# Equations and Example Benchmark Calculations for Emergency Scenario Required Relief Loads

V8.8: Control Valve Failure, Heat Exchanger Tube Rupture, Hydraulic Expansion and Fire

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# Introduction

Introduced in Aspen HYSYS<sup>®</sup> V8.3, the Safety Analysis Environment provides a tool for adding pressure relief devices and calculating relief loads inside Aspen HYSYS. Leveraging this tool within the rigorous Aspen HYSYS simulator, and in combination with Aspen Flare System Analyzer, provides an integrated solution for pressure relief analysis (PRA) work.

This paper contains hand calculations for the relief loads inside the Safety Analysis Environment. This paper shows examples and equations for emergency scenarios, including control valve failure, heat exchanger tube rupture, hydraulic expansion, and fire, which will help you to validate the calculations of this tool located within Aspen HYSYS.

# Control Valve Failure

For a control valve failure scenario, the required relief load is the maximum flow through the control valve at full open. API Standard 521 allows that credit for normal minimum flow may be taken under certain circumstances.<sup>1</sup>

# **PSV Plus Vapor Equations**

The critical pressure drop for gas or vapor flow across a control valve is defined as below, where  $P_1$  is the upstream pressure in psia,  $\Delta P^*$  is the critical limit in psi, and  $C_1$  is a characteristic parameter of the control valve.

### $Eq. 1 \qquad \Delta P^* = 0.5 C_f^2 P_1$

If the pressure drop across the control valve exceeds the critical limit, then the mass flow rate through the valve is given by Equation 2 below.

#### Eq. 2 $w = 2.8C_f P_1 C_v \sqrt{SG/Z}$

Otherwise, the mass flow rate through the valve is given by Equation 3 below, where  $P_r$  is the downstream (relieving) pressure in psia, *SG* is the specific gravity relative to air at upstream conditions, *Z* is the compressibility of the stream at upstream conditions, and  $C_v$  is a characteristic parameter of the control valve.

Eq. 3 
$$w = 3.22C_v \sqrt{\frac{\Delta P^*(P_r + P_1)SG}{Z}}$$

The specific gravity may be calculated as below, where M is the molecular weight and  $T_r$  is the upstream temperature in °F.

Eq. 4 
$$SG = \frac{M}{29} \times \frac{520}{T_r + 460}$$

# PSV Plus Vapor Example with Unchoked Flow

The example is based on the following conditions:

Composition	40% isobutane, 45% isopentane, 15% n-hexane using the Aspen HYSYS SRK package for physical properties
Upstream conditions	320 psia / 320 F
Normal flowrate	9,000 lb/h
Relief pressure	260 psig set pressure + 10% allowable overpressure = 286 psig
Control valve	$C_v = 20.0, \ C_f = F_l = 0.75$

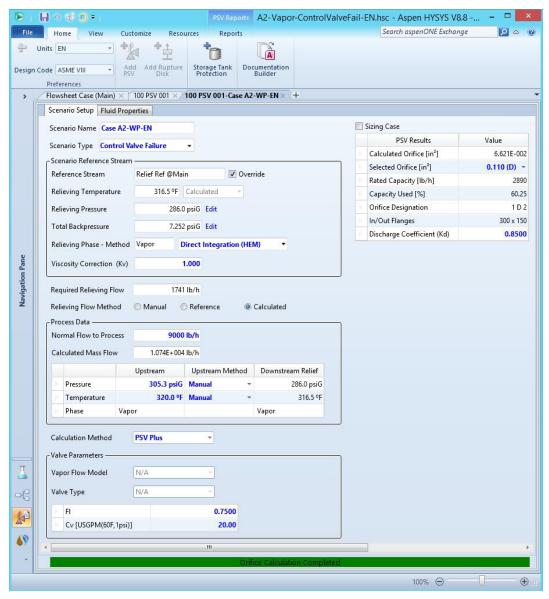


Figure 1: Subcritical vapor control valve case calculated in Aspen HYSYS using PSV Plus equations

Setting up a stream in Aspen HYSYS at the upstream conditions will yield the following properties: M = 68.64Z = 0.68

The critical pressure drop may be calculated using (Eq. 1):

$$\Delta P^* = 0.5(0.75)^2 320 = 90 \text{ psi}$$

The pressure drop across the valve at relieving conditions is only 19.3 psi, so the flow is subcritical.

The specific gravity may be calculated using (Eq. 4):

$$SG = \frac{68.64}{29} \times \frac{520}{320 + 460} = 1.578$$

The control valve capacity at relief conditions is calculated using (Eq. 3):

$$w = 3.22(20) \sqrt{\frac{19.3(286 + 14.7 + 320)1.578}{0.68}} = 10737 \, \text{lb/h}$$

Subtracting the normal flowrate of 9,000 lb/h gives a required relief load of 1,737 lb/h.

The results calculated above are compared to results obtained in Aspen HYSYS in Table 1.

Variable	Units	Example Calculation	Aspen HYSYS
Inlet Pressure ( $P_1$ )		320 psia	305.3 psig
Normal Flow to Process	lb/h	9,000	9,000
Control Valve CV ( $C_V$ )		20	20.00
Critical Flow Factor ( <i>C<sub>f</sub></i> )		0.75	0.7500
Molecular Weight ( <i>M</i> )	lb/lbmol	68.64	
Compressibility (Z)		0.68	
Specific Gravity ( <i>SG</i> )		1.578	
Critical Pressure Drop ( $\Delta P^*$ )	psi	90.0	
Flow type		Subcritical	Subcritical
Full-open Flow ( <i>w</i> )	lb/h	10,737	
Required Relieving Flow	lb/h	1,737	1,741
В	lue = Calculation input	Gray = Calculated value	·

Table 1: Comparison of example calculation and Aspen HYSYS calculation for control valve failure with subcritical vapor flow

# PSV Plus Vapor Example with Choked Flow

The example is based on the following conditions:

Composition	40% isobutane, 45% isopentane, 15% n-hexane using the Aspen HYSYS SRK package for physical properties
Upstream conditions	420 psia / 355 F
Normal flowrate	3,300 lb/h
Relief pressure	260 psig set pressure + 10% allowable overpressure = 286 psig
Control valve	$C_v = 5.5, \ C_f = F_l = 0.75$

Setting up a stream in Aspen HYSYS at the upstream conditions will yield the following properties: M = 68.64

**Z**= 0.624

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					Rated Capacity [lb/h]	504
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Figure 2: Critical vapor control valve case calculated in Aspen HYSYS using PSV Plus equations ( aspentech

The critical pressure drop may be calculated using (Eq. 1):

$$\Delta P^* = 0.5(0.75)^2 420 = 118.1 \text{ psi}$$

The pressure drop across the valve at relieving conditions is only 119.3 psi, so the flow is critical.

The specific gravity may be calculated using (Eq. 4):

$$SG = \frac{68.64}{29} \times \frac{520}{355 + 460} = 1.51$$

The control valve capacity at relief conditions is calculated using (Eq. 2):

#### $w = 2.8(0.75)(420)(5.5)\sqrt{1.51/0.624} = 7,546 \text{ lb/h}$

Subtracting the normal flowrate of 3,300 lb/h gives a required relief load of 4,246 lb/h.

The results calculated above are compared to results obtained in Aspen HYSYS in Table 2.

Variable	Units	Example Calculation	Aspen HYSYS
Inlet Pressure (P1)		420 psia	405.3 psig
Normal Flow to Process	lb/h	3,300	3,300
Control Valve CV ( <i>C<sub>V</sub></i> )		5.5	5.500
Critical Flow Factor ( $C_f$ )		0.75	0.7500
Molecular Weight ( <i>M</i> )	lb/lbmol	68.64	
Compressibility (Z)		0.624	
Specific Gravity (SG)		1.51	
Critical Pressure Drop ( $\Delta P^*$ )	psi	118.1	
Flow type		Critical	Critical
Full-open Flow ( <i>w</i> )	lb/h	7,546	
Required Relieving Flow	lb/h	4,246	4,242
В	lue = Calculation input	Gray = Calculated value	

Table 2: Comparison of example calculation and Aspen HYSYS calculation for control valve failure with critical vapor flow using PSV Plus equations

# **PSV Plus Liquid Equations**

The critical pressure drop for liquid flow across a control valve is defined as below, where  $F_F$  is a calculated critical flow parameter,  $P_v$  is the vapor pressure/bubble point pressure of the liquid in psia, and  $P_c$  is the critical pressure of the liquid in psia.

*Eq.* 5 
$$F_F = 0.96 - 0.28 \sqrt{\frac{P_v}{P_c}}$$

$$Eq. 6 \qquad \Delta P^* = C_f^2 (P_1 - F_F P_v)$$

The volumetric capacity of the control valve may be calculated as shown below, where  $\Delta P_{min}$  is actual  $\Delta P$  or  $\Delta P^*$ , whichever is smaller of the actual pressure drop across the valve and the critical pressure drop across the valve, *SG* is the specific gravity of the fluid at upstream conditions relative to water at 60 F (15.6 C), and *Q* is the capacity of the control valve in gpm.

Eq. 7 
$$Q = C_v \sqrt{\frac{\Delta P_{min}}{SG}}$$

The required relief load in gpm may be converted to lb/h, as shown below:

*Eq. 8* 
$$w = Q \times \frac{60 \text{ min}}{1 \text{ h}} \times \frac{1 \text{ ft}^3}{7.4805 \text{ gal}} \times \rho$$

# PSV Plus Liquid Example with Unchoked Flow

The example is based on the following conditions:

Composition	15% propane, 30% isobutane, 30% n-butane, 25% isopentane using the Aspen HYSYS PR package for physical properties
Upstream conditions	275 psia / 195 F
No credit taken for norma	I flowrate across the valve
Relief pressure	190 psig set pressure + 10% allowable overpressure = 209 psig
Control valve	$C_v = 8, C_f = F_l = 0.75$

Setting up a stream in Aspen HYSYS at the upstream conditions will yield the following properties:

 $P_c = 562.6 \text{ psia}$  $P_v = 216.1 \text{ psia}$ 

 $\rho$  = 29.95 lb/ft<sup>3</sup> hence *SG* = 29.95/62.3 = 0.4807

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The critical pressure drop is calculated from (Eq. 5) and (Eq. 6):

$$F_F = 0.96 - 0.28 \sqrt{\frac{216.1}{562.6}} = 0.7865$$

$$\Delta P^* = 0.75^2 (275 - 0.7865 \times 216.1) = 59 \text{ psi}$$

The pressure drop at relief conditions is 51.3 psi, which is less than the critical limit; therefore, the flow is unchoked. The required relief load is calculated from (Eq. 7) and (Eq. 8):

$$Q = 8\sqrt{\frac{51.3}{0.4807}} = 82.6 \text{ gpm}$$

 $w = 82.6 \text{ gpm} \times \frac{60 \text{ min}}{1 \text{ h}} \times \frac{1 \text{ ft}^3}{7.4805 \text{ gal}} \times 29.95 \text{ lb/ft}^3 = 19,840 \text{ lb/h}$ 

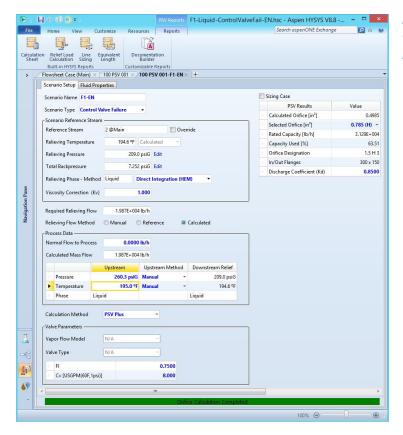


Figure 3: Unchoked liquid control valve case calculated in Aspen HYSYS using PSV Plus equations

Variable	Units	Example Calculation	Aspen HYSYS
Inlet Pressure ( $P_1$ )		275 psia	260.3 psig
Normal Flow to Process	lb/h	0	0.0000
Control Valve CV ( $C_V$ )		8	8.000
Critical Flow Factor ( $C_f$ )		0.75	0.7500
Specific Gravity (SG)		0.4807	
Liquid Critical Pressure ( $P_C$ )		562.2 psia	
Liquid Vapor Pressure ( $P_V$ )		216.1 psia	
Critical Pressure Drop ( $\Delta P^*$ )	psi	59	
Flow type		Unchoked	Subcritical
Required Relieving Flow	lb/h	19,840	19,870
В	lue = Calculation input	Gray = Calculated value	

The results calculated above are compared to results obtained in Aspen HYSYS in Table 3.

Table 3: Comparison of example calculation and Aspen HYSYS calculation for control valve failure with subcritical liquid flow using PSV Plus equations

# PSV Plus Liquid Example with Choked Flow

The example is based on the following conditions:

Composition	15% propane, 25% n-butane, 30% n-pentane, 30% n-heptane using the Aspen HYSYS PR package for physical properties
Upstream conditions	275 psia / 265 F
No credit taken for norma	I flowrate across the valve
Relief pressure	105 psig set pressure + 10% allowable overpressure = 115.5 psig
Control valve	$C_v = 120, \ C_f = F_l = 0.75$

Setting up a stream in Aspen HYSYS at the upstream conditions will yield the following properties:

 $P_c$  = 583.5 psia  $P_v$  = 247.1 psia

 $\rho$  = 30.85 lb/ft<sup>3</sup> hence *SG* = 30.85/62.3 = 0.495

The critical pressure drop is calculated from (Eq. 5) and (Eq. 6):

$$F_F = 0.96 - 0.28 \sqrt{\frac{247.1}{583.5}} = 0.778$$

$$\Delta P^* = 0.75^2 (275 - 0.778 \times 247.1) = 46.6 \text{ psi}$$

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					inte	Rated Capacity [lb/h]	4.614E+00
Rel	lieving Temperature	224.3 °F	Calculated	-		Capacity Used [%]	62.5
Rel	lieving Pressure	115.5	5 psiG Edit			Orifice Designation	8 T 1
To	tal Backpressure	7.252	2 psiG Edit			In/Out Flanges	300 x 15
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Figure 4: Choked liquid control valve case calculated in Aspen HYSYS using PSV Plus equations

The pressure drop at relief conditions is 144.8 psi, which is greater than the critical limit, therefore the flow is choked. The required relief load is calculated from (Eq. 7) and (Eq. 8):

$$Q = 120 \sqrt{\frac{46.6}{0.495}} = 1164 \text{ gpm}$$

$$w = 1164 \text{ gpm} \times \frac{60 \text{ min}}{1 \text{ h}} \times \frac{1 \text{ ft}^3}{7.4805 \text{ gal}} \times 30.85 \text{ lb/ft}^3 = 288,100 \text{ lb/h}$$

The results calculated above are compared to results obtained in Aspen HYSYS in Table 4.

Variable	Units	Example Calculation	Aspen HYSYS
Inlet Pressure ( $P_1$ )		275 psia	260.3 psig
Normal Flow to Process	lb/h	0	0.0000
Control Valve CV ( $C_V$ )		120	120.0
Critical Flow Factor ( $C_f$ )		0.75	0.7500
Specific Gravity (SG)		0.495	
Liquid Critical Pressure ( $P_C$ )		583.5 psia	
Liquid Vapor Pressure ( $P_V$ )		247.1 psia	
Critical Pressure Drop ( $\Delta P^*$ )	psi	46.6	
Flow type		Choked	Critical
Required Relieving Flow	lb/h	288,100	288,400
В	lue = Calculation input	Gray = Calculated value	

Table 4: Comparison of example calculation and Aspen HYSYS calculation for control valve failure with critical liquid flow using PSV Plus equations

# Heat Exchanger Tube Break

For a heat exchanger tube break scenario, API Standard 521 states that the calculation should be based on a sharp break in one tube, at the back of the tube sheet, with high pressure fluid assumed to flow both through the stub in the tube sheet and through the long section of tube. A calculation basis of flow through two orifices is allowed as a simplifying assumption, because the resulting relief load is larger than would be calculated based on flow through a long tube.<sup>1</sup>

The tube rupture calculation in the Safety Analysis Environment uses a two-orifice calculation as described in the literature.<sup>23</sup>

## Vapor Equations

As with control valves, vapor flow through a tube rupture is subject to a critical flow limit. The downstream critical limit pressure may be calculated as below, where  $P_{cfr}$  is the critical limit pressure in psia,  $P_1$  is the high-pressure-side pressure in psia, and k is the ideal gas specific heat ratio  $C_{P/}(C_P - R)$  at relief conditions.

Eq. 9 
$$P_{cfr} = P_1 \left[ \frac{2^{k/k-1}}{k+1} \right]$$

The flow through the rupture is given by the calculation below, where w is the required relief load in lb/h, C is the orifice coefficient, A is the total rupture area in in<sup>2</sup>,  $\Delta P$  is the pressure difference between the  $P_1$  and the greater of the downstream relief pressure or  $P_{cfr}$ , and  $\rho$  is the vapor density at upstream conditions in lb/ft<sup>3</sup>.

#### Eq. 10 $w = 2407.7 \ C \ A \ Y \sqrt{\Delta P \cdot \rho}$

For flow from the tube side into the shell side, the orifice coefficient used is typically 0.74 (so the product with the leading coefficient is 1,781.7), and the expansion coefficient Y may be calculated, as shown in Equation 11 below.

*Eq. 11* 
$$Y = 1 - 0.4 \frac{\Delta P}{P_1}$$

For flow from the shell side into the tube side, the orifice coefficient used is typically 0.6 (so the product with the leading coefficient is 1,444.6), and the expansion coefficient may be calculated as shown below.

*Eq. 12* 
$$Y = 1 - 0.317 \frac{\Delta P}{P_1}$$

# Vapor Example with Unchoked Shell-Into-Tube Flow

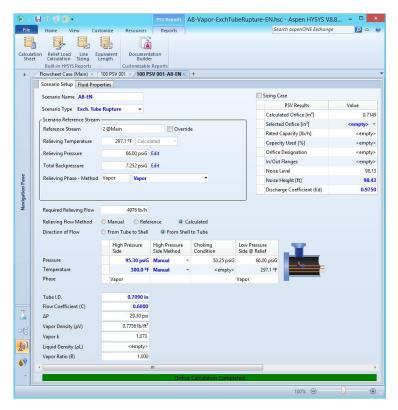
The example is based on the following conditions:

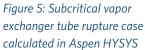
Composition	30% propane, 70% n-butane using the Aspen HYSYS SRK package for physical properties
Upstream conditions	110 psia / 300 F
Normal flowrate	9,000 lb/h
Relief pressure	60 psig set pressure + 10% allowable overpressure = 66 psig
Tubes are 14 ga 7/8" tube with	n an inner diameter of 0.709 in

Setting up a stream in Aspen HYSYS at the high-pressure side conditions will yield the following properties:

 $\rho = 0.7756 \, \text{lb/ft}^3$ 

Flashing to relief conditions will yield the following properties: k = 1.073





The critical flow pressure is calculated using (Eq. 9):

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$$P_{cfr} = 110 \text{ psia} \left[ \frac{2}{(1.073)/(1.073)-1} \right] = 64.9 \text{ psia}$$

Since the critical pressure of 64.9 psia is less than the low-pressure side relief pressure of 80.7 psia, flow is not choked and the pressure drops across the break  $\Delta P$  = 29.3 psi.

The required relief load may be calculated using (Eq. 10) and (Eq. 12):

$$A = 2\frac{\pi}{4}(0.709 \text{ in})^2 = 0.7896 \text{ in}^2$$

$$Y = 1 - 0.317 \frac{29.3}{110} = 0.9156$$

$$w = 1444.6(0.7896)(0.9156)\sqrt{(29.3)(0.7756)} = 4,979 \text{ lb/h}$$

The results calculated above are compared to results obtained in Aspen HYSYS in Table 5.

Variable	Units	Example Calculation	Aspen HYSYS
High Side Pressure ( <i>P</i> <sub>1</sub> )		110 psia	95.3 psig
High Side Temperature	F	300	300.0
Tube Inside Diameter	in	0.709	0.7090
$C_P/(C_P-R)$ (k)		1.073	1.073
Mass Density ( $ ho$ )	lb/ft³	0.7756	0.7756
Critical Pressure (P <sub>cfr</sub> )		64.9 psia	50.25 psig
Flow Type		Subcritical	Subcritical
Expansion Factor (Y)		0.9156	
Required Relieving Flow	lb/h	4,979	4,976
	Blue = Calculation input	Gray = Calculated value	

Table 5: Comparison of example calculation and Aspen HYSYS calculation for exchanger tube rupture with subcritical vapor flow

# Vapor Example with Choked Tube-Into-Shell Flow

The example is based on the following conditions:

Composition	30% propane, 70% n-butane using the Aspen HYSYS SRK package for physical properties
Upstream conditions	275 psia / 250 F
Relief pressure	60 psig set pressure + 10% allowable overpressure = 66 psig
Tubes are 20 ga 1 ¼″ tube wi	th an inner diameter of 1.18 in

Setting up a stream in Aspen HYSYS at the high-pressure side conditions will yield the following properties:

 $\rho$  = 2.493 lb/ft<sup>3</sup>

Flashing to relief conditions will yield the following properties: k = 1.079

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Scenario Typ	pe Exch. Tube	e Rupture 👻					Value
Scenario Re	ference Stream					ated Orifice [in <sup>2</sup> ]	7.36
Reference S	itream	2 @Main	C Overrid	de		ed Orifice [in <sup>2</sup> ]	11.050 (Q)
Relieving Te	emperature	222.5 °F Calcu	lated -			Capacity [lb/h]	8.199E+00- 66.6
						ity Used [%] • Designation	6 O
Relieving Pr	ressure	66.00 psiG	Edit			t Flanges	150 x 15
Total Backp	oressure	7.252 psiG	Edit		Noise		100 x 13
Relieving Ph	hase - Method	Vapor Vapor		-		Height [ft]	98.4
						arge Coefficient (Kd)	0.975
Required Re Relieving Fli Direction of		5.463E+004 lb/h Manual Refe From Tube to Shell		alculated I to Tube			0,313
Relieving Fl	ow Method	<ul> <li>Manual</li> <li>Refe</li> <li>From Tube to Shell</li> </ul>	From Shel	I to Tube			
Relieving Fl	ow Method	🔘 Manual 🛛 🔘 Refe			Low Pressure Side @ Relief		
Relieving Flu Direction of Pressure	ow Method Flow	Manual Refe From Tube to Shell High Pressure Side Side Side	From Shel High Pressure Side Method Manual	I to Tube Choking Condition 147.3 psiG	Low Pressure Side @ Relief 66.00 psiG		
Relieving Fl Direction of Pressure Temperatur	ow Method Flow	Manual Refe From Tube to Shell High Pressure Side 260.3 psiG 250.0 °F	From Shel High Pressure Side Method	I to Tube Choking Condition 147.3 psiG 233.5 °F	Low Pressure Side @ Relief 66.00 psiG 222.5 °F		
Relieving Flu Direction of Pressure	ow Method Flow	Manual Refe From Tube to Shell High Pressure Side Side Side	From Shel High Pressure Side Method Manual	I to Tube Choking Condition 147.3 psiG	Low Pressure Side @ Relief 66.00 psiG		
Relieving Fl Direction of Pressure Temperatur	ow Method Flow	Manual Refe From Tube to Shell High Pressure Side 260.3 psiG 250.0 °F	From Shel High Pressure Side Method Manual	I to Tube Choking Condition 147.3 psiG 233.5 °F	Low Pressure Side @ Relief 66.00 psiG 222.5 °F		
Relieving Fl Direction of Pressure Temperatur Phase	ow Method Flow re	Manual Refe From Tube to Shell High Pressure 260.3 psiG 250.0 °F Vapor	From Shel High Pressure Side Method Manual	I to Tube Choking Condition 147.3 psiG 233.5 °F	Low Pressure Side @ Relief 66.00 psiG 222.5 °F		
Relieving Fla Direction of Pressure Temperatur Phase Tube I.D.	ow Method Flow re	Manual Refe From Tube to Shell High Pressure Side 260.3 psiG 250.0 °F Vapor 1.180 in	<ul> <li>From Shel</li> <li>High Pressure</li> <li>Side Method</li> <li>Manual</li> <li>Manual</li> </ul>	I to Tube Choking Condition 147.3 psiG 233.5 °F	Low Pressure Side @ Relief 66.00 psiG 222.5 °F		
Relieving Fli Direction of Pressure Temperatur Phase Tube I.D. Flow Coeffii AP	ow Method Flow re cient (C)	Manual Refe From Tube to Shell High Pressure Side 260.3 psiG 250.0 °F Vapor 1.180 in 0.7400	<ul> <li>From Shel</li> <li>High Pressure</li> <li>Side Method</li> <li>Manual</li> <li>Manual</li> </ul>	I to Tube Choking Condition 147.3 psiG 233.5 °F	Low Pressure Side @ Relief 66.00 psiG 222.5 °F		
Relieving Fli Direction of Pressure Temperatur Phase Tube I.D. Flow Coeffi ΔP	ow Method Flow re cient (C)	Manual Refe From Tube to Shell High Pressure Side 260.3 psiG 250.0 °F Vapor 1.180 in 0.7400 113.0 psi	<ul> <li>From Shel</li> <li>High Pressure</li> <li>Side Method</li> <li>Manual</li> <li>Manual</li> </ul>	I to Tube Choking Condition 147.3 psiG 233.5 °F	Low Pressure Side @ Relief 66.00 psiG 222.5 °F		
Relieving Fli Direction of Pressure Temperatur Phase Tube I.D. Flow Coeffri ΔP Vapor Densi	ow Method Flow re cient (C) ity (pV)	Manual         Refe           Image: Side         From Tube to Shell           High Pressure         Side           260.3 psiG         2500.9F           Vapor         1.180 im           0.7400         113.0 psi           2.493 lb/rt <sup>1</sup> 2.493 lb/rt <sup>1</sup>	<ul> <li>From Shel</li> <li>High Pressure</li> <li>Side Method</li> <li>Manual</li> <li>Manual</li> </ul>	I to Tube Choking Condition 147.3 psiG 233.5 °F	Low Pressure Side @ Relief 66.00 psiG 222.5 °F		
Relieving Fk Direction of Pressure Temperatur Phase Tube I.D. Flow Coeffin AP Vapor Densi Vapor k	ow Method Flow re cient (C) ity (pV) ity (pL)	Manual         Refe           Image: State S	<ul> <li>From Shel</li> <li>High Pressure</li> <li>Side Method</li> <li>Manual</li> <li>Manual</li> </ul>	I to Tube Choking Condition 147.3 psiG 233.5 °F	Low Pressure Side @ Relief 66.00 psiG 222.5 °F		
Relieving FH Direction of Pressure Temperatur Phase Tube I.D. Flow Coeffin ΔP Vapor Densi Vapor k Liquid Dens	ow Method Flow re cient (C) ity (pV) ity (pL)	Manual         Refe           Prom Tube to Shell         High Pressure Side           250.3 psid         250.0 F           Vapor         1.180 in 0.7400           113.0 psi         2493 lb/rtf           1.079 <empty></empty>	<ul> <li>From Shel</li> <li>High Pressure</li> <li>Side Method</li> <li>Manual</li> <li>Manual</li> </ul>	I to Tube Choking Condition 147.3 psiG 233.5 °F	Low Pressure Side @ Relief 66.00 psiG 222.5 °F		
Relieving FH Direction of Pressure Temperatur Phase Tube I.D. Flow Coeffin ΔP Vapor Densi Vapor k Liquid Dens	ow Method Flow re cient (C) ity (pV) ity (pL)	Manual         Refe           Prom Tube to Shell         High Pressure Side           250.3 psid         250.0 F           Vapor         1.180 in 0.7400           113.0 psi         2493 lb/rtf           1.079 <empty></empty>	From Shell High Pressure Side Method Manual (choked flow)	I to Tube Choking Condition 147.3 psiG 233.5 °F	Low Pressure Side © Relief 66.00 psid 222.5 % Vapor		

#### Figure 6: Critical vapor exchanger tube rupture case calculated in Aspen HYSYS

The critical flow pressure is calculated using (Eq. 9):

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$$P_{cfr} = 275 \text{ psia}\left[\frac{2}{(1.079)/(1.079)-1}\right] = 162.0 \text{ psia}$$

Since the critical pressure of 162.0 psia is greater than the low-pressure side relief pressure of 80.7 psia, flow is choked and the pressure drops across the break  $\Delta P$  = 113.0 psi.

The required relief load may be calculated using (Eq. 10) and (Eq. 11):

$$A = 2\frac{\pi}{4}(1.18 \text{ in})^2 = 2.187 \text{ in}^2$$

$$Y = 1 - 0.4 \frac{113.0}{275} = 0.8356$$

$$w = 1781.7(2.187)(0.8356)\sqrt{(113.0)(2.493)} = 54,650 \text{ lb/h}$$

The results calculated above are compared to results obtained in Aspen HYSYS in Table 6.

Variable	Units	Example Calculation	Aspen HYSYS
High Side Pressure ( $P_1$ )		375 psia	360.3 psig
High Side Temperature	F	250	250.0
Tube Inside Diameter	in	1.18	1.180
$C_P/(C_P - R)$ (k)		1.079	1.079
Mass Density ( $ ho$ )	lb∕ft³	2.493	2.493
Critical Pressure (P <sub>cfr</sub> )		162.0 psia	147.3 psig
Flow Type		Critical	Critical
Expansion Factor (Y)		0.8356	
Required Relieving Flow	lb/h	54,650	54,630
	Blue = Calculation input	Gray = Calculated value	

Table 6: Comparison of example calculation and Aspen HYSYS calculation for exchanger tube rupture with critical vapor flow

# Liquid Equations

Liquid flow is not checked for choking. The flow through the rupture is given by Equation 13 below.

## Eq. 13 $w = 2407.7CA\sqrt{\Delta P \cdot \rho}$

As with vapor cases, for a tube-into-shell break, a value of 0.74 is typically used for the orifice coefficient, giving a combined leading coefficient of 1781.7. For a shell-into-tube break, a value of 0.6 is typically used for the orifice coefficient, giving a combined leading coefficient of 1444.6.

# Liquid Example with Tube-Into-Shell Flow

The example is based on the following conditions:

Composition	35% n-heptane, 35% n-decane, 30% n-C13 using the Aspen HYSYS SRK package for physical properties
High-pressure side conditions	740 psia / 120 F
Relief pressure	400 psig set pressure + 10% allowable overpressure = 440 psig
Tubes have an inner	diameter of 1.375 in

Setting up a stream in Aspen HYSYS at the relief conditions will yield the following properties:  $\rho = 44.13 \text{ lb/ft}^3$ 

			à l				
culat	tion Relief Load Line E t Calculation Sizing	quivalent Documen Length Builde	tation er				
	Built-in HYSYS Reports	Customizable					
	Flowsheet Case (Main) ×	100 PSV 001 × 100 P	SV 001-B3-EN ×	+			
	Scenario Setup Fluid Prop	perties					
	Scenario Name B3-EN				📰 Sizing	Case	
	Scenario Type Exch. Tub	e Rupture -				PSV Results	Value
	Scenario Reference Stream				Calcu	lated Orifice [in <sup>2</sup> ]	2.743
	Reference Stream	2 @Main	C Overrid	-	> Select	ted Orifice [in <sup>2</sup> ]	<empty> -</empty>
				le	Rated	Capacity [lb/h]	<empty></empty>
	Relieving Temperature	122.0 °F Calcu	lated -		Capa	city Used [%]	<empty></empty>
	Relieving Pressure	440.0 psiG	Edit		Orific	e Designation	<empty></empty>
	Total Backpressure	7.252 psiG	Edit		E In/Ou	it Flanges	<empty></empty>
	Relieving Phase - Method			-	Disch	arge Coefficient (Kd)	0.6500
	Required Relieving Flow Relieving Flow Method	5.934E+005 lb/h Manual Refe	erence @ Ca	lculated			
		Manual Refe From Tube to Shell High Pressure	From Shell High Pressure	to Tube Choking	Low Pressure	Ŧ	
	Relieving Flow Method Direction of Flow	Manual Refe From Tube to Shell High Pressure Side	From Shell High Pressure Side Method	to Tube Choking Condition	Side @ Relief	, ŭ	
	Relieving Flow Method Direction of Flow Pressure	Manual Refe From Tube to Shell High Pressure Side 725.3 psiG	© From Shell High Pressure Side Method Manual	to Tube Choking Condition <empty></empty>	Side @ Relief 440.0 psiG		
	Relieving Flow Method Direction of Flow Pressure Temperature	Manual Refe From Tube to Shell High Pressure Side 725.3 psiG 120.0 °F	From Shell High Pressure Side Method	to Tube Choking Condition	Side @ Relief 440.0 psiG 122.0 °F		
	Relieving Flow Method Direction of Flow Pressure	Manual Refe From Tube to Shell High Pressure Side 725.3 psiG	© From Shell High Pressure Side Method Manual	to Tube Choking Condition <empty></empty>	Side @ Relief 440.0 psiG		
	Relieving Flow Method Direction of Flow Pressure Temperature Phase	Manual Refe From Tube to Shell High Pressure 725.3 psiG 120.0 °F Liquid	From Shell High Pressure Side Method Manual Manual	to Tube Choking Condition <empty></empty>	Side @ Relief 440.0 psiG 122.0 °F		
	Relieving Flow Method Direction of Flow Pressure Temperature	Manual Refe From Tube to Shell High Pressure Side 725.3 psiG 120.0 °F	From Shell High Pressure Side Method Manual Manual	to Tube Choking Condition <empty></empty>	Side @ Relief 440.0 psiG 122.0 °F		
	Relieving Flow Method Direction of Flow Pressure Temperature Phase Tube I.D.	Manual Refe From Tube to Shell High Pressure 725.3 psiG 120.0 °F Liquid 1.375 in	From Shell High Pressure Side Method Manual Manual	to Tube Choking Condition <empty></empty>	Side @ Relief 440.0 psiG 122.0 °F		
	Relieving Flow Method Direction of Flow Pressure Temperature Phase Tube I.D. Flow Coefficient (C) ΔP	Manual Refe From Tube to Shell High Pressure Side 20.0 °F Liquid 1.375 in 0.7400	From Shell High Pressure Side Method Manual Manual	to Tube Choking Condition <empty></empty>	Side @ Relief 440.0 psiG 122.0 °F	ji ka	
	Relieving Flow Method Direction of Flow Pressure Temperature Phase Tube I.D. Flow Coefficient (C)	Manual Refe From Tube to Shell High Pressure Side 725.3 psiG 120.0 °F Liquid 1.375 in 0.7400 285.3 psi	From Shell High Pressure Side Method Manual Manual	to Tube Choking Condition <empty></empty>	Side @ Relief 440.0 psiG 122.0 °F		
	Relieving Flow Method Direction of Flow Pressure Temperature Phase Tube I.D. Flow Coefficient (C) ΔP Vapor Density (pV) Vapor k	Manual Refe From Tube to Shell High Pressure Side 725.3 psiG 120.0 % Liquid 1.375 in 0.7400 285.3 psi <empty></empty>	From Shell High Pressure Side Method Manual Manual	to Tube Choking Condition <empty></empty>	Side @ Relief 440.0 psiG 122.0 °F		
	Relieving Flow Method Direction of Flow Pressure Temperature Phase Tube I.D. Flow Coefficient (C) ΔP Vapor Density (pV)	Manual Refe From Tube to Shell High Pressure Side 120.0 °F Liquid 1.375 in 0.7430 pai 2853 pai <empty></empty>	From Shell High Pressure Side Method Manual Manual	to Tube Choking Condition <empty></empty>	Side @ Relief 440.0 psiG 122.0 °F		
	Relieving Flow Method Direction of Flow Pressure Temperature Phase Tube I.D. Flow Coefficient (C) ΔP Vapor Density (pV) Vapor k Liquid Density (pL)	Manual Refe From Tube to Shell High Pressure Side 125.3 psiG Liquid 1.375 in 0.7400 285.3 psi <emptyp <emptyp 44.13 ib/rt<sup>2</sup></emptyp </emptyp 	From Shell High Pressure Side Method Manual Manual	to Tube Choking Condition <empty></empty>	Side @ Relief 440.0 psiG 122.0 °F		

Figure 7: Liquid exchanger tube rupture case calculated in Aspen HYSYS @aspentech

The required relief load may be calculated using (Eq. 13):

$$A = 2\frac{\pi}{4}(1.375 \text{ in})^2 = 2.97 \text{ in}^2$$
$$w = 1781.7(2.97)\sqrt{(740 - 455.3)(44.13)} = 593,132 \text{ lb/h}$$

The results calculated above are compared to results obtained in Aspen HYSYS in Table 7.

Variable	Units	Example Calculation	Aspen HYSYS
High Side Pressure ( $P_1$ )		740 psia	725.3 psig
Tube Inside Diameter	in	1.375	1.375
Mass Density ( $ ho$ )	lb∕ft³	44.13	44.13
Required Relieving Flow	lb/h	593,132	593,400
	Blue = Calculation input	Gray = Calculated value	

Table 7: Comparison of example calculation and Aspen HYSYS calculation for exchanger tube rupture with liquid flow

#### Mixed Two-Phase Flow Equations

For two-phase flashing flow, the calculation is performed based on a division of the total rupture area in order to obtain a ratio of mass flows that is equal to the mass fraction vapor of the high-pressureside stream flashed isenthalpically to the low-pressure-side relief pressure. The choke condition is obtained for the vapor and applies to both phases. The downstream critical limit pressure may be calculated using (Eq. 9):

$$P_{cfr} = P_1 \left[ \frac{2}{k+1}^{k/k-1} \right]$$

Here, *k* is taken at the low-pressure-side relief conditions.

Once the critical limit pressure is obtained, the vapor and liquid properties for calculating the required relief load are determined at the greater of the critical limit pressure and the low-pressure-side relief pressure (high-pressure-side conditions may be used if a vapor phase exists).

The fraction of the total flow area that is assigned to the vapor phase may be computed as shown below, where *C* is the orifice coefficient, typically 0.6 for shell-into-tube flow or 0.74 for tube-into-shell flow, *Y* is the vapor expansion coefficient computed using (Eq. 11) or (Eq. 12) as appropriate,  $\Delta P$  is the pressure drop across the tube break subject to the downstream critical limit,  $\rho$  values are the respective phase densities, and *x* is the vapor mass fraction at the low-pressure-side pressure subject to the downstream critical limit.



Eq. 14  

$$N_{v} = 2404.7CY \sqrt{\Delta P \cdot \rho_{v}}$$
Eq. 15  

$$N_{\ell} = 2404.7C \sqrt{\Delta P \cdot \rho_{\ell}}$$
Eq. 16  

$$f_{v} = \frac{x N_{\ell}}{(1-x)N_{v} + x N_{\ell}}$$

Then, the required relief load is calculated as the sum of the vapor and liquid flows, as shown below.

Eq. 17  $w_{v} = f_{v} A N_{v}$ Eq. 18  $w_{\ell} = (1 - f_{v}) A N_{\ell}$ Eq. 19  $w = w_{v} + w_{\ell}$ 

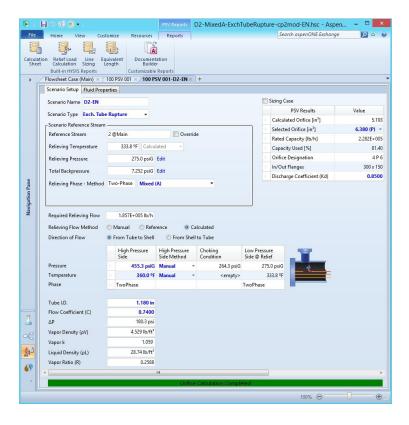


Figure 8: Mixed-phase, subcritical exchanger tube rupture case calculated in Aspen HYSYS

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Scenario Setup Fluid Pro	perties					
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Scenario Type Exch. Tub	e Rupture 🔹				PSV Results	Value
- Scenario Reference Stream	ı —				ated Orifice [in <sup>2</sup> ]	7.57
Reference Stream	5 @Main	V Overric	de		ed Orifice [in <sup>2</sup> ]	11.050 (Q)
Relieving Temperature	308.1 °F Calcul	lated -			Capacity [lb/h]	2.258E+00
					ity Used [%]	68.5 6 Q
Relieving Pressure	165.0 psiG	Edit			Designation	6 Q 150 x 15
Total Backpressure	7.252 psiG	Edit			t Flanges Irge Coefficient (Kd)	0.850
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Required Relieving Flow Relieving Flow Method Direction of Flow Pressure Temperature	1.548E+005 lb/h Manual Refer From Tube to Shell High Pressure Side 455.3 psiG 360.0 °F	rence © Ca @ From Shell High Pressure Side Method Manual ~	I to Tube Choking Condition 264.0 psiG 331.7 °F	Side @ Relief 165.0 psiG 308.1 °F		
Required Relieving Flow Relieving Flow Method Direction of Flow Pressure	1.548E+005 lb/h Manual Refer From Tube to Shell High Pressure Side 455.3 psiG	rence © Ca @ From Shell High Pressure Side Method Manual ~	I to Tube Choking Condition 264.0 psiG	Side @ Relief 165.0 psiG	L.	
Required Relieving Flow Relieving Flow Method Direction of Flow Pressure Temperature	1.548E+005 lb/h Manual Refer From Tube to Shell High Pressure Side 455.3 psiG 360.0 °F	rence © Ca @ From Shell High Pressure Side Method Manual ~	I to Tube Choking Condition 264.0 psiG 331.7 °F	Side @ Relief 165.0 psiG 308.1 °F	Ľ.	
Required Relieving Flow Relieving Flow Method Direction of Flow Pressure Temperature Phase	1.548E+005 lb/h Manual Refer From Tube to Shell High Pressure Side 360.0 °F TwoPhase	rence © Ca @ From Shell High Pressure Side Method Manual ~	I to Tube Choking Condition 264.0 psiG 331.7 °F	Side @ Relief 165.0 psiG 308.1 °F	<u>i</u>	
Required Relieving Flow Relieving Flow Method Direction of Flow Pressure Temperature Phase Tube LD.	1.548E+005 lb/h Manual Refee From Tube to Shell High Pressure Side 360.0 °F TwoPhase 1.180 in	rence © Ca @ From Shell High Pressure Side Method Manual ~	I to Tube Choking Condition 264.0 psiG 331.7 °F	Side @ Relief 165.0 psiG 308.1 °F	<u>i</u>	
Required Relieving Flow Relieving Flow Method Direction of Flow Pressure Temperature Phase Tube I.D. Flow Coefficient (C)	1.548E-005 lb/h Manual Refee From Tube to Shell High Pressure Side 455.3 psiG 360.0 °F TwoPhase 1.180 in 0.6600	rence © Ca ® From Shell High Pressure Side Method Manual ~ Manual ~	I to Tube Choking Condition 264.0 psiG 331.7 °F	Side @ Relief 165.0 psiG 308.1 °F	<u>i</u>	
Required Relieving Flow Relieving Flow Method Direction of Flow Pressure Temperature Phase Tube LD. Flow Coefficient (C) ΔP	1.5485+005 lb/h Manual Refee From Tube to Shell High Pressure 3 45:3 psG 3 360.0° TwoPhase 1.180 im 0.6000 191.3 psi	rence © Ca ® From Shell High Pressure Side Method Manual ~ Manual ~	I to Tube Choking Condition 264.0 psiG 331.7 °F	Side @ Relief 165.0 psiG 308.1 °F	j <b>i</b>	
Required Relieving Flow Relieving Flow Method Direction of Flow Pressure Temperature Phase Tube I.D. Flow Coefficient (C) ΔP Vapor Density (pV)	1.5485+005 lb/h Manual Refee From Tube to Shell High Pressure Side 4.55.3 puid 360.0 % TwoPhase 1.180 in 0.6000 191.3 psi 4.529 lb/h <sup>2</sup>	rence © Ca ® From Shell High Pressure Side Method Manual ~ Manual ~	I to Tube Choking Condition 264.0 psiG 331.7 °F	Side @ Relief 165.0 psiG 308.1 °F	j <b>i i</b>	
Required Relieving Flow Relieving Flow Method Direction of Flow Pressure Temperature Phase Tube LD. Flow Coefficient (C) ΔP Vapor Density (pV) Vapor k	1.5485+005 lb/h Manual Refee From Tube to Shell High Pressure Side 455.3 puid 360.0 °F TwoPhase 1.180 in 0.6600 191.3 psi 4.529 lb/h <sup>2</sup>	rence © Ca ® From Shell High Pressure Side Method Manual ~ Manual ~	I to Tube Choking Condition 264.0 psiG 331.7 °F	Side @ Relief 165.0 psiG 308.1 °F	<u>i</u>	
Required Relieving Flow Relieving Flow Method Direction of Flow Pressure Temperature Phase Tube I.D. Flow Coefficient (C) ΔP Vapor Denity (pV) Vapor k Liquid Denity (pL)	1.5485-005 lb/h Manual Refee From Tube to Shell High Pressure Side 455.3 psiG 360.0 F TwoPhase 1.180 in 0.66000 1913.psi 4.529 lb/ht <sup>2</sup> 1.0811 28.74 lb/ht <sup>2</sup> 0.2717	rence © Ca ® From Shell High Pressure Side Method Manual ~ Manual ~	I to Tube Choking Condition 264.0 psiG 331.7 °F	Side @ Relief 165.0 psiG 308.1 °F	i <b>k</b>	

Figure 9: Mixed-phase, critical exchanger tube rupture case calculated in Aspen HYSYS

# Mixed-Phase Example with Unchoked Tube-Into-Shell Flow

The example is based on the following conditions:

Composition	35% propane, 40% n-heptane, 25% CC6= using the Aspen HYSYS SRK package for physical properties
High-pressure side conditions	470 psia / 360 F
Relief pressure	250 psig set pressure + 10% allowable overpressure = 275 psig
Tubes are 20 ga 1 1/4″ tube w	ith an inner diameter of 1.18 in

Setting up a stream in Aspen HYSYS at the high-pressure side conditions and performing an isenthalpic flash to relief pressure will yield the following properties:

*T* = 333.8 F

**k** = 1.059

The critical flow pressure is calculated using (Eq. 9):

$$P_{cfr} = 470 \text{ psia}\left[\frac{2}{(1.059) + 1}^{(1.059)/(1.059) - 1}\right] = 278.9 \text{ psia}$$

Since the critical pressure of 278.9 psia is less than the low-pressure side relief pressure of 289.7 psia, flow is not choked and the pressure drop across the break  $\Delta P$  = 180.3 psi. Liquid and vapor properties may be obtained in Aspen HYSYS at the high side pressure using the previously-flashed stream, yielding:

 $\rho_l = 28.74 \text{ lb/ft}^3$   $\rho_v = 4.529 \text{ lb/ft}^3$ 

The vapor fraction at relief conditions is: x = 0.2588

The required relief load may be calculated using (Eq. 12) and (Eq. 14) through (Eq. 19):

 $A = 2\frac{\pi}{4} (1.18 \text{ in})^2 = 2.187 \text{ in}^2$   $Y = 1 - 0.4 \frac{180.3}{470} = 0.8466$   $N_v = 1781.7(0.8466)\sqrt{(180.3)(4.529)} = 43103$   $N_\ell = 1781.7\sqrt{(180.3)(28.74)} = 128255$   $f_v = \frac{(0.2588)(128255)}{(1 - 0.2588)(43103) + (0.2588)(128255)} = 0.5096$   $w_v = (0.5096)(2.187)(43103) = 48,040 \text{ lb/h}$   $w_\ell = (1 - 0.5096)(2.187)(128255) = 137,600 \text{ lb/h}$   $w = w_v + w_\ell = 185,600 \text{ lb/h}$ 

The results calculated above are compared to results obtained in Aspen HYSYS in Table 8.

Variable	Units	Example Calculation	Aspen HYSYS
High Side Pressure ( <i>P</i> <sub>1</sub> )		470 psia	455.3 psig
High Side Temperature	F	360	360.0
Tube Inside Diameter	in	1.18	1.180
$C_P/(C_P-R) (k)$		1.059	1.059
Vapor Mass Density ( $ ho_v$ )	lb∕ft³	4.529	4.529
Liquid Mass Density ( $ ho_l$ )	lb∕ft³	28.74	28.74
Critical Pressure (P <sub>cfr</sub> )		278.9 psia	264.3 psig
Flow Type		Subcritical	
Expansion Factor (Y)		0.8466	
Mass Fraction Vapor (x)		0.2588	0.2588
Required Relieving Flow	lb/h	185,600	185,700
	Blue = Calculation input	Gray = Calculated value	

Table 8: Comparison of example calculation and Aspen HYSYS calculation for exchanger tube rupture with subcritical mixed phase flow

# Mixed-Phase Example with Choked Shell-Into-Tube Flow

The example is based on the following conditions:

Composition	35% propane, 40% n-heptane, 25% CC6= using the Aspen HYSYS SRK package for physical properties
High-pressure side conditions	470 psia / 360 F
Relief pressure	150 psig set pressure + 10% allowable overpressure = 165 psig
Tubes are 20 ga 1 1/4″ tube w	ith an inner diameter of 1.18 in

Setting up a stream in Aspen HYSYS at high-pressure side conditions and performing an isenthalpic flash to relief pressure will yield the following properties: k = 1.061

The critical flow pressure is calculated using (Eq. 9):

$$P_{cfr} = 470 \text{ psia}\left[\frac{2}{(1.061)+1}^{(1.061)/(1.061)-1}\right] = 278.7 \text{ psia}$$

Since the critical pressure of 278.7 psia exceeds the low-pressure side relief pressure of 179.7 psia, flow is choked and the pressure drop across the break  $\Delta P$  = 191.3 psi. Liquid and vapor properties may be obtained in Aspen HYSYS at the high side pressure using the previously-flashed stream, yielding:

 $ho_\ell$  = 28.74 lb/ft<sup>3</sup>  $ho_v$  = 4.529 lb/ft<sup>3</sup>

The vapor fraction at the choke condition is: x = 0.2718

The required relief load may be calculated using (Eq. 11) and (Eq. 14) through (Eq. 19):

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 $f_v =$ 

$$A = 2\frac{\pi}{4} (1.18 \text{ in})^2 = 2.187 \text{ in}^2$$
$$Y = 1 - 0.317 \frac{191.3}{470} = 0.8710$$
$$N_v = 1444.6(0.8710)\sqrt{(191.3)(4.529)} = 37036$$
$$N_\ell = 1444.6\sqrt{(191.3)(28.74)} = 107114$$
$$\frac{(0.2718)(107114)}{(1 - 0.2718)(37036) + (0.2718)(107114)} = 0.5191$$

 $w_v = (0.5191)(2.187)(37036) = 42,050 \text{ lb/h}$ 

 $w_{\ell} = (1 - 0.5191)(2.187)(107114) = 112,700 \text{ lb/h}$ 

 $w = w_v + w_\ell = 154,800 \text{ lb/h}$ 

The results calculated above are compared to results obtained in Aspen HYSYS in Table 9.

Variable	Units	Example Calculation	Aspen HYSYS
High Side Pressure ( <i>P</i> <sub>1</sub> )		470 psia	455.3 psig
High Side Temperature	F	360	360.0
Tube Inside Diameter	in	1.18	1.18
$C_P/(C_P-R)$ (k)		1.061	1.061
Vapor Mass Density ( $ ho_v$ )	lb/ft <sup>3</sup>	4.529	4.529
Liquid Mass Density ( $ ho_l$ )	lb/ft³	28.74	28.74
Critical Pressure (P <sub>cfr</sub> )		278.7 psia	264.0 psig
Flow Type		Critical	Choked Flow
Expansion Factor (Y)		0.8710	
Mass Fraction Vapor (x)		0.2718	0.2717
Required Relieving Flow	lb/h	154,800	154,800
	Blue = Calculation input	Gray = Calculated value	

Table 9: Comparison of example calculation and Aspen HYSYS calculation for exchanger tube rupture with critical mixed phase flow

# Hydraulic Expansion

# Equations

For a scenario where heat input causes hydraulic expansion in blocked-in, liquid-full equipment or process piping, API Standard 521 gives two equations for calculating the required relief load, one for U.S. customary units and one for SI units.<sup>1</sup> These equations may be combined and written as shown below, where q is the volumetric required relief load in m<sup>3</sup>/s or gpm, N is a dimensional constant with a value of 1000 for SI units or 500 for U.S. customary units,  $\alpha_V$  is the cubic expansion coefficient in 1/K or 1/R,  $\varphi$  is the total heat transfer rate in W or BTU/h, *SG* is the specific gravity of the fluid referenced to water at 60 F or 15.6 C (a reference density of 998.9 kg/m<sup>3</sup> or 62.3 lb/ft<sup>3</sup>), and *C<sub>P</sub>* is the fluid heat capacity in J/kg-K or BTU/lb-R.

$$Eq. 20 \qquad q = \frac{\alpha_V \phi}{N SG C_P}$$

# Example

The example is based on the following conditions:

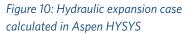
*f* = 500,000 kcal/h = 2,093,400 kJ/h = 581.5 kW

*aV* = 0.0085 1/K

*SG* = 0.63

*CP* = 0.591 kcal/kg-K = 2.474 kJ/kg-K

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et Calculation Sizing Ler	ngth Builde	er			
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		SV 001-Test BT A	T		
Scenario Setup Fluid Proper	ties				
Scenario Name Test B1			V	Sizing Case	
Scenario Type Thermal Exp	pansion -			PSV Results	Value
Scenario Reference Stream -				Calculated Orifice [cm <sup>2</sup> ]	0.82
Reference Stream	1 @Main	🔲 Overni	de	Selected Orifice [cm <sup>2</sup> ]	1.264 (E)
Relieving Temperature	80.00 °C Refer			Rated Capacity [kg/h]	1.101E+0
				Capacity Used [%]	65.
Relieving Pressure	11.00 barG	Edit	2	Orifice Designation	16
Total Backpressure	0.0000 barG	Edit		In/Out Flanges	150 x 1
Relieving Phase - Method	Liquid Liquid			Discharge Coefficient (Kd)	0.65
	7198 kg/h ) Manual 💿 Refe	erence 💿 C	Calculated		
-	Manual 🔘 Refe	erence 💿 C	alculated		
Relieving Flow Method	Manual Refe	erence (a) C +005 Kcal/h	alculated Calculated Specific Grav	ity 0.6	1299
Relieving Flow Method	Manual Refe				
Relieving Flow Method 《 Liquid Thermal Ex Heat Input	Manual Refe pansion 5.000E- ent 8.500	+005 Kcal/h 0E-003 1/°C	Calculated Specific Grav		
Relieving Flow Method	Manual Refe pansion 5.000E ent 8.500 Expansion Coefficient	+005 Kcal/h 0E-003 1/°C	Calculated Specific Grav		
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Relieving Flow Method Liquid Thermal Ex Heat Input Cubical Expansion Coeffici Typical Values for Cubical E Gravity of Liquid API 33:50.9	Manual         Reference           cpansion         5.000F-           ent         8.500           Capansion Coefficient         Value (per °F)           0.0004         0           0.0005         0	+005 Kcal/h 0E-003 1/°C t Value (per °C) 1.0007	Calculated Specific Grav		
Relieving Flow Method Liquid Thermal Ex Heat Input Cubical Expansion Coefficit Typical Values for Cubical E Growhy of Liquid API 3:5:509 31:63,9 64:78,9 79:88,9	Manual         Refer           cpansion         5.000E+           ent         8.500           cpansion         Comparison           Value (per %)         0.0004           0.0005         0           0.0005         0           0.0006         0           0.0007         0           0.0008         0	•005 Kcal/h DE-003 1/*C : Value (per °C) .0007 .0008 .0011	Calculated Specific Grav		
Relieving Flow Method Liquid Thermal Ex Heat Input Cubical Expansion Coefficit Gravity of Liquid API 3-349 3-509 51-639 64-78.9	Manual         Refer           cpansion         5.000E+           ent         8.500           Spansion         Comparison           Value (per %)         0.0004           0.0005         0           0.0005         0           0.0006         0           0.0007         0           0.0008         0	+005 Kcal/h 0E-003 1/°C : Value (per °C) 1,0007 1,0008 1,00011 1,0013	Calculated Specific Grav		
Relieving Flow Method Liquid Thermal Ex Heat Input Cubical Expansion Coefficit Typical Values for Cubical E Growhy of Liquid API 3:5:509 31:63,9 64:78,9 79:88,9	Manual         Refer           cpansion         5.000E-           ent         8.500           Expansion Coefficient         0.0005           Value (per €F)         0.0006           0.0006         0.00005           0.0008         0.00008           0.00009         0.00009	+005 Kcal/h 0E-003 1/°C Value (per °C) 0007 0008 00011 00013 00014 00015 00016	Calculated Specific Grav		
Relieving Flow Method Liquid Thermal Ex Heat Input Cubical Expansion Coeffici Gravity of Liquid API 3-34,9 3-55,09 51-63,9 51-63,9 64-78,9 798,8,9 69-93,9	Manual         Refer           cpansion         5.000E-           ent         8.500           Expansion Coefficient         0.0005           Value (per €F)         0.0006           0.0006         0.00005           0.0008         0.00008           0.00009         0.00009	+005 Kcal/h 0E-003 1/*C 2 Value (per *C) 0.0007 0.0008 0.0011 0.0014 0.0015	Calculated Specific Grav		



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The required relief load is calculated using (Eq. 20), and converted to a mass flow rate:

$$q = \frac{(0.0085)(581,500)}{1000(0.63)(2,474)} = 0.00317 \text{ m}^3\text{/s}$$

$$w = 0.00317 \text{ m}^3/\text{s} \times \frac{3600 \text{ s}}{1 \text{ h}} \times (0.63)(998.9 \text{ kg/m}^3) = 7182 \text{ kg/h}$$

The results calculated above are compared to results obtained in Aspen HYSYS in Table 10.

Variable	Units	Example Calculation	Aspen HYSYS
Expansion Coefficient ( $\alpha_V$ )	1/K	0.0085	0.0085
Heat Input Rate ( $arphi$ )		581,500 W	500,000 kcal/h
Specific Gravity ( <i>SG</i> )		0.63	0.6299
Mass Heat Capacity ( <i>C</i> <sub>P</sub> )		2,474 J/kg-K	0.5910 kcal/kg-K
Required Relieving Flow	lb/h	7,182	7,198
В	<b>lue</b> = Calculation input	Gray = Calculated value	

Table 10: Comparison of example calculation and Aspen HYSYS calculation for hydraulic expansion

# Fire

## Wetted Fire Equations

The required relief load due to vaporization of liquid inventory is calculated using equations obtained from API Standard 521.<sup>1</sup>

The required relief load is calculated using the following equations shown below, where Q is the rate at which heat is added to the vessel contents in W;  $C_{DF}$  is a constant to account for the presence or absence of adequate draining and firefighting, with a value of 43,200 when adequate drainage and firefighting are present or 70,900 when they are not; F is an environment factor to account for the presence of fireproof insulation, with a value of 1.0 for a vessel without fireproof insulation;  $A_{ws}$  is the exposed wetted surface area of the vessel, subject to certain conditions, in m<sup>2</sup>.

#### $Eq. 21 \qquad Q = C_{DF}F A_{ws}^{0.82}$

Per the standard, for horizontal and vertical vessels, only the portion of the liquid inventory within 7.6 m of grade should be considered. For spherical vessels, the portion of the liquid inventory within 7.6 m of grade or up to the maximum horizontal diameter, whichever is greater, should be considered, where w is the required relief load in kg/h and I is the latent heat of the vessel contents at appropriate relieving conditions in kJ/kg.

Eq. 22 
$$w = 3.6 Q/\lambda$$

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tion Relief Load L t Calculation Siz	ine Equivalent zing Length	Documentation Builder				
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Scenario Setup F	uid Properties					
Scenario Name A	6-alt			Sizing Case		
				PSV Results	Value	
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Scenario Referenc				Selected Orifice [cm <sup>2</sup> ]	11.858 (K) 👻	Select
Reference Stream	3 @Main	V 0	Override	Rated Capacity [kg/h]	1.994E+004	
Relieving Temper	ature 69.75	°C Wetted (API) -		Capacity Used [%]	69.67	
Relieving Pressure	. 1	14.52 barG Edit		Orifice Designation	0 K 0	
Total Backpressur		5000 barg Edit		In/Out Flanges	0 x 0	
				Noise Level	92.18	
Relieving Phase -	Method Vapor	Vapor	-	Noise Height [m]	30.00	
				Discharge Coefficient (Kd)	0.9750	
Required Relieving Relieving Flow Me	ethod 🔘 Manual	Reference     O	alculated	Number of Vessels 1  Vessel Parameters Specify Equipment Dimensions	Vessel 1	•
	ethod 🔘 Manual	Reference     O	alculated	Vessel Parameters	Yes	.89
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Relieving Flow Me Calculation Metho Calcul Drainage & F Estimate Late Latent Heat [ Initial % Vapo	etthod Manual Metted (API: ation Parameters irefighting nt Heat? kl/kg] vrized [mol%] rized [mol%]	Reference <ul> <li>Colored</li> <li>Value</li> <li>Present</li> <li>Yes</li> <li>280.8</li> <li>0.0000</li> <li>Colored</li> <li>Colored</li></ul>	alculated	Vessel Parameters           Specify Equipment Dimensions:           Exposed Area [m³]           Vessel Type           Head Type           Diameter [m]           Vessel Tan/Tan [m]           Liquid Level [m]           Elevation [m]           Maximum Flame Height [m]	<ul> <li>Yes</li> <li>Vertical (Incl. Boi 2:1 Ellipsoidal</li> <li>3.:</li> <li>8.0</li> <li>3.0</li> <li>0.00</li> <li>7.0</li> </ul>	500 500 500 500 500 520
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Figure 11: External fire case with a wetted vertical vessel calculated in Aspen HYSYS

# Wetted Fire Example with a Vertical Vessel

The example is based on the following conditions:

Composition	50% propane, 50% isobutane using the Aspen HYSYS PR package for physical properties
Normal operating conditions	1000 kPaa, 85% vapor
Relief pressure	12 barg set pressure + 21% allowable overpressure = 14.52 barg
Vessel	Vertical with exposed bottom head, 3.5 m diameter, 8 m T/T height, with 2:1 ellipsoidal heads; 0 m above grade; normal liquid level is 3 m
Additional fire area	10% to allow for process piping
Insulation	No fireproof insulation is present
Drainage and firefighting	Adequate drainage and firefighting are present
Latent heat	The latent heat of the liquid at relieving conditions is estimated to be 280.8 kJ/kg

No correction needs to be made to the portion of liquid inventory that is considered, as the normal liquid level is less than 7.6 m above grade. The wetted surface area is computed as shown below.

 $A_{shell} = \pi D LL = 32.99 \text{ m}^2$  $A_{head} = 1.084 D^2 = 13.28 \text{ m}^2$ 

 $A_{ws} = 1.10 \times (A_{shell} + A_{head}) = 50.9 \text{ m}^2$ 

The required relief load is calculated using (Eq. 21) and (Eq. 22):

 $Q = (43200)(1.0)(50.9)^{0.82} = 1,084,000 \text{ W}$ 

$$w = 3.6 \frac{(1,084,000)}{280.8} = 13,900 \text{ kg/h}$$

The results calculated above are compared to results obtained in Aspen HYSYS in Table 11.

Variable	Units	Example Calculation	Aspen HYSYS	
Vessel Type		Vertical	Vertical	
Bottom Head Included?		Yes	Yes	
Vessel Diameter ( <i>D</i> )	m	3.5	3.500	
Vessel T/T Length ( <i>L</i> )	m	8.0	8.000	
Vessel Liquid Level ( <i>LL</i> )	m	3.0	3.000	
Vessel Elevation Above Grade	m	0.0	0.000	
Additional Area		10%	10.00%	
Environment Factor (F)		1.0	1.000	
Latent Heat ( $\lambda$ )	kJ/kg	280.8	280.8	
Adequate drainage and firefighting present?		Yes	Yes	
Heat Input Area (A <sub>ws</sub> )	m <sup>2</sup>	50.9	50.89	
Heat Input ( <i>Q</i> )		1,084,000 W	3,901,000 kJ/h	
Required Relieving Flow	kg/h	13,900	13,890	
Blue = Calculation input Gray = Calculated value				

Table 11: Comparison of example calculation and Aspen HYSYS calculation for external fire on a vertical wetted vessel

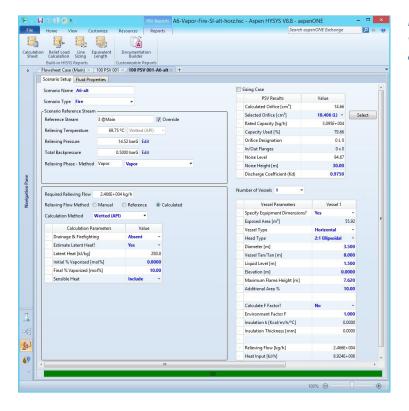


Figure 12: External fire case with a wetted horizontal vessel calculated in Aspen HYSYS

# Wetted Fire Example with a Horizontal Vessel

The example is based on the following conditions:

Composition	50% propane, 50% isobutane using the Aspen HYSYS PR package for physical properties
Normal operating conditions	1000 kPaa, 85% vapor
Relief pressure	12 barg set pressure + 21% allowable overpressure = 14.52 barg
Vessel	Horizontal, 3.5 m diameter, 8 m T/T length, with 2:1 ellipsoidal heads; 0 m above grade; normal liquid level is 1.5 m
Additional fire area 10% to allow for process piping	
Insulation	No fireproof insulation is present
Drainage and firefighting	Adequate drainage and firefighting are not present
Latent heat	The latent heat of the liquid at relieving conditions is estimated to be 280.8 kJ/kg

The fraction of the total area of the horizontal shell that is wetted may be computed as shown below.

$$\cos \theta = \frac{r-h}{r}$$
  

$$\theta = 1.427$$
  

$$f_{ws} = \frac{2\theta}{2\pi} = \frac{\theta}{\pi} = 0.454$$
  

$$A_{shell} = f_{ws} \pi D L = 39.97 \text{ m}^2$$
  

$$B = \sqrt{1+12(h/D-0.5)^2} = 1.030$$
  

$$A_{head} = 2 \times \frac{\pi D^2}{8} \left[ B(h/D-0.5) + 1 + 0.2887 \ln \left( \frac{3.464(h/D-0.5) + B}{2-\sqrt{3}} \right) \right] = 11.89 \text{ m}^2$$
  

$$A_{ws} = 1.10 \times (A_{shell} + A_{head}) = 57.0 \text{ m}^2$$

The required relief load is calculated using (Eq. 21) and (Eq. 22):

 $Q = (70900)(1.0)(57.0)^{0.82} = 1,952,000 \text{ W}$ 

$$w = 3.6 \frac{(1,952,000)}{280.8} = 25,030 \text{ kg/h}$$

The results calculated above are compared to results obtained in Aspen HYSYS in Table 12.

Variable	Units	Example Calculation	Aspen HYSYS	
Vessel Type		Horizontal	Horizontal	
Vessel Diameter (D)	m	3.5	3.500	
Vessel T/T Length ( <i>L</i> )	m	8.0	8.000	
Vessel Liquid Level ( <i>LL</i> )	m	1.5	1.500	
Vessel Elevation Above Grade	m	0.0	0.000	
Additional Area		10%	10.00%	
Environment Factor (F)		1.0	1.000	
Latent Heat ( $\lambda$ )	kJ/kg	280.8	280.8	
Adequate drainage and firefighting present?		Νο	Νο	
Heat Input Area (A <sub>ws</sub> )	m <sup>2</sup>	57.0	55.92	
Heat Input ( <i>Q</i> )		1,952,000 W	6,924,000 kJ/h	
Required Relieving Flow	kg/h	25,030	24,660	
Blue = Calculation input Gray = Calculated value				

Table 12: Comparison of example calculation and Aspen HYSYS calculation for external fire on a horizontal wetted vessel

# Wetted Fire Example with a Spherical Vessel

The example is based on the following conditions:

Composition	50% propane, 50% isobutane using the Aspen HYSYS PR package for physical properties
Normal operating conditions	1000 kPaa, 85% vapor
Relief pressure	12 barg set pressure + 21% allowable overpressure = 14.52 barg
Vessel	Spherical, 5 m diameter
Additional fire area	10% to allow for process piping
Insulation	No fireproof insulation is present
Drainage and firefighting	Adequate drainage and firefighting are present
Latent heat	The latent heat of the liquid at relieving conditions is estimated to be 280.8 kJ/kg

Five variations will be considered:

1	Elevation of 6 m, liquid level of 2 m
2	Elevation of 6 m, liquid level of 3 m
3	Elevation of 5 m, liquid level of 2 m
4	Elevation of 5 m, liquid level of 3 m
5	Elevation of 4 m, liquid level of 3 m

The wetted area exposed to heat input will be calculated using the equation below.

#### Eq. 23 $A_{sphere} = \pi D h$

The appropriate value for *h* depends on the variation of the example that we consider. In case 1, the liquid level is above 7.6 m above grade, but below the equator of the vessel, so the full level of 2 m is considered. In case 2, the liquid level is above 7.6 m above grade and above the equator of the vessel; the equator is higher, so that level of 2.5 m is used. In case 3, the liquid level is not above 7.6 m above grade nor above the equator of the vessel, so the full level of 2 m is considered. In case 4, the liquid level is above 7.6 m above grade and above the equator of the vessel, so the full level of 2 m is considered. In case 4, the liquid level is above 7.6 m above grade and above the equator of the vessel; 7.6 m above grade is higher, so a level of (7.6 m - 5 m = 2.6 m) is used. In case 5, the liquid level is below 7.6 m above grade and below the equator of the vessel, so the full level of 3 m is considered.

	ources Reports		
ion Relief Load Line Equivalent De	Cumentation		
t Calculation Sizing Length	Builder mizable Reports		
Flowsheet Case (Main) × 100 PSV 001 ×	100 PSV 001-A6-alt × +		
Scenario Setup Fluid Properties			
		Sizing Case	
Scenario Name A6-alt		PSV Results	Value
Scenario Type Fire	-	Calculated Orifice [cm <sup>2</sup> ]	5,562
Scenario Reference Stream		Selected Orifice [cm <sup>2</sup> ]	8.303 (J) - Select
Reference Stream 3 @Main	Verride	Rated Capacity [kg/h]	1.396E+004
Relieving Temperature 69.75 °C	Wetted (API) -	Capacity Used [%]	66.99
Relieving Pressure 14.5	2 barG Edit	Orifice Designation	010
		In/Out Flanges	0 x 0
Total Backpressure 0.500	0 barG Edit	Noise Level	90.46
Relieving Phase - Method Vapor	Vapor •	Noise Height [m]	30.00
		Discharge Coefficient (Kd)	0.9750
Calculation Method Wetted (API)	•	Specify Equipment Dimensions? Exposed Area [m <sup>2</sup> ]	Yes - 31.42
Calculation Parameters	Value	Vessel Type	Sphere -
Drainage & Firefighting	Present +	Head Type	2:1 Ellipsoidal
Estimate Latent Heat?	Yes 🔹	Diameter [m]	5.000
Latent Heat [kJ/kg]	280.8	Vessel Tan/Tan [m]	8.000
Initial % Vaporized [mol%]	0.0000	Eiquid Level [m]	2.000
Final % Vaporized [mol%]	10.00	Elevation [m]	4.000
Sensible Heat	Include •	Maximum Flame Height [m]	7.620
		Additional Area %	0.0000
		Calculate F Factor?	No -
		Environment Factor F	1.000
		Insulation k [Kcal/m/h/°C]	0.0000
		Insulation Thickness [mm]	0.0000
		Relieving Flow [kg/h]	9353
		Heat Input [kJ/h]	2.626E+006
	т		

Figure 13: External fire case with a wetted spherical vessel calculated in Aspen HYSYS

The resulting wetted areas are:

1	$A_{ws} = \pi(5)(2)$	= 31.4 m <sup>2</sup>
2	$A_{ws} = \pi(5)(2.5)$	= 39.3 m <sup>2</sup>
3	$A_{ws} = \pi(5)(2)$	= 31.4 m <sup>2</sup>
4	$A_{ws} = \pi(5)(2.6)$	= 40.8 m <sup>2</sup>
5	$A_{ws} = \pi(5)(3)$	$= 47.1 \text{ m}^2$

The required relief loads are:

1	w=(43200(31.4) <sup>0.82</sup> )/(280.8×3.6)	= 9,351 kg/h
2	w=(43200(39.3) <sup>0.82</sup> )/(280.8×3.6)	= 11,240 kg/h
3	w=(43200(31.4) <sup>0.82</sup> )/(280.8×3.6)	= 9,351 kg/h
4	w=(43200(40.8) <sup>0.82</sup> )/(280.8×3.6)	= 11,590 kg/h
5	w=(43200(47.1) <sup>0.82</sup> )/(280.8×3.6)	= 13,030 kg/h

The results calculated above for case 3 are compared to results obtained in Aspen HYSYS in Table 13.

Variable	Units	Example Calculation	Aspen HYSYS
Vessel Type		Spherical	Spherical
Vessel Diameter (D)	m	5.0	5.000
Vessel Liquid Level ( <i>LL</i> )	m	2.0	2.000
Vessel Elevation Above Grade	m	4.0	4.000
Additional Area		0%	0.0000%
Environment Factor (F)		1.0	1.000
Latent Heat ( $\lambda$ )	kJ/kg	280.8	280.8
Adequate drainage and firefighting present?		Yes	Yes
Heat Input Area (A <sub>ws</sub> )	m <sup>2</sup>	31.4	31.42
Heat Input ( <i>Q</i> )		729,400 W	2,626,000 kJ/h
Required Relieving Flow	kg/h	9,351	9,353
В	<b>lue</b> = Calculation input	Gray = Calculated value	

Table 13: Comparison of example calculation and Aspen HYSYS calculation for external fire on a spherical wetted vessel

## **Unwetted Fire Equations**

The required relief load for a vessel filled with vapor (or vapor-like supercritical fluid) exposed to a fire are obtained from API Standard 521.<sup>1</sup>

The required relief load is calculated using the following equations, where for Equation 24, k is the ideal gas specific heat ratio  $C_P/(C_P - R)$ .

Eq. 24  
$$C = 0.0395 \sqrt{k \left(\frac{2}{k+1}\right)^{\frac{k+1}{k-1}}}$$

For Equation 25,  $T_1$  is the temperature at the upstream relieving pressure in K,  $T_n$  is the normal operating temperature in K, and  $p_1/p_n$  is the ratio of relief to normal operating pressure in kPaa.

$$Eq. 25 T_1 = \frac{p_1}{p_n} T_n$$

For Equation 26,  $T_w$  is the maximum wall temperature of the vessel in K and  $K_D$  is the coefficient of discharge of the relief valve (a value of 0.975 is typically used for preliminary design calculations).

Eq. 26 
$$F' = \frac{0.2772}{C K_D} \left[ \frac{(T_w - T_1)^{1.25}}{T_1^{0.6506}} \right]$$

A minimum value of 182 should be used for F'.

For equation 27, w is the required relief load in kg/h, M is the molecular weight of the fluid, and A' is the vessel area exposed to fire, which is calculated using the same method as the wetted area for a liquid-full vessel exposed to fire.

Eq. 27 
$$w = 0.2772\sqrt{M \cdot p_1} \left[ \frac{A'(T_w - T_1)^{1.25}}{T_1^{1.1506}} \right]$$

## Unwetted Fire Example

The example is based on the following conditions:

Composition	100% water using the Aspen HYSYS NBS Steam package for physical properties	
Normal operating conditions	2600 kPaa / 226.1 C	
Relief pressure	25.17 barg set pressure + 10% overpressure = 27.7 barg = 2870 kPaa	
Maximum wall temperature	866.5 K (from 1100 F)	
Vessel	Horizontal, 1.016 m diameter, 3 m T/T length, with 2:1 ellipsoidal heads; 0 m above grade	
Additional fire area	15% to allow for process piping	

( aspentech

Relief temperature is calculated using (Eq. 25):

$$T_1 = \frac{2870}{2600} \ 499.25 = 551.1 \ \mathrm{K}$$

Flashing the contents at relief pressure and temperature in Aspen HYSYS yields the following properties:

**k** = 1.210

Then, the required relief load is calculated using (Eq. 24), (Eq. 26), and (Eq. 27):

$$C = 0.0395 \sqrt{(1.210) \left(\frac{2}{1.210+1}\right)^{\frac{1.210+1}{1.210-1}}} = 0.0257$$
$$F' = \frac{0.2772}{(0.0257)(0.975)} \left[\frac{(866.5 - 551.1)^{1.25}}{551.1^{0.6506}}\right] = 242.1$$

This value is greater than 182, so no modification is needed to proceed.

H on Cl-Steam-Fire-Sl.h	isc - Aspen HYSYS V8.8 - aspenONE Search asp	enONE Exchange
Jation Relief Load Line Equivalent Documentation Builder		
Built-in HYSYS Reports         Customizable Reports           Flowsheet Case (Main) × 100 PSV 001 × 100 PSV 001-C1-SI × +		
Scenario Setup Fluid Properties		
Scenario Name C1-SI	Sizing Case	
	PSV Results	Value
Scenario Type Fire -	Calculated Orifice [cm <sup>2</sup> ]	0.6136
Scenario Reference Stream	Selected Orifice [cm <sup>2</sup> ]	0.709 (D) - Select
Reference Stream 1 @Main Override	Rated Capacity [kg/h]	922.1
Relieving Temperature 277.9 °C Unwetted (API) -	Capacity Used [%]	86.54
Relieving Pressure 27.69 barG Edit	Orifice Designation	1 D 2
	In/Out Flanges	300 x 150
Total Backpressure 0.5000 barG Edit	Noise Level	101.4
Relieving Phase - Method Vapor Vapor •	Noise Height [m]	30.00
	Discharge Coefficient (Kd)	0.9750
Required Relieving Flow 798.0 kg/h Relieving Flow Method Manual Reference Calculated	Number of Vessels 1 -	Vessel 1
	Specify Equipment Dimensions?	Yes +
Calculation Method Unwetted (API)	Exposed Area [m <sup>2</sup> ]	13.59
Calculation Parameters Value	Vessel Type	Horizontal -
Max. Wall Temp. [°C] 593.3	Head Type	2:1 Ellipsoidal 👻
Relief Temperature Calculation Option	Diameter [m]	1.016
Ideal Gas Assumption (API 521)	Vessel Tan/Tan [m]	3.000
	> Liquid Level [m]	0.5000
	Elevation [m]	0.0000
	Maximum Flame Height [m]	7.620
	Additional Area %	15.00
	Relieving Flow [kg/h]	798.0
* [		

Figure 14: External fire case with an unwetted horizontal vessel calculated in Aspen HYSYS

 $A_{shell} = \pi DL = 9.58 \text{ m}^2$   $A_{heads} = 2 \times 1.084 D^2 = 2.24 \text{ m}^2$   $A' = 1.15 \times (A_{shell} + A_{heads}) = 13.6 \text{ m}^2$   $w = 0.2772 \sqrt{(18.02)(1600)} \left[ \frac{13.6(866.5 - 551.1)^{1.25}}{551.1^{1.1506}} \right] = 799.1 \text{ kg/h}$ 

The results calculated above are compared to results obtained in Aspen HYSYS in Table 14.

Variable	Units	Example Calculation	Aspen HYSYS	
Maximum Wall Temperature		866.5 K	593.3 C	
Operating Temperature	С	226.1		
Operating Pressure	kPaa	2600		
Vessel Type		Horizontal	Horizontal	
Vessel Diameter (D)	m	1.016	1.016	
Vessel T/T Length ( <i>L</i> )	m	3.0	3.000	
Vessel Elevation Above Grade	m	0.0	0.000	
Additional Area		15%	15.00%	
Heat Input Area ( <i>A'</i> )	m <sup>2</sup>	13.6	13.59	
С		0.0257		
F'		242.1		
Required Relieving Flow	kg/h	799.1	798.0	
Blue = Calculation input Gray = Calculated value				

Table 14: Comparison of example calculation and Aspen HYSYS calculation for external fire on a horizontal unwetted vessel

# In Conclusion

Safety is of the highest priority to every process, and ensuring accurate, validated calculations is a key component of this work. To view additional validation papers, access tutorial documents and videos, and learn more about the tools AspenTech provides to address process safety work, please visit the safety page on our company website, today!

# References

- 1. American Petroleum Institute, API Standard 521 6th Ed.: Pressure-relieving and Depressuring Systems, Washington, DC: API Publishing Services, 2014.
- 2. W. Y. Wong, "PRV sizing for exchanger tube rupture," Hydrocarbon Processing, pp. 59-64, February 1992.
- 3. W. Y. Wong, "Correction to 'PRV sizing for exchanger tube rupture'," Hydrocarbon Processing, p. 44, May 1992.

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