Rupture Disc Sizing

The objective of this bulletin is to provide detailed guidance for sizing rupture discs using standard methodologies found in ASME Section VIII Div. 1, API RP520, and Crane TP-410. To assist in the sizing process, Fike offers disCalc, a PC based sizing program. Call Fike or your local representative for a copy.

Overpressure Allowance

When sizing pressure relief devices, the Code defines the maximum pressure that may build up in the pressure vessel while the device is relieving. This pressure varies depending on the application of the device. The following table defines the various overpressure allowances.

Primary	Multiple Devices (Secondary)	External Fire	External Fire (Ambient temperature compressed gas storage vessels only)
10% or 3 psi, whichever is greater, above the vessel MAWP	16% or 4 psi, whichever is greater, above the vessel MAWP	21% above the vessel MAWP	20% above the vessel MAWP

Rupture Disc Sizing Methodologies

There are 3 basic methodologies for sizing rupture disc devices:

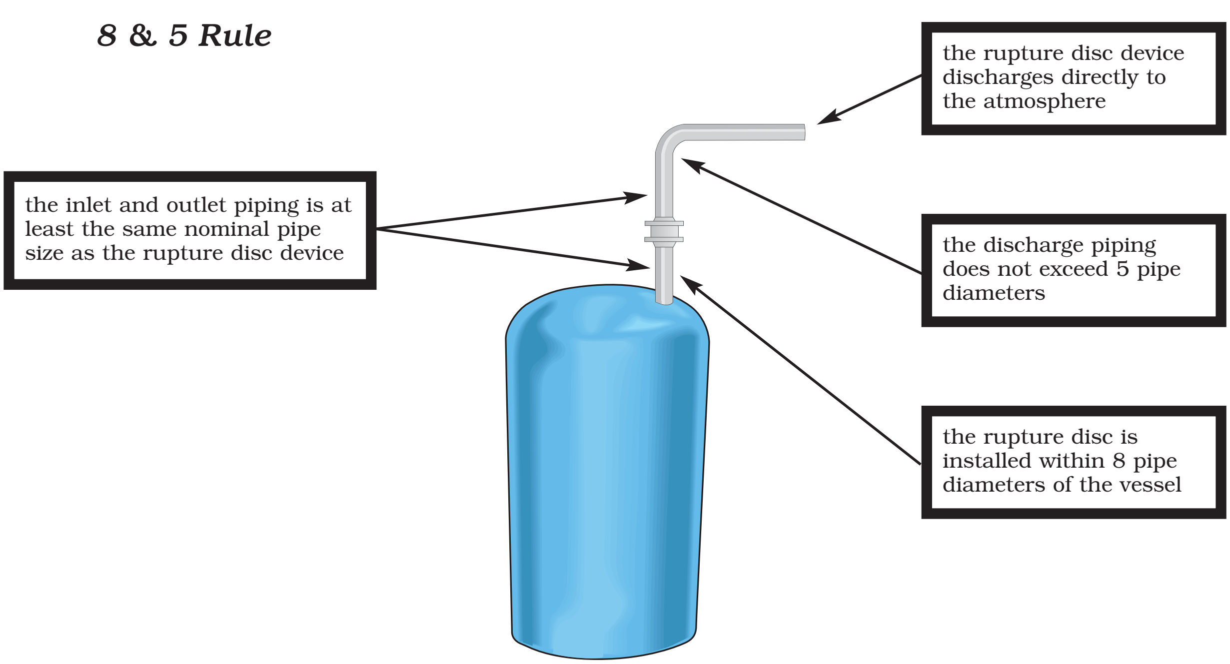
Coefficient of Discharge Method (K_D) — The K_D is the coefficient of discharge that is applied to the theoretical flow rate to arrive at a rated flow rate for simple systems.

Resistance to Flow Method (K_R) — The K_R represents the velocity head loss due to the rupture disc device. This head loss is included in the overall system loss calculations to determine the size of the relief system.

Combination Capacity Method — When a rupture disc device is installed in combination with a pressure relief valve, the valve capacity is derated by a default value of 0.9 or a tested value for the disc/valve combination. See technical bulletin TB8101 for specific application requirements when using rupture disc devices in combination with PRVs.

Coefficient of Discharge Method (K_D)

When to use this method — Use this method for simple systems where the following conditions are true (8&5 Rule). This method takes into account the vessel entrance effects, 8 pipe diameters of inlet piping, 5 pipe diameters of discharge piping, and effects of discharging to atmosphere.



Gas / Vapor Sizing

Determination of Critical vs. Subcritical Flow per API RP520

Critical Pressure: $$P_{cf} = P\left(\frac{2}{(k+1)}\right)^{k/(k-1)}$$

If $P_e \le P_{cf}$ use critical flow equations

Calculations per ASME Section VIII (assumes critical flow)

Critical Flow: $$W = K_D \cdot C \cdot A \cdot P\sqrt{\frac{M}{T \cdot Z}}$$

$$A = \frac{W}{K_D \cdot C \cdot P}\sqrt{\frac{T \cdot Z}{M}}$$

Calculation per API RP520

Subcritical Flow:

$$A = \frac{W}{735 \cdot F_2 \cdot K_D}\sqrt{\frac{T \cdot Z}{M \cdot P(P - P_e)}}$$

$$A = \frac{V}{4645 \cdot F_2 \cdot K_D}\sqrt{\frac{T \cdot Z \cdot M}{P(P - P_e)}}$$

$$A = \frac{V}{864 \cdot F_2 \cdot K_D}\sqrt{\frac{T \cdot Z \cdot SG}{P(P - P_e)}}$$

Critical Flow:

$$A = \frac{W}{K_D \cdot C \cdot P}\sqrt{\frac{T \cdot Z}{M}}$$

$$A = \frac{V\sqrt{T \cdot Z \cdot M}}{6.32 \cdot K_D \cdot C \cdot P}$$

$$A = \frac{V\sqrt{T \cdot Z \cdot SG}}{1.175 \cdot K_D \cdot C \cdot P}$$

TABLE 1
Gas Constants

Gas or Vapor	Molecular Weight	$k = c_p/c_v$
Air	28.97	1.40
Acetic Acid	60	1.15
Acetylene	26.04	1.26
Ammonia	17.03	1.33
Argon	40	1.67
Benzene	78.1	1.12
N-Butane	58.12	1.094
ISO-Butane	58.12	1.094
Butene	56.1	1.10
Carbon Monoxide	28	1.40
Carbon Disulfide	76	1.21
Carbon Dioxide	44.01	1.30
Chlorine	70.9	1.36
Cyclohexane	84.16	1.09
Ethane	30.07	1.22
Ethyl Alcohol	46.07	1.13
Ethyl Chloride	64.5	1.19
Ethylene	28.05	1.26
Helium	4	1.66
Hydrochloric Acid	36.5	1.41
Hydrogen	2.016	1.41
Hydrogen Sulfide	34.07	1.32
Methane	16.04	1.31
Methyl Alcohol	32.04	1.20
Methyl Chloride	50.48	1.20
Natural Gas (Ave.)	19	1.27
Nitric Acid	30	1.40
Nitrogen	28	1.404
Oxygen	32	1.40
Pentane	72.15	1.07
Propane	44.09	1.13
Sulfur Dioxide	64.06	1.29
Water Vapor	18.02	1.324

W = rated flow capacity, lb/hr
V = rated flow capacity, scfm
Q = rated flow capacity, US gallons/min
A = minimum net flow area, sq. in.
C = constant based on the ratio of specific heats k
k = c_p/c_v
K_D = coefficient of discharge (0.62 for rupture disc devices)
K_N = correction factor for steam
K_{SH} = superheated steam correction factor. For saturated steam use 1.0.
K_v = viscosity correction factor
F_2 = $\sqrt{\left(\frac{k}{k-1}\right)(r)^{2/k}\left[\frac{1-r^{(k-1)/k}}{1-r}\right]}$
r = $\frac{Pe}{P}$
P = set pressure plus overpressure allowance plus atmospheric pressure, psia
P_e = exit pressure, psia
M = molecular weight
SG = specific gravity of gas at standard conditions, SG=1.00 for air at 14.7 psia and 60,°C
T = absolute temperature at inlet, R (°F + 460°F)
w = specific weight of water at inlet
Z = compressibility factor for corresponding to P and T. Use 1.0 if unknown.

TABLE 2
Gas Flow Constant C for Sonic Flow

k	*C*	*k*	*C*
1.00	315	1.40	356
1.02	318	1.42	358
1.04	320	1.44	360
1.06	322	1.46	361
1.08	325	1.48	363
1.10	327	1.50	365
1.12	329	1.52	366
1.14	331	1.54	368
1.16	333	1.56	369
1.18	335	1.58	371
1.20	337	1.60	373
1.22	339	1.62	374
1.24	341	1.64	376
1.26	343	1.66	377
1.28	345	1.68	379
1.30	347	1.70	380
1.32	349	2.00	400
1.34	351	2.10	406
1.36	352	2.20	412
1.38	354		

Steam Sizing

Calculation per ASME Section VIII

Steam:

$$W = 51.5 A \cdot P \cdot K_D \cdot K_N$$

$$A = \frac{W}{51.5 \cdot P \cdot K_D \cdot K_N}$$

$K_N = 1.0$ when $P \leq 1500$ psia

$$K_N = \left(\frac{0.1906P - 1000}{0.2292P - 1061}\right) \text{ when } P > 1500 \text{ psia and } P \leq 3200 \text{ psia}$$

Calculation per API RP520

Steam:

$$A = \frac{W}{51.5 \cdot P \cdot K_D \cdot K_N \cdot K_{SH}}$$

K_{SH}= See Table 3 for superheated steam correction factors

TABLE 3

Superheated Steam Correction Factors, K_{SH}

Burst Pressure (psig)	Temperature (°F)									
	300	400	500	600	700	800	900	1000	1100	1200
15	1.00	0.98	0.93	0.88	0.84	0.80	0.77	0.74	0.72	0.70
20	1.00	0.98	0.93	0.88	0.84	0.80	0.77	0.74	0.72	0.70
40	1.00	0.99	0.93	0.88	0.84	0.81	0.77	0.74	0.72	0.70
60	1.00	0.99	0.93	0.88	0.84	0.81	0.77	0.75	0.72	0.70
80	1.00	0.99	.093	0.88	0.84	0.81	0.77	0.75	0.72	0.70
100	1.00	0.99	0.94	0.89	0.84	0.81	0.77	0.75	0.72	0.70
120	1.00	0.99	0.94	0.89	0.84	0.81	0.78	0.75	0.72	0.70
140	1.00	0.99	0.94	0.89	0.85	0.81	0.78	0.75	0.72	0.70
160	1.00	0.99	0.94	0.89	0.85	0.81	0.78	0.75	0.72	0.70
180	1.00	0.99	0.94	0.89	0.85	0.81	0.78	0.75	0.72	0.70
200	1.00	0.99	0.95	0.89	0.85	0.81	0.78	0.75	0.72	0.70
220	1.00	0.99	0.95	0.89	0.85	0.81	0.78	0.75	0.72	0.70
240	-	1.00	0.95	0.90	0.85	0.81	0.78	0.75	0.72	0.70
260	-	1.00	0.95	0.90	0.85	0.81	0.78	0.75	0.72	0.70
280	-	1.00	0.96	0.90	0.85	0.81	0.78	0.75	0.72	0.70
300	-	1.00	0.96	0.90	0.85	0.81	0.78	0.75	0.72	0.70
350	-	1.00	0.96	0.90	0.86	0.82	0.78	0.75	0.72	0.70
400	-	1.00	0.96	0.91	0.86	0.82	0.78	0.75	0.72	0.70
500	-	1.00	0.96	0.92	0.86	0.82	0.78	0.75	0.73	0.70
600	-	1.00	0.97	0.92	0.87	0.82	0.79	0.75	0.73	0.70
800	-	-	1.00	0.95	0.88	0.83	0.79	0.76	0.73	0.70
1000	-	-	1.00	0.96	0.89	0.84	0.78	0.76	0.73	0.71
1250	-	-	1.00	0.97	0.91	0.85	0.80	0.77	0.74	0.71
1500	-	-	-	1.00	0.93	0.86	0.81	0.77	0.74	0.71
1750	-	-	-	1.00	0.94	0.86	0.81	0.77	0.73	0.70
2000	-	-	-	1.00	0.95	0.86	0.80	0.76	0.72	0.69
2500	-	-	-	1.00	0.95	0.85	0.78	0.73	0.69	0.66
3000	-	-	-	-	1.00	0.82	0.74	0.69	0.65	0.62

Liquid Sizing

Calculation per ASME Section VIII

Water:

$$W = 2407A\sqrt{(P - P_e)w}$$

$$A = \frac{W}{2407\sqrt{(P - P_e)w}}$$

Calculation per API RP520

Non-viscous liquid:

$$A_R = \frac{Q}{38 \cdot K_D \cdot K_v}\sqrt{\frac{SG}{P - P_e}}$$

A_R = Required Area without viscosity corrections (sq. in.)
A_V = Required Area with viscosity correction (sq. in.)

Viscous liquid:

$$A_V = \frac{A_R}{K_v}$$

$$K_v = \left(0.9935 + \frac{2.878}{R^{0.5}} + \frac{342.75}{R^{1.5}}\right)^{-1.0}$$

For viscous liquid sizing, first calculate A_R using K_v of 1.0 Apply the area A of the next larger size disc to the Reynolds number calculations to arrive at K_v. Then re-calculate required area A_V using the derived K_v.

$$R = \frac{Q(2800 \cdot SG)}{u\sqrt{A}}$$ (u is in centipoise)

or

$$R = \frac{12700 \cdot Q}{U\sqrt{A}}$$ (U is in Saybolt Universal Seconds, SSU)

Resistance to Flow Method (K_R)

When to use this method — Use this method when the 8&5 Rule does not apply. When the disc is installed in combination with a pressure relief valve, this method can be used to calculate the pressure drop between the pressure vessel and the valve.

Rupture disc devices can be characterized as to their respective resistance to fluid flow. The K_R value represents the velocity head loss due to the rupture disc device. This head loss is included in the overall system loss calculations to determine the capacity of the relief system.

ASME PTC25 provides standardized test methods to measure the K_R of rupture disc devices. By quantifying this performance characteristic, rupture disc devices may be accounted for in piping system sizing calculations in the same way as piping and piping components (exit nozzles on vessels, elbows, tees, reducers, valves).

> ***NOTE:*** *It is important to understand that the certified* K_R *is representative of the device (disc and holder), not simply the rupture disc. In cases where there is no holder, the* K_R *value is for the disc, which is then defined as the device.*

The following examples will illustrate how K_R values are used to establish the flow capacity of a pressure relief piping system.

Vapor Sizing

The following example, see Figure 1, assumes that $k = C_p/C_v = 1.4$ which results in a conservative calculation. The example shown is based on Crane TP-410 methods. It also assumes a steady state relieving condition where the vessel volume is large relative to the relieving capacity.

Given information:

1. Pressure vessel MAWP = 1000 psig.
2. Relieving pressure as allowed by ASME Section VIII Div.1 = 110% x MAWP = 1114.7 psia = P'_1
3. Back pressure (outlet pressure) = 14.7 psia = P_2
4. Working fluid - air ($k = C_p/C_v = 1.4$)
5. Air temperature at disc rupture = 500°F = 960°R = T_1
6. Maximum flow rate into the vessel = 20,000 SCFM-Air
7. Rupture Disc - FIKE 3" *SRX*-GI ➜ K_R = 0.99

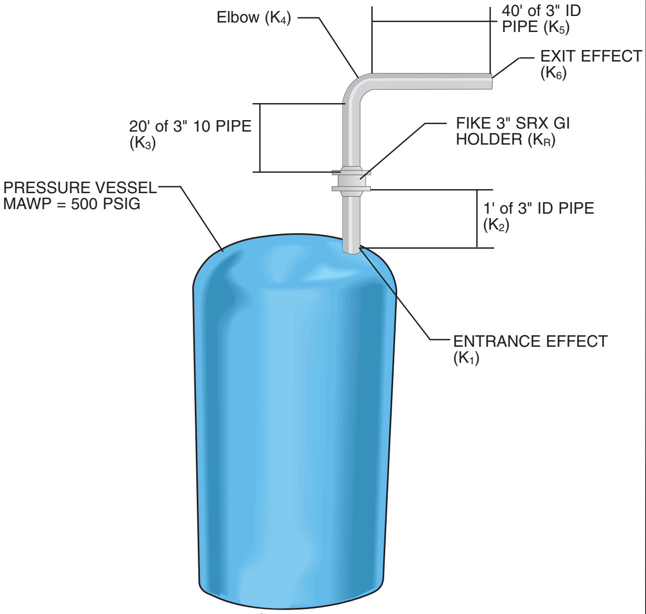


Figure 1.

Determine the Total Piping System Resistance Factor:

Piping Component Or Feature	Flow Resistance Value (K)	Reference
Entrance - Sharp Edged	$K_1 = 0.50$	Crane 410 Pg A-29
1 ft. of 3" Sch. 40 Pipe	$K_2 = 0.07$	K=fL/D; f = .018 (Crane 410 Pg A-26) L = 1 ft, ID = 3.068/12 ft
FIKE 3" SRX-GI Rupture Disc	$K_R = 0.99$	National Board Cert. No. FIK-M80042
20 ft. of 3" Sch. 40 Pipe	$K_3 = 1.41$	K=fL/D; f = .018 (Crane 410 Pg A-26) L = 20 ft, ID = 3.068/12 ft
3" Sch. 40 Standard 90° Elbow	$K_4 = 0.54$	Crane 410 Pg A-29
40 ft. of 3" Sch. 40 Pipe	$K_5 = 2.82$	K=fL/D; f = .018 (Crane 410 Pg A-26) L = 40 ft, ID = 3.068/12 ft
Pipe exit - Sharp Edged	$K_6 = 1.00$	Crane 410 Pg A-29
Total System Flow Resistance	$K_T = 7.33$	$K_T = K_1 + K_2 + K_R + K_3 + K_4 + K_5 + K_6$

The Darcy Equation defines the discharge of compressible fluids through valves, fittings and pipes. Since the flow rate into the example vessel is defined in SCFM, the following form of the Darcy equation is used:

Crane Equation 3-20

$$q'_m = 678 * Y * d^2 \sqrt{\frac{\Delta P * P'_1}{K T_1 S_g}} SCFM$$

- q'_m = rate of flow in cubic feet per minute at standard conditions (14.7 psia and 60°F)
- Y = net expansion factor for compressible flow through orifices, nozzles and pipes (Crane 410 Pg A-22)
- d = internal diameter of pipe (in.)
- ΔP = Change in pressure from state 1 to 2 (entrance to exit).
- P'_1 = Pressure at state 1 (entrance) = psia
- K = Loss coefficient
- T_1 = Absolute temperature at state 1 (entrance) in degrees Rankine (°R)
- Sg = Specific gravity relative to air = 1.0 (for this example)

To determine *Y*, first it must be determined if the flow will be sonic or subsonic. This is determined by comparing the ***actual*** $\Delta P/P'_1$ to the ***limiting*** $\Delta P/P'_1$ for sonic flow. Crane Table A-22 shows limiting factors for k=1.4 for sonic flow at a known value of K_T. If $(\Delta P/P'_1)_{sonic} < (\Delta P/P'_1)_{actual}$, then the flow will be sonic.

Limiting Factors for Sonic Velocity (k = 1.4)
Excerpted from Crane 410 Pg A-22

K	$\Delta P/P'_1$	Y
1.2	.552	.588
1.5	.576	.606
2.0	.612	.622
3	.622	.639
4	.697	.649
6	.737	.671
8	.762	.685
10	.784	.695
15	.818	.702
20	.839	.710
40	.883	.710
100	.926	.710

For this example: $(\Delta P / P'_1)_{actual} = \frac{1114.7 - 14.7}{1114.7} = 0.9868$

From table A-22 at K_T =7.33

$$(\Delta P / P'_1)_{sonic} = 0.754$$

Since $(\Delta P / P'_1)_{sonic} < (\Delta P / P'_1)_{actual}$, the flow is sonic in the piping. Thus, we will use Y_{sonic} = 0.680 in the flow calculations (Crane 410 Eq. 3-20.)

Since $(\Delta P / P'1)_{sonic}$ = .762, then $\Delta P = 0.754 * P'_1$ = 0.754*1114.7 = 840.5 psi
Calculating the system capacity is completed by substituting the known values into Crane 410 Equation 3-20.

$$q'_m = 678 * Y * d^2 \sqrt{\frac{\Delta P * P'_1}{KT_1 S_g}}$$

$$q'_m = 678*0.680*(3.068)^2 \sqrt{\frac{840.5 * 1114.7}{7.33 * 960 *1}}$$

$$q'_m = 50{,}074 SCFM - Air$$

The ASME Pressure Vessel Code, Section VIII, Division 1, paragraph UG-127(a)(2)(b), also requires that the calculated system capacity using the resistance to flow method must also be multiplied by a factor of 0.90 or less to account for uncertainties inherent with this method.

$$q'_{m-ASME} = 50{,}074*0.90 = 45{,}066\ SCFM - Air$$

Thus, the system capacity is greater than the required process capacity (20,000 SCFM $_{Air}$)

> ***Subsonic Flow Case***
> In the case where the flow subsonic, or $(\Delta P / P'_1)_{sonic} < (\Delta P / P'_1)_{actual}$, simply read the value of Y_{actual} from Crane 410 chart A-22, Substitute $(\Delta P / P'_1)_{actual}$ and Y_{actual} into the calculations.

Liquid Sizing

For this example Figure 2 is assumed, water will be considered the flow media. The example shown is based on Crane TP-410 methods. It also assumes a steady state relieving condition where the vessel volume is large relative to the relieving capacity.

Given information:

1. Pressure vessel MAWP = 500 psig.
2. Relieving pressure as allowed by ASME Section VIII Div. 1 = 110% x MAWP = 550 psig = P_1
3. Back pressure (outlet pressure) = 0 psig = P_2
4. Working fluid - Water
5. Temperature = 70°F
6. Maximum flow rate into the vessel = 50 ft^3/min
7. Rupture Disc - FIKE 2" *SRX*-GI ➜ K_R = 0.38

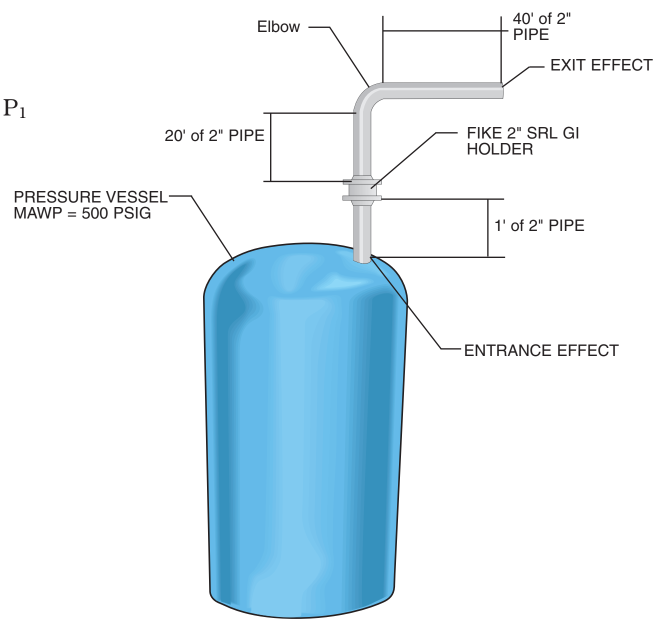


Figure 2.

From Crane 410:

"Bernoulli's Theorem is a means of expressing the application of the law of conservation of energy to the flow of fluids in a conduit [piping]. The total energy at any particular point, above some arbitrary horizontal datum plane, is equal to the sum of the elevation head ["***Z***"], the pressure head ["***P***"], the velocity head ["***V***"]."

In real applications, there are energy losses in piping systems between states (or location) 1 and 2. Those losses are accounted for in the term h_l, which are predominantly frictional head losses. The energy balance is then expressed

Crane Equation 1-3 Δ

$$Z_1 + \frac{144 P_1}{\rho_1} + \frac{V_1^2}{2g} = Z_2 + \frac{144 P_2}{\rho_2} + \frac{V_2^2}{2g} + h_l$$

Where:

Z_1 and Z_2 = elevation head at states 1 and 2 (ft. - "feet")
P_1 and P_2 = pressure at states 1 and 2 (psig)
V_1 and V_2 = velocity at states 1 and 2 (ft/sec)
ρ_1 and ρ_1 = fluid density at states 1 and 2 (lb/ft3)
g = acceleration due to gravity (32.2 ft sec^2)
h_l = frictional head loss (ft.)

As in the previous example, head losses due to friction in the piping and the head losses due to fittings are proportional to the sum of the flow resistances:

$$h_l \approx \sum K$$

Since the actual head loss is velocity dependent,

$$h_l = \sum K\left(\frac{V^2}{2g}\right)$$

Frictional loss coefficients and fitting loss coefficients for the example are as follows:

Piping Component Or Feature	Flow Resistance Value *(K)*	Reference
Piping Frictional Losses		
1 ft. of 2" Sch. 40 Pipe	$K_{1'\ pipe}$ = 0.11	**K=fL/D;** f = .019 (Crane 410 Pg A-26) L = 1 ft, ID = 2.067/12 ft
20 ft. of 2" Sch. 40 Pipe	$K_{20'\ pipe}$ = 2.21	**K=fL/D;** f = .019 (Crane 410 Pg A-26) L = 20 ft, ID = 2.067/12 ft
40 ft. of 2" Sch. 40 Pipe	$K_{40'\ pipe}$ = 4.41	**K=fL/D;** f = .019 (Crane 410 Pg A-26) L = 40 ft, ID = 2.067/12 ft
Fitting Losses		
Entrance - r/d = 0.10	K_{ent} = 0.09	Crane 410 Pg A-29
FIKE 2" ***SRL***-GI Rupture Disc	K_R = 0.38	National Board Cert. No. FIK-M80031
2" Sch. 40 Standard 90° Elbow	K_{el} = 0.57	Crane 410 Pg A-29
Pipe exit - Sharp Edged	K_{exit} = 1.00	Crane 410 Pg A-29
Total Losses	K_T = **8.77**	

Thus,

$$h_l = 8.77\left(\frac{V^2}{2g}\right)$$

Other known conditions:

V_{vessel} = 0 ft/sec
Z_{vessel} = 0 ft
Z_{exit} ~ 1 ft + 20 ft = 21 ft = elevation change of piping
P_{exit} = 0 psig
$\rho_1 = \rho_2$ = 62.3 lb/ft^3 for water at room temperature

Substituting values into Equation 1-3,

$$0 + \frac{144 * 550}{62.3} + 0 = 21 + 0 + \frac{V_2^{\,2}}{2 * 32.2} + \left[8.77 * \left(\frac{V_2^{\,2}}{2 * 32.2}\right)\right]$$

Solving for V_2 (exit velocity),

$$V_2 = 90.78\, ft/\mathrm{sec}$$

The friction factor used earlier in the calculations for piping frictional losses assumed that the flow in the pipes was fully turbulent flow. The value of the friction factor is related to the Reynolds Number (***Re***) of the resulting flow (Ref: Crane 410 pg 1-1). For ***Re*** < 2000, the flow is laminar and the friction factor is a function of Reynolds Number, only. For ***Re*** > 4000, the flow is fully turbulent and the friction factor is also a function of the character of the piping wall (relative roughness).

The friction factor used earlier must be verified. First calculate the Reynolds Number:

$$R_e = \frac{Vd}{\nu}$$

V = fluid velocity = 90.78 ft/sec
d = pipe diameter = 2.067in/12 in/ft
ν = kinematic viscosity = 0.000011 ft^2/sec

$$R_e = \frac{90.78\left(2.067/12\right)}{1.1*10^{-5}} = 1.42*10^6$$

Since the Reynolds Number is >>4000, the flow is turbulent, and the friction factor is now a function of the relative roughness of the pipe. From Crane 410 Figure A-23, the friction factor, ***f***, for 2" commercial steel pipe in fully turbulent flow is 0.019. This verifies the original assumption for friction factor.

Laminar Flow Considerations

If the flow had been laminar, ***Re*** < 2000, the friction factor is calculated as:

$$f = 64/R_e$$

If this friction factor had not been close to the same value used to determine frictional loss coefficients used earlier, the calculation must be repeated and iteratively solved until the assumed friction factor equals the calculated friction factor.

Now that the fluid velocity is known, the volumetric flow rate can be calculated.

$$Q = A * V$$

Where

Q = Volumetric flow rate (ft^3/sec)
A = Area of pipe (ft^2) - $\pi d^2/4$
V = Fluid velocity (ft/sec)

Substituting values,

$$Q = \frac{\pi}{4} * \left(2.067/12\right)^2 * 90.78$$

$$Q_{calc} = 2.12 ft^3/\sec = 125.9 ft^3/\min$$

Per the ASME Code, the rated system capacity is,

$$Q_{rated} = Q_{calc} * 0.90 = 125.9 * 0.90 = 113.3 ft^3/\min$$

Therefore, the relief system can flow the required 50 ft^3/min.

References:

American Society of Mechanical Engineers, Boiler and Pressure Vessel Code Section VIII, Division 1, 1998 Edition
American Socity of Mechanical Engineers, PTC25
American Petroleum Institute, RP520
Crane Valves, Technical Paper 410
Crane Valves, Crane Companion Computer Program
Fike Technical Bulletin TB8104 Certified K_R Factors

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