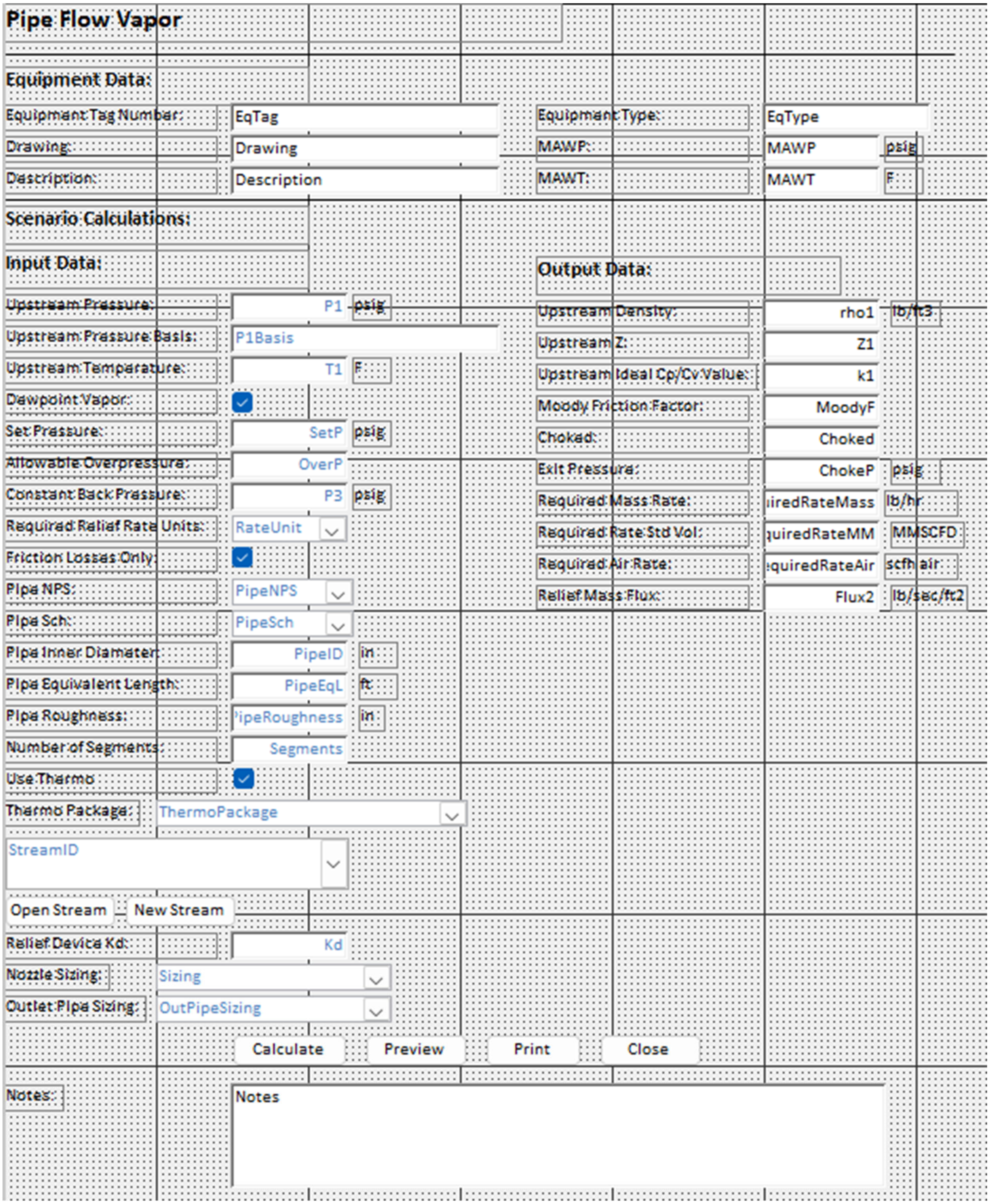
Pipe Flow – Vapor



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:

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.

T1 – Temperature at inlet to pipe for non-dewpoint, superheated vapors. Calculated for PQ Dewpoint Flash.

Dewpoint – If yes, then a PQ Flash is performed with Q = 1.0.

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.

FrictionOnly – If yes, flow will be calculated based on non-recoverable friction losses only.

PipeNPS – Nominal pipe size (used along with PipeSch to get PipeID)

PipeSch – Pipe schedule (used along with PipeNPS to get PipeID)

PipeID = Pipe inner diameter (calculated if PipeNPS and PipeSch entered, otherwise must be input)

PipeEql - Pipe equivalent length

PipeRoughness - Pipe roughness used to quantify friction factor (default = 0.0018 in for carbon steel)

Segments - Number of segments the pipe is divided into for calculation

UseThermo – If yes, the ThermoPackage will be used to get properties. If no, additional inputs are required.

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.

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 through a pipe of constant diameter and fixed length. The pipe is divided into the specified number of Segments, so for example a 20' pipe with 10 specified segments is divided into 2' sections that are each calculated individually. The solution process is based on iterating the flow until the calculated inlet pressure to the pipe equals the entered value of P1. The calculation starts at the exit or downstream end of the pipe where the velocity is checked to determine if the flow is sonic/choked. In the event that it is found to be choked the exit pressure is adjusted such that the exit velocity is equal to the sonic velocity.

$$SonicV = 223\sqrt{(K(T + 460)Z/MW)}$$

Where:

K = Ideal specific heat ratio

T = Temperature at pipe exit (°F)

Z = Compressibility at pipe exit

MW = Gas molecular weight

The pressure drop for each segment is quantified based on the full isothermal flow Equation 3-16 from Crane 410 with the density being modified as the pressure changes.

$$W = 0.371\sqrt{\frac{d^4\rho}{\left(f\frac{L}{D}+2\ln\frac{P_1}{P_2}\right)}\left(\frac{(P_1^2-P_2^2)}{P_1}\right)}$$

Where:

W = Mass Flowrate (lb/hr)

d = Pipe inner diameter (in)

ρ = Density (lb/ft^3)

f = Moody friction factor

L = Pipe (or segment) length (ft)

P_1 = Pipe (or segment) inlet pressure (psia)

P_2 = Pipe (or segment) outlet pressure (psia)

Scenario Output Data:

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

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.

MoodyF – Moody friction factor

Choked – Yes for critical flow, no for subcritical flow

ChokeP – Calculated choke pressure or downstream pressure if not choked

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 vapor pipe flow calculation was benchmarked against and alternative, empirical method from Crane 410 that uses an expansion factor Y (Equation 3-20) and quantified a flowrate of 18,491 lb/hr. In addition, the results were checked with the pipe segment from a commercial simulator noting that the simulator does not check for choked flow at the exit which yielded a flow of 18,026 lb/hr. Finally, a spreadsheet using the full isothermal equation was also developed and predicted a flowrate of 17,823 lb/hr. All of these methods are in reasonable agreement with the 17,792 lb/hr quantified by Pressio. Crane 410 Equation 3-20 is an empirical method and not expected to be an exact match while the commercial simulator predicts a slightly higher flow due to the fact that it does not check for choked flow (see Mach = 1.14 in report).

Pipe Flow Vapor

1" Drain Valve Open

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 1" drain ball valve could result in overpressure due to gas blowby. The required relief rate was based on the recovery residue gas composition at 800 psig and 120 F upstream of the valve with the relief pressure of 165 psig downstream. The estimated length of the 1" Sch 80 drain line is 20'.

Scenario Calculation Results:

Required Rate:	17,792.0	lb/hr	Device Choke Pressure:	98.3	psig
Actual Capacity:	19,675.0	lb/hr	Outlet Temperature:	80.6	F
Required Area:	1.662	in2	Outlet Mass Quality:	1.000	
Actual Area:	1.838	in2	Outlet Density:	0.057	lb/ft3
Relief Pressure:	165.0	psig	Outlet Ideal Cp/Cv:	1.296	
Relief Temperature:	89.4	F	Outlet Viscosity:	0.011	cP
Relief MW:	16.74		Inlet Non-Recoverble dP:	0.8	psi
Relief Mass Quality:	1.000		Inlet dP % Set:	0.6	% Set
Relief Density:	0.522	lb/ft3	Built-Up Back Pressure:	6.6	psig
Relief SG:	0.577		Built-Up Back P % Set:	4.4	% Set
Relief Z:	0.979		Total Back Pressure:	11.6	psig
Relief Ideal Cp/Cv:	1.293		Total Back P % Set:	7.7	% Set
Relief Viscosity:	0.011	cP	Reaction Force:	293	lbf

Pipe Flow Vapor

1" Drain Valve Open

Equipment Data:

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

Input Data:

Upstream Pressure:	800	psig
Upstream Pressure Basis:	MAWP	
Upstream Temperature:	120	F
Dewpoint Vapor:	☐	
Set Pressure:	150	psig
Allowable Overpressure:	10.00%	
Constant Back Pressure:	5	psig
Required Relief Rate Units:	lb/hr	
Friction Losses Only:	☐	
Pipe NPS:	1"	
Pipe Schedule:	80	
Pipe Inner Diameter:	0.957	in
Pipe Equivalent Length:	20	ft
Pipe Roughness:	0.0018	ft
Use Thermo	☑	
Thermo Package:	REFPROP 10.0	
Relief Device Kd:	0.975	
Nozzle Sizing:	API 520 Vapor	
Outlet Pipe Sizing:	Adiabatic	

Output Data:

Upstream Density:	2.364	lb/ft3
Upstream Z:	0.927	
Upstream Ideal Cp/Cv:	1.286	
Moody Friction Factor:	0.0231	ft
Choked:	Yes	
Exit Pressure:	222.5	
Required Mass Rate:	17,792.0	psig
Required Rate Std Vol:	9.7	lb/hr
Required Air Rate:	314,994.1	MMSCFD
Relief Mass Flux:	428.2	scfh air
		lb/sec/ft2

Notes:

RKR Engineering and Consulting
Gas Plant XYZ
Pressio 2024 Help Benchmarks
2024-1000

Pipe Flow Vapor

1" Drain Valve Open

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	
	0.0070
	0.0025

Vapor Pipe Flow per Crane 410
Equation 3-20

Inputs

Patm	14.7	psia
MW	16.74	
T	120	F
Z	0.912	
K value	1.28	
P1	800	psig
P2	165	psig
Tube ID	0.957	in
Tube Length	20	ft
Friction Factor	0.023	
dP/P1 Critcal	0.720	
Y	0.683	

Outputs

K	5.768	
dP/P1 Actual	0.779	
dP Actual	635	psi
dP Critical	586.6	psi
P2 Critical	213.4	psig
Critical Flow	Yes	
Rho1	2.40	lb/ft3
W	18,491	lb/hr

Compressible flow:

$$q'_h = 40\,700\ Yd^2 \sqrt{\frac{\Delta P\, P'_1}{K T_1 S_g}} \qquad \textit{Equation 3-20}$$

$$q'_h = 24\,700\ \frac{Yd^2}{S_g} \sqrt{\frac{\Delta P\, \rho_1}{K}}$$

$$q'_m = 678\ Yd^2 \sqrt{\frac{\Delta P\, P'_1}{K T_1 S_g}} = 412\ \frac{Yd^2}{S_g} \sqrt{\frac{\Delta P\, \rho_1}{K}}$$

$$q' = 11.30\ Yd^2 \sqrt{\frac{\Delta P P'_1}{K T_1 S_g}} = 6.87\ \frac{Yd^2}{S_g} \sqrt{\frac{\Delta P \rho_1}{K}}$$

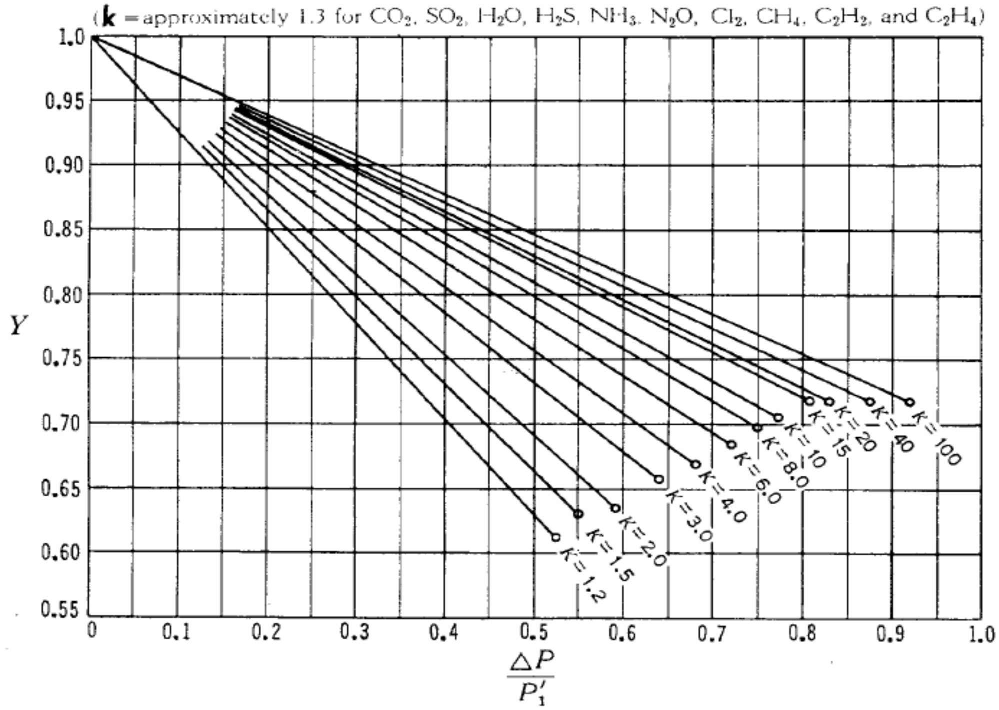
$$w = 0.525\ Yd^2 \sqrt{\frac{\Delta P}{K \overline{V}_1}} \qquad W = 1891\ Yd^2 \sqrt{\frac{\Delta P}{K \overline{V}_1}}$$

Values of Y are shown on page A-22. For K, Y, and ΔP determination, see examples on pages 4-13 and 4-14.

Net Expansion Factor Y for Compressible Flow Through Pipe to a Larger Flow Area

k = 1.3

(k = approximately 1.3 for CO_2, SO_2, H_2O, H_2S, NH_3, N_2O, Cl_2, CH_4, C_2H_2, and C_2H_4)



Limiting Factors For Sonic Velocity
k = 1.3

K	$\frac{\Delta P}{P'_1}$	Y
1.2	.525	.612
1.5	.550	.631
2.0	.593	.635
3	.642	.658
4	.678	.670
6	.722	.685
8	.750	.698
10	.773	.705
15	.807	.718
20	.831	.718
40	.877	.718
100	.920	.718

/Pipe1_1 (Pipe Segment)

Flow is close to the speed of sound

Name **Pipe1_1** Description

S1_1 → S2_1

Pressure Drop Corr. **Colebrook** Filter **All**

Summary | Pipe Detail | Profiles | Heat Transfer | Sizing | Settings | Equilibrium Results | Report | Notes

Main Data

Name	Value
Delta P [psi]	635.00
OutQ [Btu/h]	0.000E+0
U [Btu/h-ft2-F]	**0.00**
Heat Transfer Calc Type	**Simple**
Outside Data	**Ambient**
External T [F]	77.0
Number of Sections	**10**
Slip Exponent	**0.00**
Friction Factor Tuning	**1.00**

Pipe Data

Name	Value
Total Length [ft]	**20.00**
Elevation	**Profile...**
Elevation In [ft]	**0.00**
Elevation Out [ft]	**0.00**
Schedule	**80**
Nominal Size (in)	**1**
Inner Diameter [in]	0.957
Outer Diameter [in]	1.315
Thickness [in]	0.179
Roughness [in]	**0.0018**

Results

Name	Value
Velocity In [ft/s]	416.91
Velocity Out [ft/s]	1572.97
Max Mach	1.21
Max RhoV2 [psi]	340.33
Inventory	
Line Pack [SCF]	4.01
Liquid [ft3]	0.000
Oil [ft3]	0.000
Water [ft3]	0.000
Bulk Std Liq Vol [ft3]	0.009

Material

PortName	In	Out
Is Recycle Port	☐	☐
Connected Stream/Unit Op	**/S1_1.Out**	**/S2_1.In**
VapFrac	1.00	1.00
T [F]	120.0	1.6
P [psia]	814.70	179.70
Mole Flow [lbmol/h]	1076.87	1076.87
Mass Flow [lb/h]	18026.18	18026.18
Volume Flow [ft3/s]	2.083	7.857
Std Liq Volume Flow [ft3/s]	0.262	0.262
Std Gas Volume Flow [MMSCFD]	9.8077E+0	9.8077E+0
Properties (Alt+R)		
Mole Fraction [Fraction]		
METHANE	0.9577	0.9577
CARBON DIOXIDE	0.007	0.007
ETHANE	0.032	0.032

Pipe Flow per Crane 410
Complete Isothermal Equation 1-6

Inputs

Patm	14.7	psia
MW	16.74	
T	120	F
Z	0.912	
K value	1.279	
P1	800.0	psig
P2	165	psig
Pipe ID	0.957	in
Pipe Length	20	ft
Friction Factor	0.023	
dP/P1 Critcal	0.720	

Outputs

P1	814.7	psia
P2	179.7	psia
dP/P1 Actual	0.779	
dP Actual	635.0	psi
dP Critical	586.6	psi
P2 Critical	213.4	psig
Critical Flow	Yes	
Rho1	2.40	lb/ft3
Pipe Area	0.005	ft2
K	5.768	
Flow	**17823**	**lb/hr**
Part 1	0.0316234	
Part 2	775.06321	
Equation	-3.573E-05	

Goal Seek B33 = 0 by Changing B30

Complete isothermal equation: The flow of gases in long pipe lines closely approximates isothermal conditions. The pressure drop in such lines is often large relative to the inlet pressure, and solution of this problem falls outside the limitations of the Darcy equation. An accurate determination of the flow characteristics falling within this category can be made by using the complete isothermal equation:

Equation 1-6

$$w^2 = \left[\frac{144\ g\ A^2}{\overline{V}_1\left(\frac{fL}{D} + 2\log_e \frac{P'_1}{P'_2}\right)}\right]\left[\frac{(P'_1)^2 - (P'_2)^2}{P'_1}\right]$$

The formula is developed on the basis of these assumptions:

1. Isothermal flow.
2. No mechanical work is done on or by the system.
3. Steady flow or discharge unchanged with time.
4. The gas obeys the perfect gas laws.
5. The velocity may be represented by the average velocity at a cross section.
6. The friction factor is constant along the pipe.
7. The pipe line is straight and horizontal between end points.