Integration

Calculate RO Flow Rate

User-Entered Inputs		
Thermo Package	PSRK	
P_1	783.0	psig
P_{atm}	14.7	psia
T_1	80.0	F
P_2	150.0	
ID_{pipe}	1.939	
$ID_{orifice}$	0.500	
C_d	0.620	
Flash Type	Isentropic	
P_{inc}	7.83	psi
Results		
Z_1	0.587	
MW	28.05	lb/lbmole
ρ_1	6.638	lb/ft3
H_1	2972.1	Btu/lbmole
S_1	35.8	Btu/lbmole/F
β	0.258	
$Area_{orifice}$	0.196	
Flow C	0.621	
W_{req}	9850.9	lb/hr

Mass Flux Calculation

P_{up} (psig)	ρ_{up} (lb/ft^3)	P_{down} (psig)	ρ_{down} (lb/ft^3)	Integral	G ($lb/in^2/hr$)	G (lb/ft2/sec)	W (lb/hr)
783.0	6.638	775.2	6.590	1.184	17,254.7	690.2	2,105.2
775.2	6.590	767.3	6.541	2.377	24,267.1	970.7	2,960.7
767.3	6.541	759.5	6.492	3.578	29,553.9	1,182.2	3,605.8
759.5	6.492	751.7	6.443	4.789	33,932.0	1,357.3	4,139.9
751.7	6.443	743.9	6.394	6.008	37,718.4	1,508.7	4,601.9
743.9	6.394	736.0	6.345	7.238	41,076.9	1,643.1	5,011.7
736.0	6.345	728.2	6.295	8.477	44,105.1	1,764.2	5,381.1
728.2	6.295	720.4	6.245	9.726	46,866.8	1,874.7	5,718.1

720.4	6.245	712.5	6.194	10.985	49,406.4	1,976.3	6,027.9
712.5	6.194	704.7	6.144	12.254	51,756.6	2,070.3	6,314.7
704.7	6.144	696.9	6.093	13.533	53,941.8	2,157.7	6,581.3
696.9	6.093	689.0	6.042	14.824	55,981.3	2,239.3	6,830.1
689.0	6.042	681.2	5.990	16.125	57,890.3	2,315.6	7,063.0
681.2	5.990	673.4	5.939	17.438	59,683.8	2,387.4	7,281.8
673.4	5.939	665.5	5.887	18.762	61,364.9	2,454.6	7,486.9
665.5	5.887	657.7	5.835	20.098	62,947.5	2,517.9	7,680.0
657.7	5.835	649.9	5.782	21.446	64,439.9	2,577.6	7,862.1
649.9	5.782	642.1	5.729	22.807	65,844.6	2,633.8	8,033.5
642.1	5.729	634.2	5.676	24.180	67,169.4	2,686.8	8,195.1
634.2	5.676	626.4	5.623	25.566	68,418.0	2,736.7	8,347.5
626.4	5.623	618.6	5.569	26.965	69,594.7	2,783.8	8,491.0
618.6	5.569	610.7	5.514	28.378	70,684.0	2,827.4	8,623.9
610.7	5.514	602.9	5.458	29.805	71,703.9	2,868.2	8,748.4
602.9	5.458	595.1	5.401	31.248	72,658.6	2,906.3	8,864.8
595.1	5.401	587.2	5.345	32.705	73,554.7	2,942.2	8,974.2
587.2	5.345	579.4	5.288	34.178	74,393.6	2,975.7	9,076.5
579.4	5.288	571.6	5.231	35.667	75,177.0	3,007.1	9,172.1
571.6	5.231	563.8	5.174	37.172	75,906.9	3,036.3	9,261.2
563.8	5.174	555.9	5.116	38.694	76,584.9	3,063.4	9,343.9
555.9	5.116	548.1	5.058	40.233	77,212.6	3,088.5	9,420.5
548.1	5.058	540.3	5.000	41.790	77,791.2	3,111.6	9,491.1
540.3	5.000	532.4	4.943	43.365	78,325.9	3,133.0	9,556.3
532.4	4.943	524.6	4.884	44.958	78,808.1	3,152.3	9,615.1
524.6	4.884	516.8	4.825	46.571	79,245.7	3,169.8	9,668.5
516.8	4.825	508.9	4.766	48.204	79,639.5	3,185.6	9,716.6
508.9	4.766	501.1	4.707	49.857	79,989.9	3,199.6	9,759.3
501.1	4.707	493.3	4.648	51.531	80,297.6	3,211.9	9,796.9
493.3	4.648	485.5	4.589	53.226	80,563.2	3,222.5	9,829.3
485.5	4.589	477.6	4.526	54.944	80,740.6	3,229.6	9,850.9
477.6	4.526	469.8	4.449	56.689	80,619.9	3,224.8	9,836.2
469.8	4.449	462.0	4.373	58.464	80,463.7	3,218.5	9,817.1
462.0	4.373	454.1	4.297	60.270	80,272.8	3,210.9	9,793.8
454.1	4.297	446.3	4.221	62.109	80,047.8	3,201.9	9,766.4
446.3	4.221	438.5	4.145	63.981	79,789.1	3,191.6	9,734.8
438.5	4.145	430.6	4.070	65.887	79,497.2	3,179.9	9,699.2
430.6	4.070	422.8	3.995	67.829	79,172.6	3,166.9	9,659.6
422.8	3.995	415.0	3.920	69.807	78,815.8	3,152.6	9,616.1