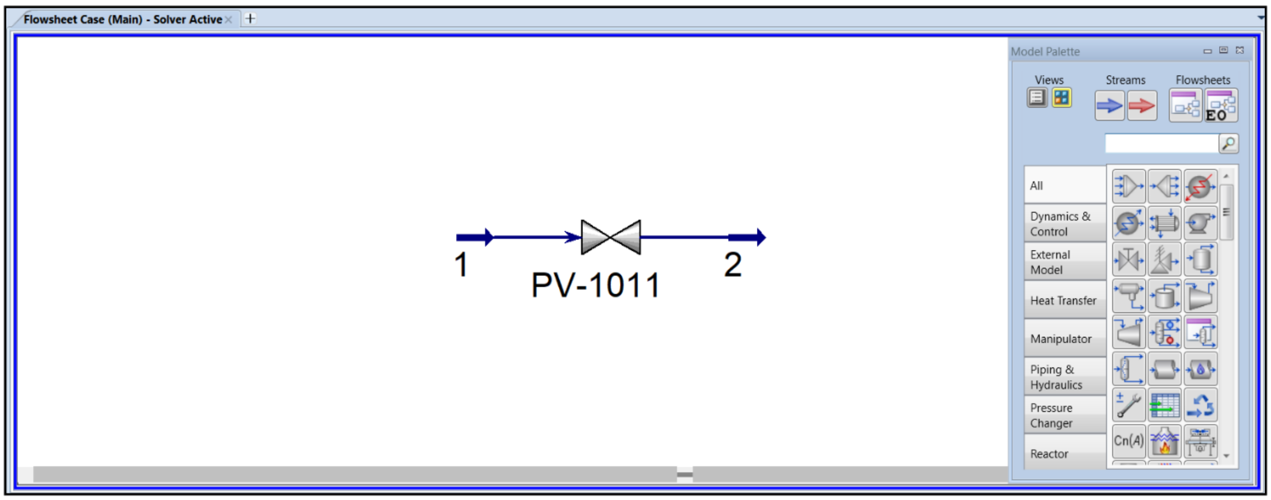
Educational Institute for Equipment and Process Design

Relief Load Calculation Note

1.PSV-1013/1014

Process description:

For fired heaters, one of the primary fuels is NG since it is more reliable and available. For a specific fired heater, 16000 kg/hr. of NG with operating pressure of 50 barg and temperature of 40C is let-down to operating pressure of 4barg via PV-1011 and later to 1 barg via another control valve to make it suitable for firing.

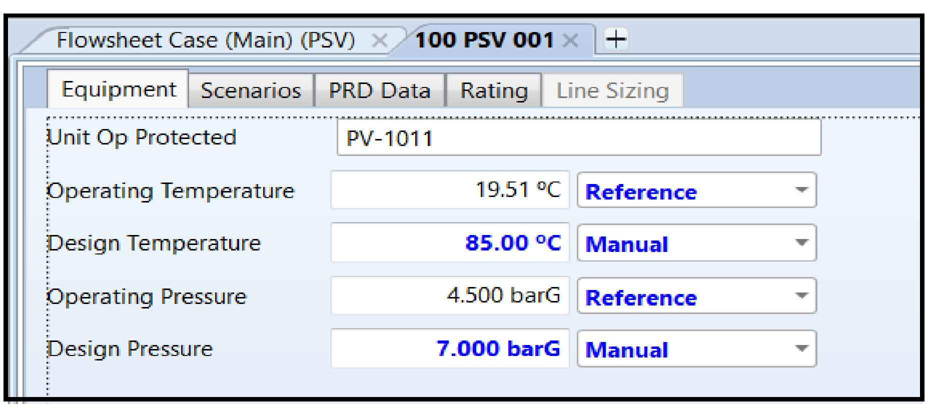


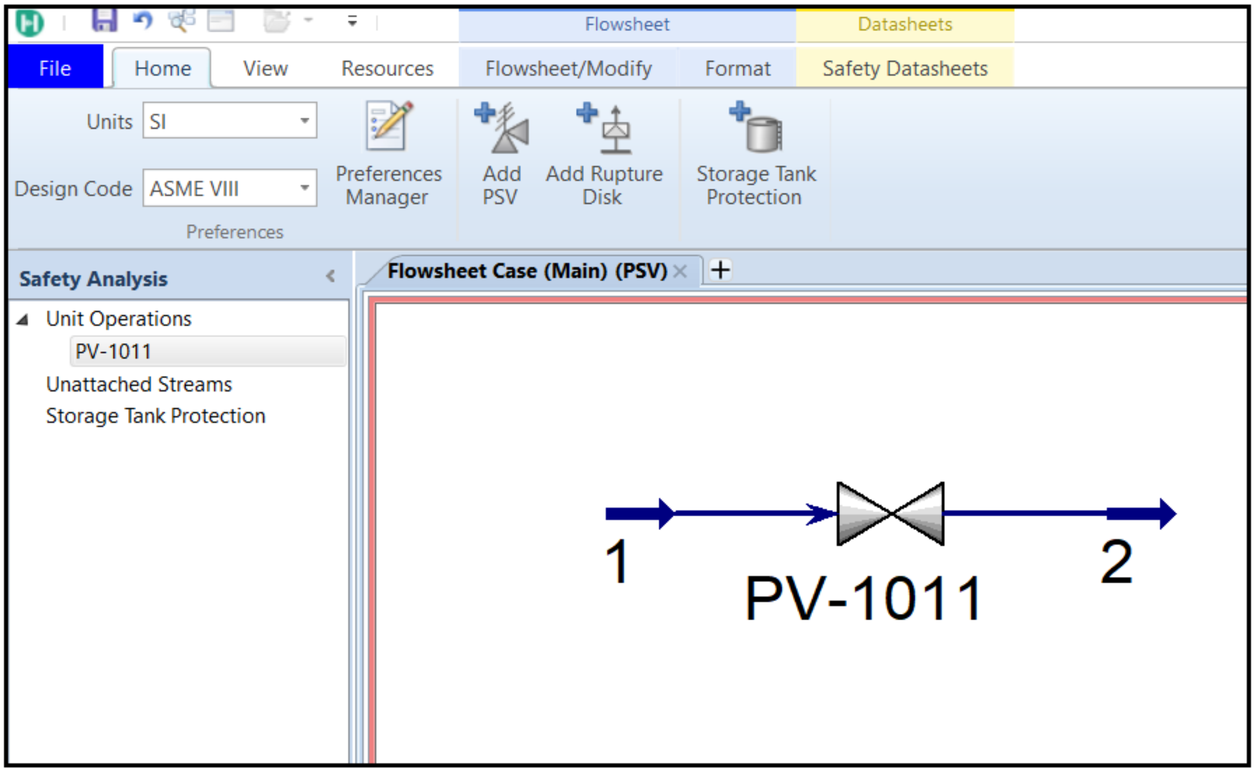
First Step: Let’s check if we need a PSV

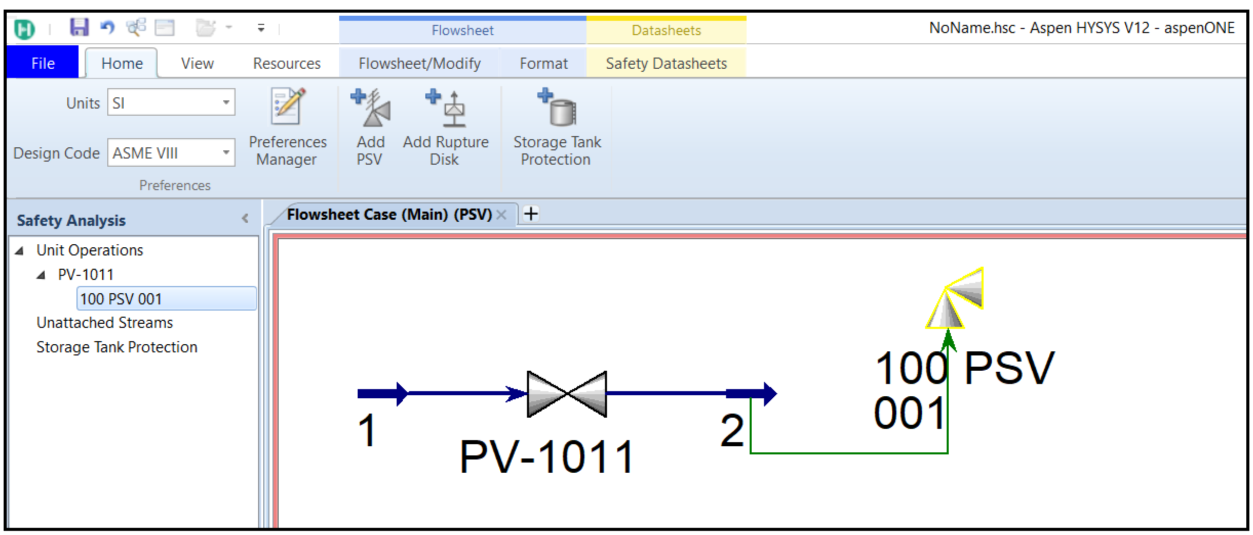
Since the difference between design pressure of high-pressure side, which is 55 barg and that of low-pressure side, which is 7 barg is high. So, we need a PSV in case of control valve failure and the possibility of high flow passage from high-pressure side to low-pressure side.

Second Step: Safety Analysis Environment

1.Go to safety analysis environment and add PSV on the outlet of control valve.
2.Double-click on PSV icon to see the following tab.

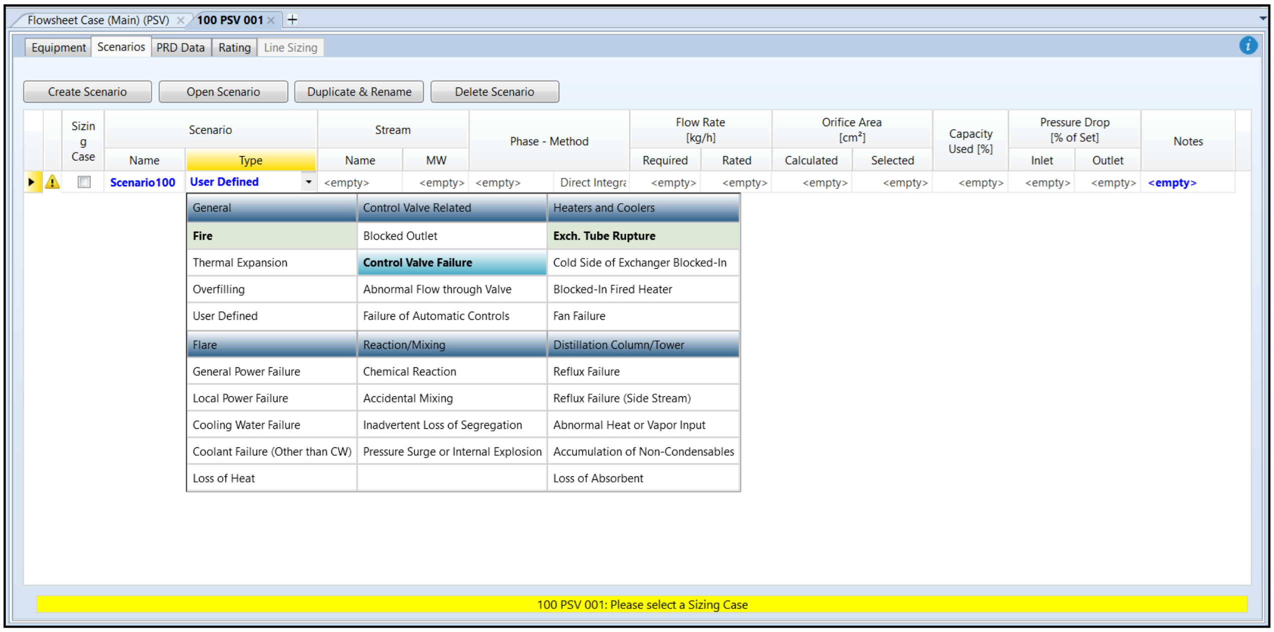



Flowsheet
Datasheets
File
Home
View
Resources
Flowsheet/Modify
Format
Safety Datasheets
Units SI
Design Code ASME VIII
Preferences Manager
Add PSV
Add Rupture Disk
Storage Tank Protection
Preferences
Safety Analysis
Unit Operations
PV-1011
Unattached Streams
Storage Tank Protection
Flowsheet Case (Main) (PSV)
1
PV-1011
2

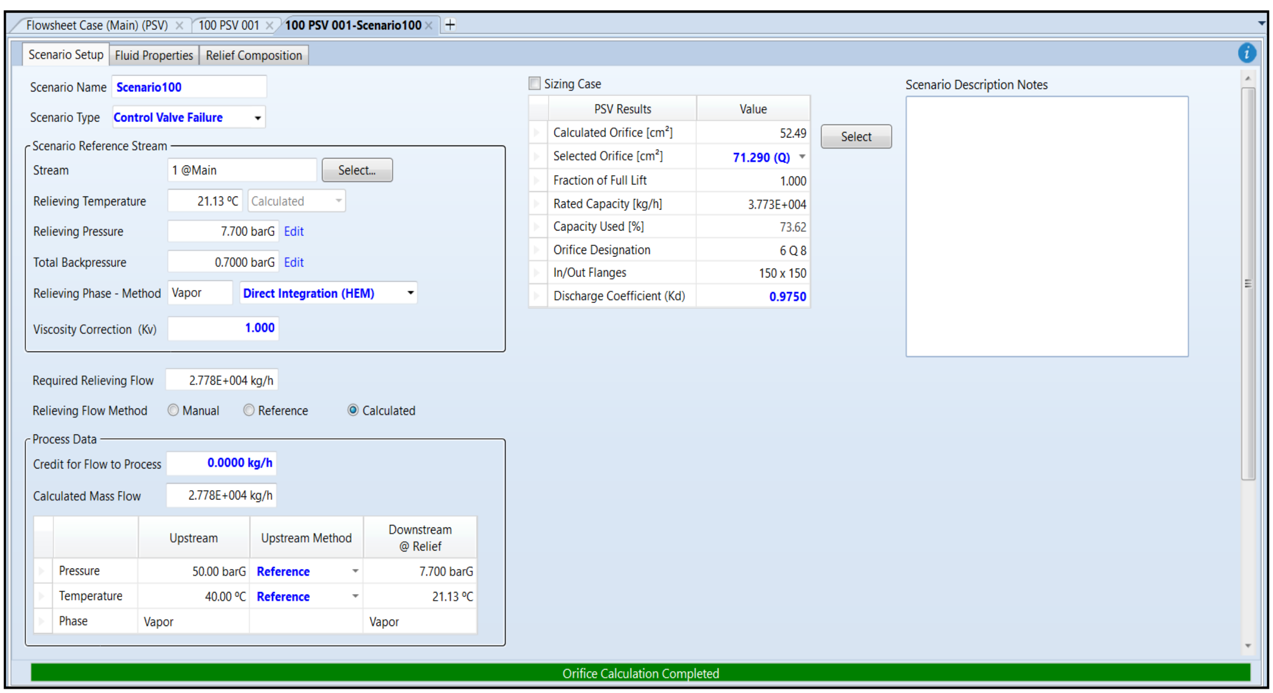

Flowsheet
Datasheets
NoName.hsc - Aspen HYSYS V12 - aspenONE
File
Home
View
Resources
Flowsheet/Modify
Format
Safety Datasheets
Units SI
Design Code ASME VIII
Preferences Manager
Add PSV
Add Rupture Disk
Storage Tank Protection
Preferences
Safety Analysis
Unit Operations
PV-1011
100 PSV 001
Unattached Streams
Storage Tank Protection
Flowsheet Case (Main) (PSV)
1
PV-1011
2
100 PSV 001

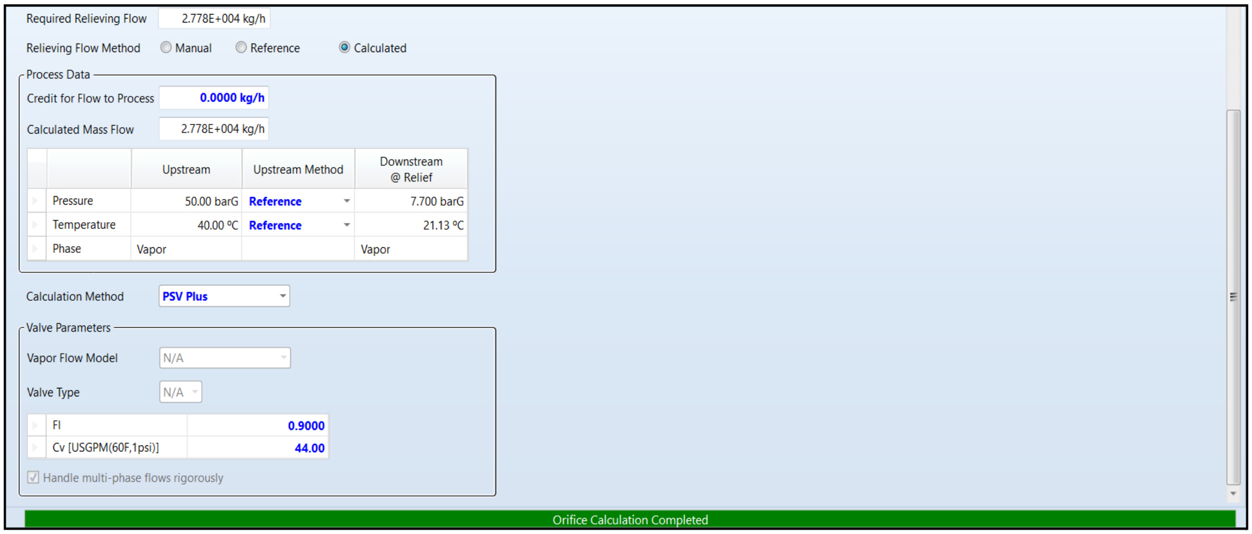
Manual means you are supposed to specify the matter while reference means the information is taken from the line, which just provides operating conditions.

3.Go to scenario tab, create a scenario and select control valve failure.

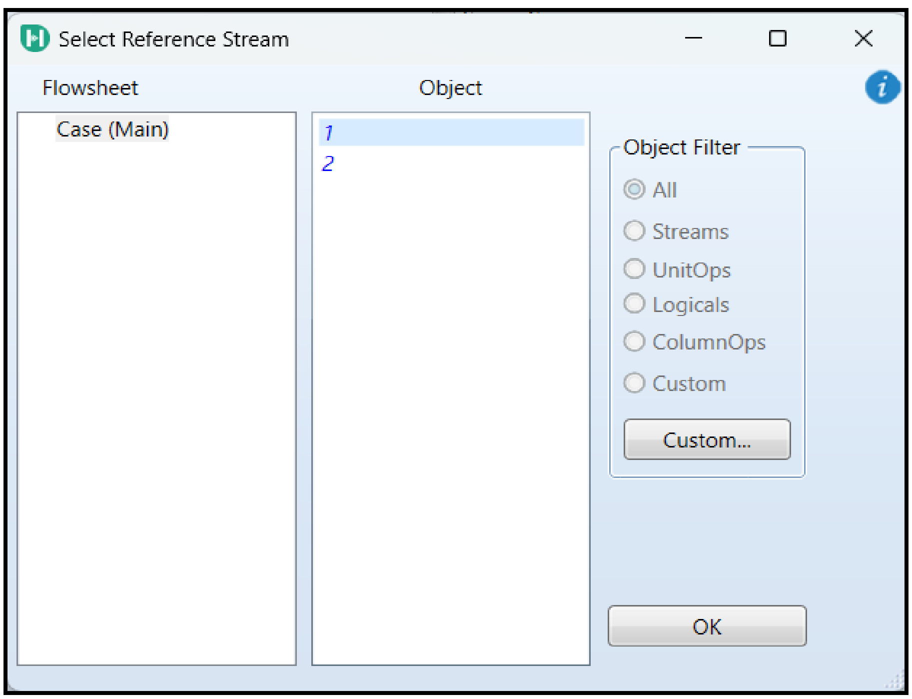


4.Now open scenario.

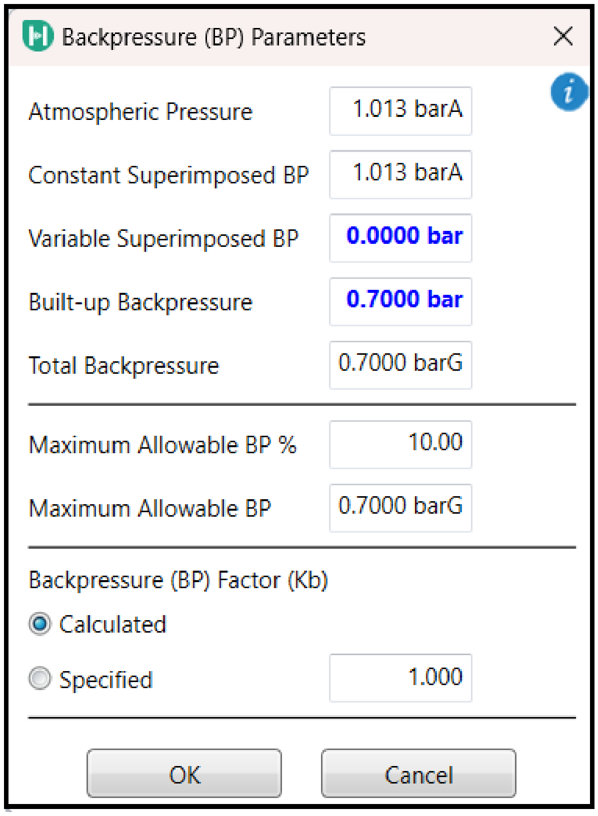




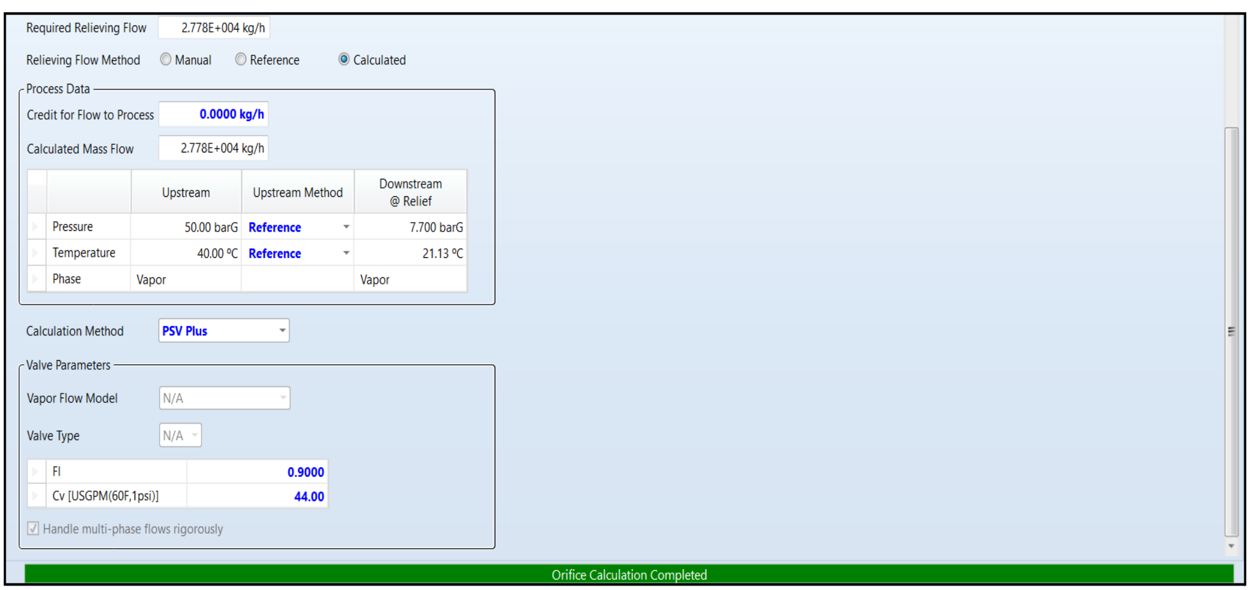
Under scenario reference stream select stream 1:



You can also change total backpressure like below:



Select relieving method to be calculated and also choose PSV plus as the calculation method. Specify the CV to be 44.

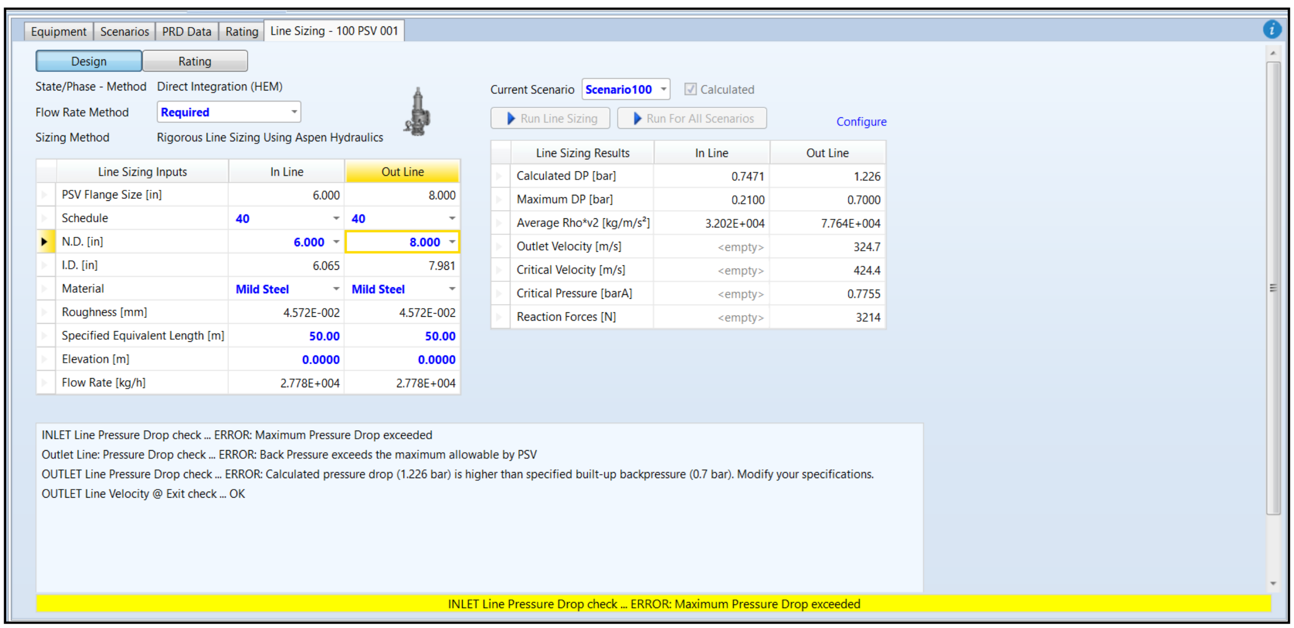


Select a bigger orifice area than calculated orifice which is 52.49 cm^2.

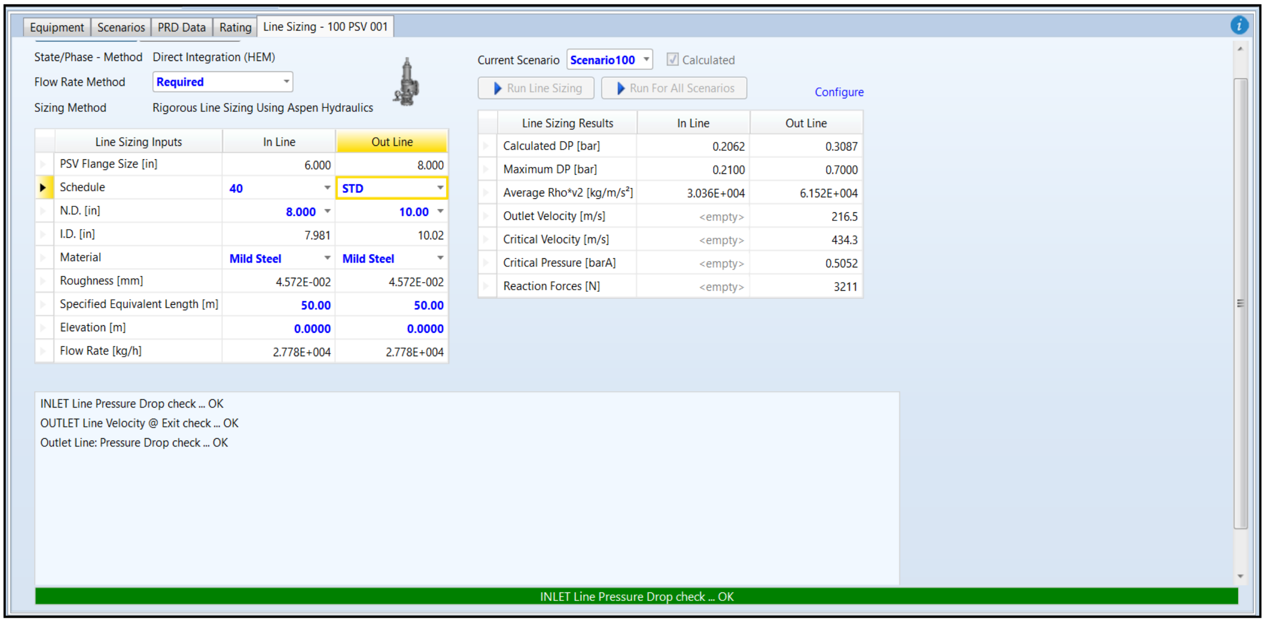
PSV Results	Value
Calculated Orifice [cm^2]	52.49
Selected Orifice [cm^2]	71.290 (Q)
Fraction of Full Lift	1.000
Rated Capacity [kg/h]	3.773E+004
Capacity Used [%]	73.62
Orifice Designation	6 Q 8
In/Out Flanges	150 x 150
Discharge Coefficient (Kd)	0.9750

Based on the calculation, the orifice designation should be 6Q8.

5.Now go to line sizing tab



Based on calculation, the pressure drop for both inlet and outlet has exceeded the criteria. In order to resolve the issue, let's select a line with bigger size for inlet and outlet.



The problem solved!

Here is the summary of what we have obtained.

Relief load	27780 kg/hr.
Scenario	Control Valve Failure
Calculation Method	PSV Plus
Selected Orifice	71.29-Q
Orifice Designation	6Q8
Inlet Line Size	8 inch
Outlet Line Size	10 inch

2.PSV-1031

1.Determine the scenario, using API-521

Since it is R-1001 and exposed to fire then a fire scenario is defined.

Parameters	Value	Parameters	Value
Diameter	4.45 m	M	16.54
Height	3.1 m	Set Pressure	55 barg
Fluid	Natural Gas	Relieving Pressure	67.55 bara
Z	1.01	Accumulation	0.21
Cp/Cv	1.18	Material	CS

2.Calculate the relief load, using API-520 Part1

$$A = \frac{F' \times A'}{\sqrt{p_1}} \quad (9)$$

where

A is the effective discharge area of the valve, expressed in mm^2 ($in.^2$);

A' is the exposed surface area of the vessel, expressed in m^2 (ft^2);

p_1 is the upstream relieving absolute pressure, expressed in kPa (psi);

NOTE p_1 is the set pressure plus the allowable overpressure plus the atmospheric pressure.

F' can be determined using Equation (10). If calculated using Equation (10) and the result is less than 182 in SI units (<0.01 in USC units), then use a recommended minimum value of F' = 182 in SI units (F' = 0.01 in USC units). If insufficient information is available to use Equation (10), then use F' = 821 in SI units (F' = 0.045 in USC units).

$$F' = \frac{C_9}{C \times K_D}\left[\frac{(T_W - T_1)^{1.25}}{T_1^{0.6506}}\right] \quad (10)$$

where

C_9 is a constant [= 0.2772 in SI units (0.1406 in USC units)];

K_D is the coefficient of discharge (obtainable from the valve manufacturer);

NOTE A K_D value of 0.975 is typically used for preliminary sizing of PRVs (see API 520, Part 1).

T_W is the maximum wall temperature of vessel material, expressed in K (°R);

T_1 is the gas absolute temperature, at the upstream relieving pressure, determined from Equation (12), expressed in K (°R).

The coefficient, C, is given by Equation (11):

$$C = C_{10}\sqrt{k\left(\frac{2}{k+1}\right)^{\frac{k+1}{k-1}}} \quad (11)$$

where

C_{10} is a constant {= 0.0395 (kg-mole-K)$^{0.5}$/(mm^2-kPa-h) in SI units [520 (lb-mole-°R)$^{0.5}$/(lbf-h) in USC units]};

k is the ideal gas specific heat ratio (C_p/C_v) of gas or vapor at relieving temperature.

$$T_1 = \frac{p_1}{p_n} \times T_n \quad (12)$$

where

p_n is the normal operating gas absolute pressure, expressed in kPa (psia);

T_n is the normal operating gas absolute temperature, expressed in K (°R).

The recommended maximum vessel wall temperature, T_w, for the usual carbon steel plate materials is 593 °C (1100 °F). If vessels are fabricated from alloy materials, the value for T_w should be based on the stress rupture data for that material. See 4.4.13.2.3, 4.4.13.2.6, 4.6.1, and Annex A for guidance on the potential for vessel failure from overtemperature due to fire exposure.

If $F' \geq 182$ in SI units ($F' \geq 0.01$ in USC units), the relief load, $q_{m,relief}$, expressed in kg/h (lb/h), can be calculated directly by rearranging the critical vapor equation and substituting Equation (9) and Equation (10), which results in Equation (13):

$$q_{m,relief} = C_{12}\sqrt{M \times p_1}\left[\frac{A'(T_w - T_1)^{1.25}}{T_1^{1.1506}}\right] \quad (13)$$

where

M is the relative molecular mass of the gas;

C_{12} is a constant [= 0.2772 in SI units (0.1406 in USC units)].

The minimum relief load recommended for sizing where $F' < 182$ in SI units ($F' < 0.01$ in USC units) is calculated by setting $F' = 182$ in SI units ($F' = 0.01$ in USC units), which results in Equation (14):

$$q_{m,relief} = C_{13}CA'\sqrt{\frac{Mp_1}{T_1}} \quad (14)$$

where

C_{13} is a constant [= 182 in SI units (0.01 in USC units)].

NOTE To derive Equation (13) and Equation (14), Z, K_b, and K_c in API 520, Part 1, Equation (3) have each been assumed to have a value of 1. For Equation (14), K_D is conservatively assumed to have a value of 1.

Calculation

Parameters	Value	Parameters	Value
Aw	65 m2	KD	0.975
C9	0.2772	F’	116
C10	0.0395	Relief Load	3874 kg/hr
C	0.0254		

$$Ws = 182 \times C \times Aw \times \sqrt{\left(\frac{M \times P \times 100}{T + 273}\right)}$$

$$Ws = 182 \times 0.0254 \times 65 \times \sqrt{\frac{16.54 \times 67.5 \times 100}{400 + 273}} = 3874 \frac{kg}{hr}$$

Note that since F’ is less than 182 the corresponding equation has been used in which F’ is set to 182. Remember that in F’ calculation T1 is set to max 400 C.

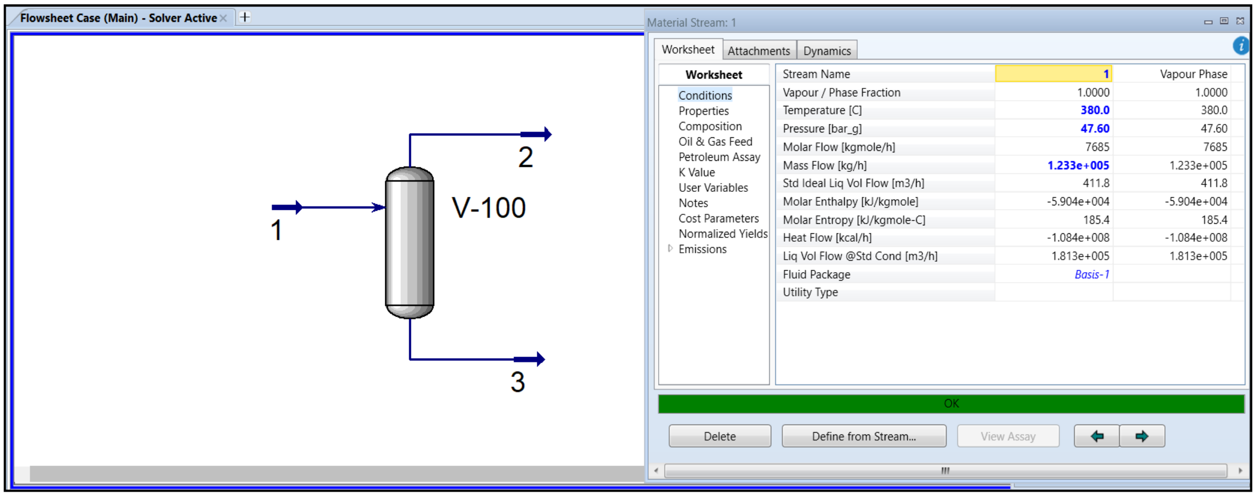
Note : Relieving Temperature Calculation

$$\text{Relieving Temperature(K)} = \frac{\text{Relieving Pressure (bara)}}{\text{Operating Pressure (bara)}} \times \text{Operating Temperature (K)}$$

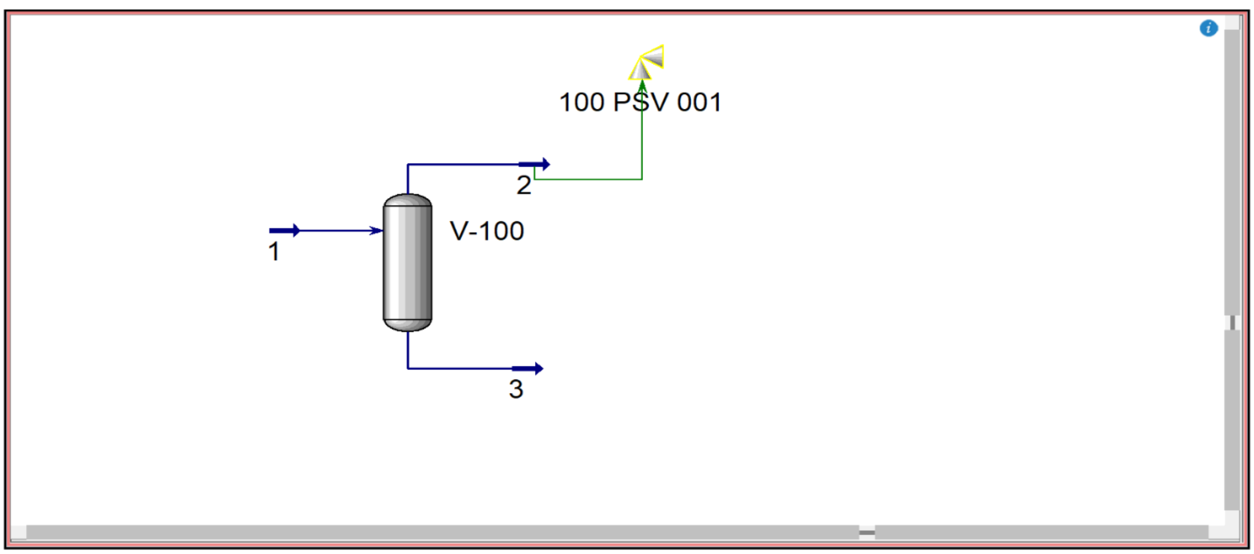
$$\text{Relieving Temperature (K)} = \frac{67.55}{49.8} \times (380 + 273) = 885.74\ K = 612.74\ C$$

since the ratio between operating pressure and PSV relieving pressure is very high, the relieving temperature calculated is not consistent (it would exceed the maximum vessel wall temperature for carbon steel, &o). The relieving temperature for PSV design has been assumed equal to 400°C (considered the max allowable value for carbon steel). The actual relieving mass flow has been calculated keeping the discharge capacity of the valve (volumetric flow rate) constant and scaling the temperature down to 400°C.

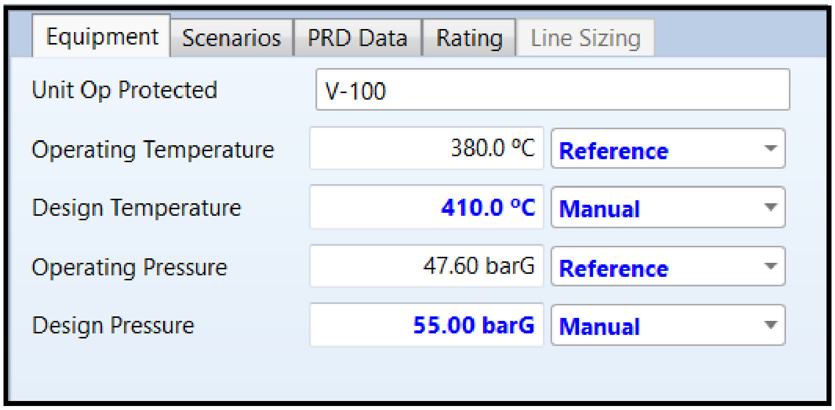
Simulation



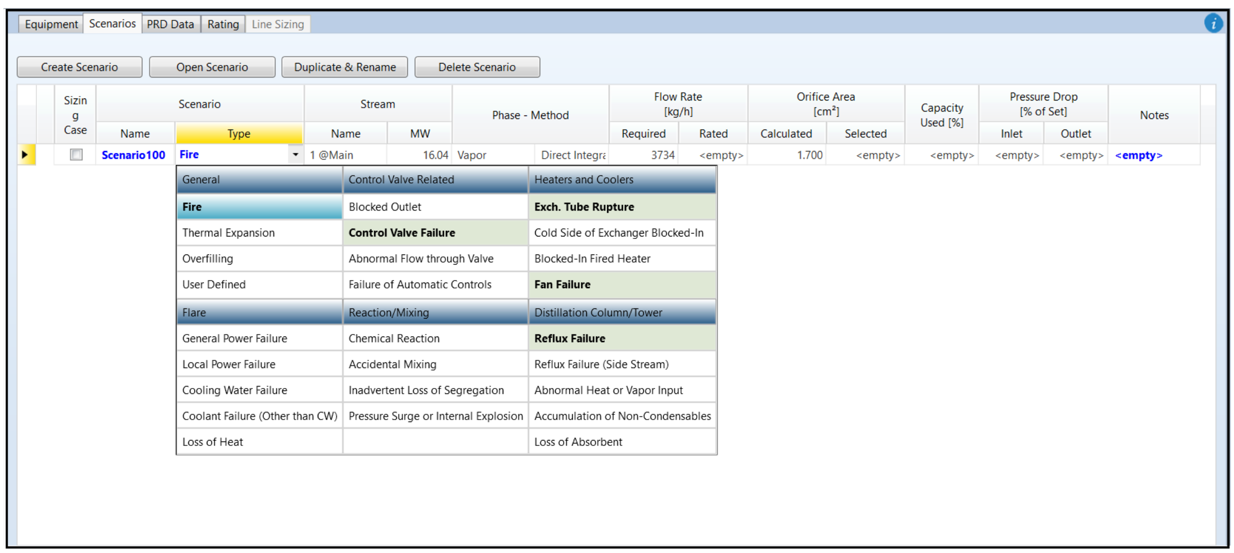
Step 1:



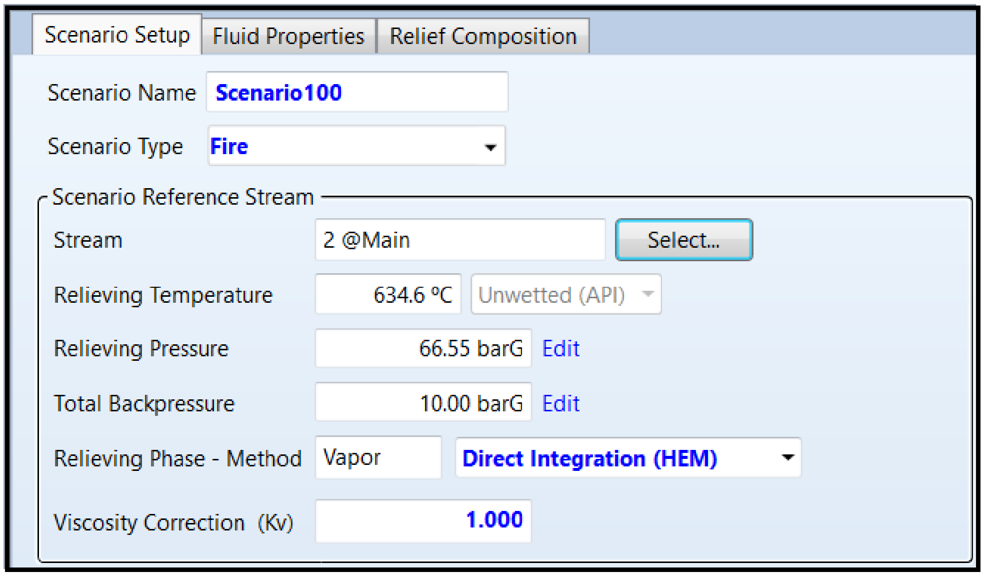
Step 2:


Equipment
Scenarios
PRD Data
Rating
Line Sizing
Unit Op Protected
V-100
Operating Temperature
380.0 °C
Reference
Design Temperature
410.0 °C
Manual
Operating Pressure
47.60 barG
Reference
Design Pressure
55.00 barG
Manual

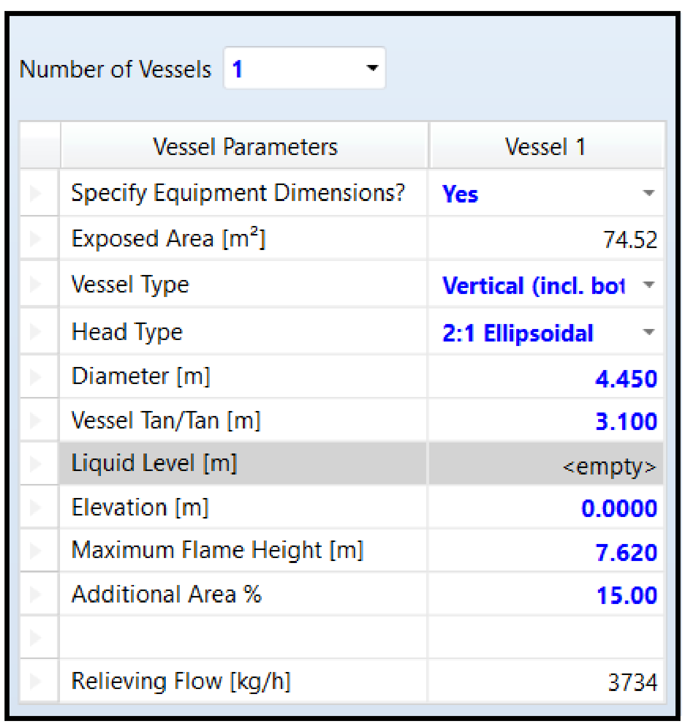
Step 3:


Equipment
Scenarios
PRD Data
Rating
Line Sizing
Create Scenario
Open Scenario
Duplicate & Rename
Delete Scenario
Sizing Case
Scenario
Name
Type
Stream
Name
MW
Phase - Method
Flow Rate [kg/h]
Required
Rated
Orifice Area [cm²]
Calculated
Selected
Capacity Used [%]
Pressure Drop [% of Set]
Inlet
Outlet
Notes
Scenario100
Fire
1 @Main
16.04
Vapor
Direct Integr
3734
<empty>
1.700
<empty>
<empty>
<empty>
<empty>
<empty>
General
Control Valve Related
Heaters and Coolers
Fire
Blocked Outlet
Exch. Tube Rupture
Thermal Expansion
Control Valve Failure
Cold Side of Exchanger Blocked-In
Overfilling
Abnormal Flow through Valve
Blocked-In Fired Heater
User Defined
Failure of Automatic Controls
Fan Failure
Flare
Reaction/Mixing
Distillation Column/Tower
General Power Failure
Chemical Reaction
Reflux Failure
Local Power Failure
Accidental Mixing
Reflux Failure (Side Stream)
Cooling Water Failure
Inadvertent Loss of Segregation
Abnormal Heat or Vapor Input
Coolant Failure (Other than CW)
Pressure Surge or Internal Explosion
Accumulation of Non-Condensables
Loss of Heat
Loss of Absorbent

Step 4:


Scenario Setup
Fluid Properties
Relief Composition
Scenario Name
Scenario100
Scenario Type
Fire
Scenario Reference Stream
Stream
2 @Main
Select...
Relieving Temperature
634.6 °C
Unwetted (API)
Relieving Pressure
66.55 barG
Edit
Total Backpressure
10.00 barG
Edit
Relieving Phase - Method
Vapor
Direct Integration (HEM)
Viscosity Correction (Kv)
1.000

Step 5:


Number of Vessels
1
Vessel Parameters
Vessel 1
Specify Equipment Dimensions?
Yes
Exposed Area [m2]
74.52
Vessel Type
Vertical (incl. bot
Head Type
2:1 Ellipsoidal
Diameter [m]
4.450
Vessel Tan/Tan [m]
3.100
Liquid Level [m]
<empty>
Elevation [m]
0.0000
Maximum Flame Height [m]
7.620
Additional Area %
15.00
Relieving Flow [kg/h]
3734

Required Relieving Flow 3734 kg/h

Relieving Flow Method ○ Manual ○ Reference ◉ Calculated

Calculation Method **Unwetted (API)**

Calculation Parameters	Value
Max. Wall Temp. [°C]	**635.0**

Relief Temperature Calculation Option

◉ Ideal Gas Assumption (API 521) ○ Ref Stream Equation of State

Step 6:

PSV Results	Value
Calculated Orifice [cm²]	1.700
Selected Orifice [cm²]	**1.980 (F)**
Fraction of Full Lift	1.000
Rated Capacity [kg/h]	4350
Capacity Used [%]	85.84
Orifice Designation	1.5 F 2
In/Out Flanges	600 x 150
Discharge Coefficient (Kd)	**0.9750**

Here is the gist of what we have obtained:

Parameters	Results	Unit
Relief Load-API	3874	kg/hr.
Relief Loaf-Hysys	3734	kg/hr.
Selected Orifice	1.98	cm^2
Orifice Designation	1.5 F 2	

3.PSV-1038/1043

1.Determine the scenario, using API-521

Since it is R-1002 and exposed to fire then a fire scenario is defined.

Parameters	Value	Parameters	Value
Diameter	4 m	M	16.54
Height-TT	2.9 m	Set Pressure	55 barg
Fluid	Natural Gas	Relieving Pressure	67.55 bara
Z	1.01	Accumulation	0.21
Cp/Cv	1.18	Material	CS

2.Calculate the relief load, using API-520 Part1

$$A = \frac{F' \times A'}{\sqrt{p_1}} \quad (9)$$

where

A is the effective discharge area of the valve, expressed in mm^2 (in.^{2});

A' is the exposed surface area of the vessel, expressed in m^2 (ft^2);

p_1 is the upstream relieving absolute pressure, expressed in kPa (psi);

NOTE p_1 is the set pressure plus the allowable overpressure plus the atmospheric pressure.

F' can be determined using Equation (10). If calculated using Equation (10) and the result is less than 182 in SI units (<0.01 in USC units), then use a recommended minimum value of $F' = 182$ in SI units ($F' = 0.01$ in USC units). If insufficient information is available to use Equation (10), then use $F' = 821$ in SI units ($F' = 0.045$ in USC units).

$$F' = \frac{C_9}{C \times K_D}\left[\frac{(T_W - T_1)^{1.25}}{T_1^{0.6506}}\right] \quad (10)$$

where

C_9 is a constant [= 0.2772 in SI units (0.1406 in USC units)];

K_D is the coefficient of discharge (obtainable from the valve manufacturer);

NOTE A K_D value of 0.975 is typically used for preliminary sizing of PRVs (see API 520, Part 1).

T_W is the maximum wall temperature of vessel material, expressed in K (°R);

T_1 is the gas absolute temperature, at the upstream relieving pressure, determined from Equation (12), expressed in K (°R).

The coefficient, C, is given by Equation (11):

$$C = C_{10}\sqrt{k\left(\frac{2}{k+1}\right)^{\frac{k+1}{k-1}}} \quad (11)$$

where

C_{10} is a constant {= 0.0395 (kg-mole-K)$^{0.5}$/(mm^2-kPa-h) in SI units [520 (lb-mole-°R)$^{0.5}$/(lbf-h) in USC units]};

k is the ideal gas specific heat ratio (C_p/C_v) of gas or vapor at relieving temperature.

$$T_1 = \frac{p_1}{p_n} \times T_n \quad (12)$$

where

p_n is the normal operating gas absolute pressure, expressed in kPa (psia);

T_n is the normal operating gas absolute temperature, expressed in K (°R).

The recommended maximum vessel wall temperature, T_w, for the usual carbon steel plate materials is 593 °C (1100 °F). If vessels are fabricated from alloy materials, the value for T_w should be based on the stress rupture data for that material. See 4.4.13.2.3, 4.4.13.2.6, 4.6.1, and Annex A for guidance on the potential for vessel failure from overtemperature due to fire exposure.

If $F' \geq 182$ in SI units ($F' \geq 0.01$ in USC units), the relief load, $q_{m,relief}$, expressed in kg/h (lb/h), can be calculated directly by rearranging the critical vapor equation and substituting Equation (9) and Equation (10), which results in Equation (13):

$$q_{m,relief} = C_{12}\sqrt{M \times p_1}\left[\frac{A'(T_w - T_1)^{1.25}}{T_1^{1.1506}}\right] \quad (13)$$

where

M is the relative molecular mass of the gas;

C_{12} is a constant [= 0.2772 in SI units (0.1406 in USC units)].

The minimum relief load recommended for sizing where $F' < 182$ in SI units ($F' < 0.01$ in USC units) is calculated by setting $F' = 182$ in SI units ($F' = 0.01$ in USC units), which results in Equation (14):

$$q_{m,relief} = C_{13}CA'\sqrt{\frac{Mp_1}{T_1}} \quad (14)$$

where

C_{13} is a constant [= 182 in SI units (0.01 in USC units)].

NOTE To derive Equation (13) and Equation (14), Z, K_b, and K_c in API 520, Part 1, Equation (3) have each been assumed to have a value of 1. For Equation (14), K_D is conservatively assumed to have a value of 1.

Calculation

Parameters	Value	Parameters	Value
Aw	53.84 m2	KD	0.975
C9	0.2772	F’	116
C10	0.0395	Relief Load	3215 kg/hr
C	0.0254		

$$Ws = 182 \times C \times Aw \times \sqrt{\left(\frac{M \times P \times 100}{T + 273}\right)}$$

$$Ws = 182 \times 0.0254 \times 53.84 \times \sqrt{\frac{16.54 \times 67.5 \times 100}{400 + 273}} = 3215.1 \frac{kg}{hr}$$

Note that since F’ is less than 182 the corresponding equation has been used in which F’ is set to 182. Remember that in F’ calculation T1 is set to max 400 C.

Note : Relieving Temperature Calculation

$$\text{Relieving Temperature(K)} = \frac{\text{Relieving Pressure (bara)}}{\text{Operating Pressure (bara)}} \times \text{Operating Temperature (K)}$$

$$\text{Relieving Temperature (K)} = \frac{67.55}{49.3} \times (375 + 273) = 887\ \text{K} = 614\ \text{C}$$

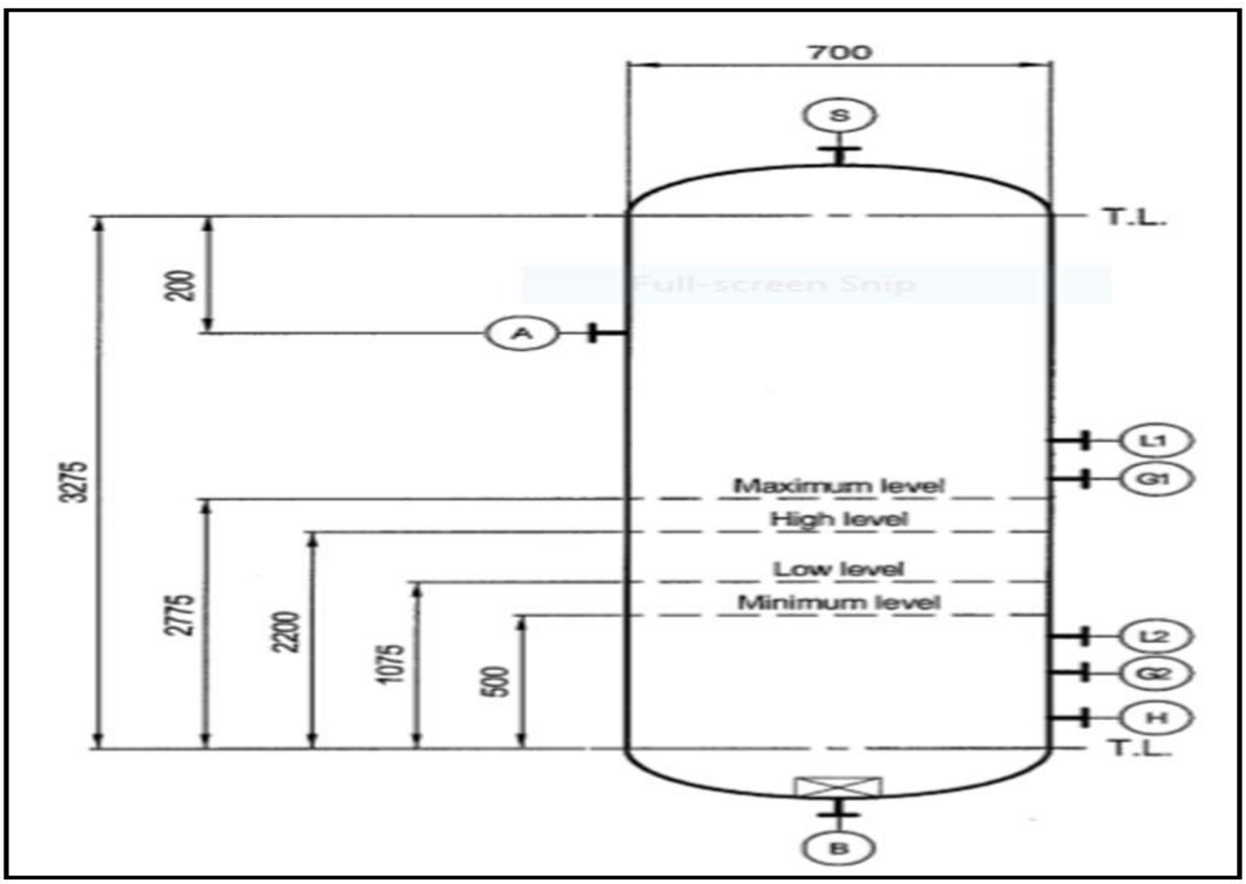
since the ratio between operating pressure and PSV relieving pressure is very high, the relieving temperature calculated is not consistent (it would exceed the maximum vessel wall temperature for carbon steel, &o). The relieving temperature for PSV design has been assumed equal to 400°C (considered the max allowable value for carbon steel). The actual relieving mass flow has been calculated keeping the discharge capacity of the valve (volumetric flow rate) constant and scaling the temperature down to 400°C.

PSV-2019

1.Determine the scenario, using API-521

Since it is exposed to fire then a fire scenario is defined.

Parameters	Value	Parameters	Value
Diameter	0.7 m	M	18.02
Height	3.275 m	Set Pressure	52 barg
Fluid	Steam Condensate	Relieving Pressure	63.9 bara
Z	0.78	Accumulation	0.21
Cp/Cv	1.09	Material	CS



2.Calculate the relief load, using API-520 Part1

$$Q = C_1 \times F \times A_{ws}^{0.82} \quad (7)$$

where

Q is the total heat absorption (input) to the wetted surface, expressed in W (Btu/h);

C_1 is a constant [= 43,200 in SI units (21,000 in USC units)];

F is an environment factor (see Table 5);

A_{ws} is the total wetted surface, expressed in m^2 (ft^2).

NOTE 1 See 4.4.13.2.2 and Table 4.

NOTE 2 The expression, $A_{ws}^{0.82}$, is the area exposure factor or ratio. This ratio recognizes that large vessels are less likely than small ones to be completely exposed to the flame of an open fire.

Where adequate drainage and firefighting equipment do not exist, Equation (8) should be used

$$Q = C_2 \times F \times A_{ws}^{0.82}$$

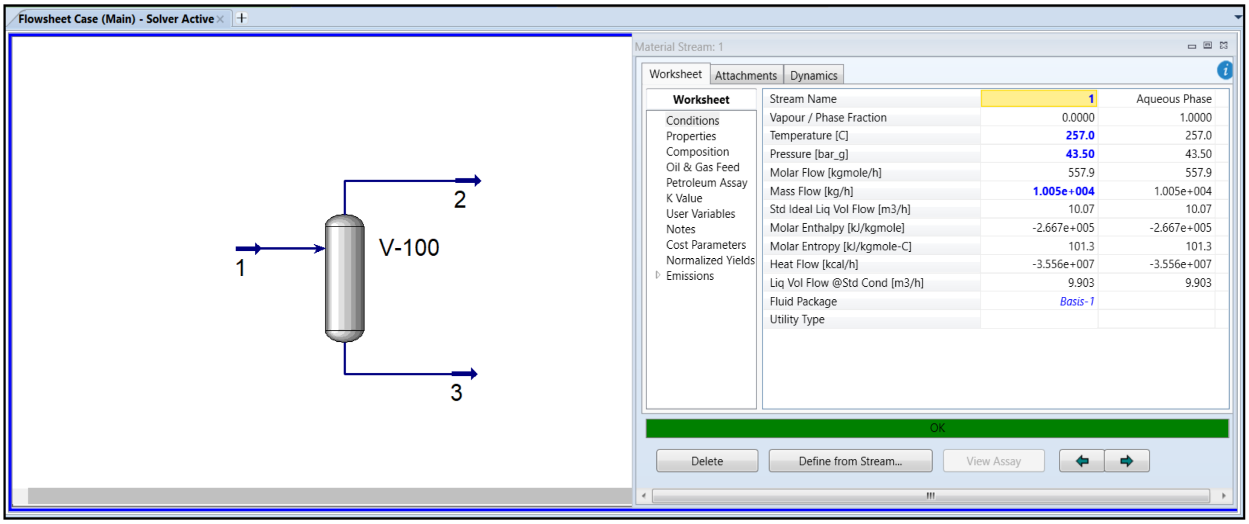
C_2 is a constant [= 70,900 in SI units (34,500 in USC units)].

Calculation

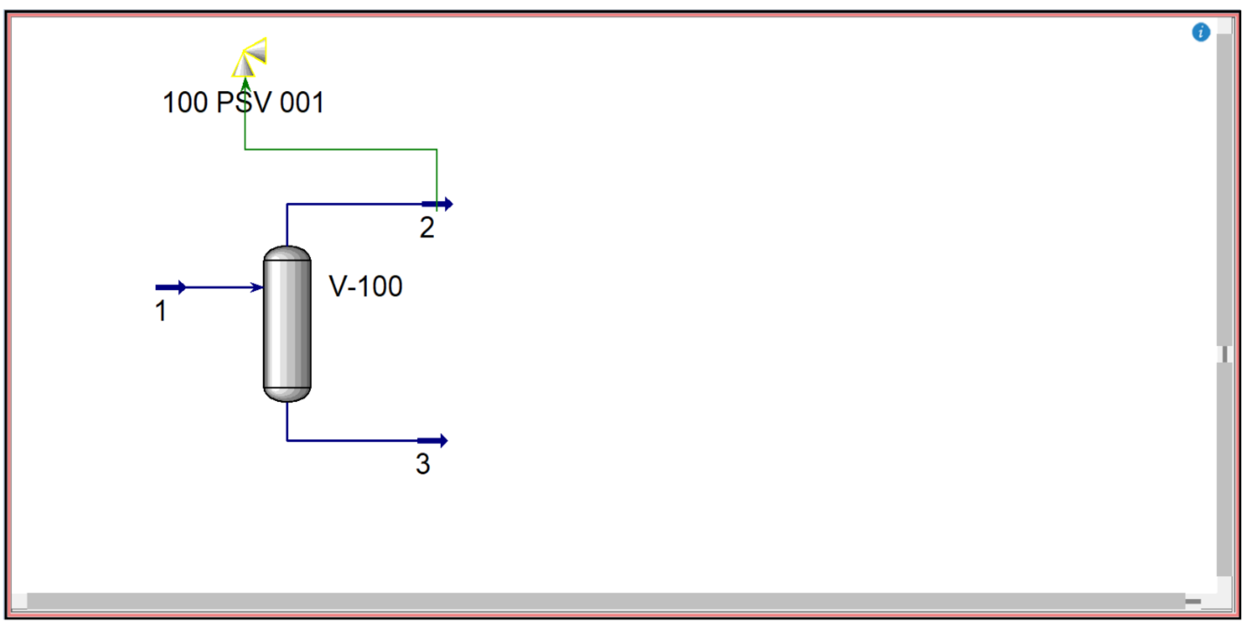
Parameters	Value
Aw	7.73 m2
C2	70900
F	1
λ	2880
Relief load	474 kg/h

$$Ws = \frac{C2 \times F \times (Aw^{0.82})}{\lambda} = \frac{70900 \times 1 \times (7.73^{0.82}) \times 3.6}{2880} = 474 \frac{kg}{hr}$$

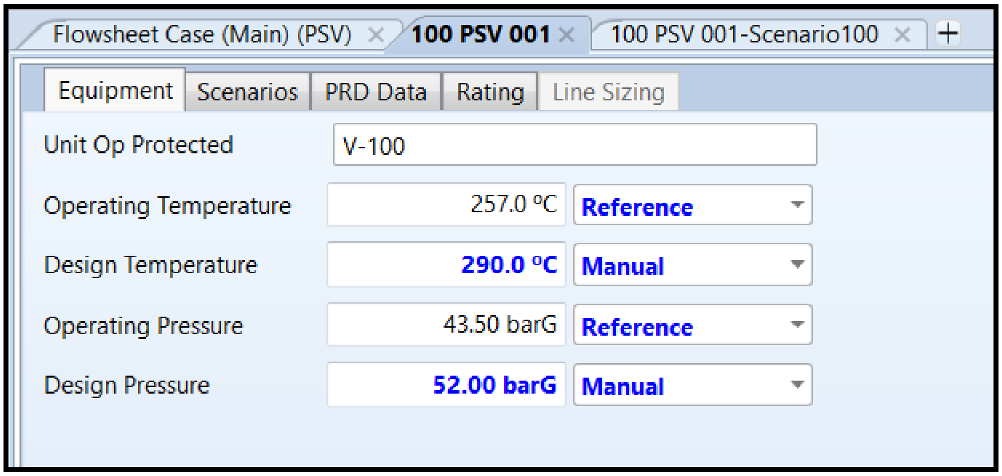
Simulation in Aspen Hysys



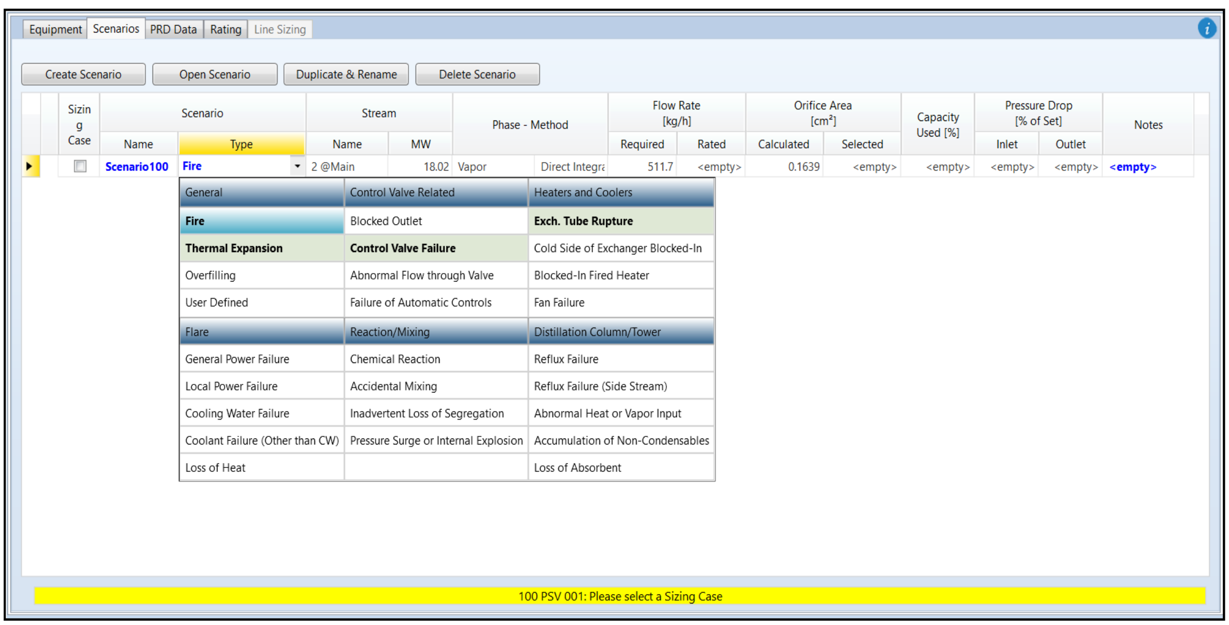
Step 1:



Step 2:


Flowsheet Case (Main) (PSV)
100 PSV 001
100 PSV 001-Scenario100
Equipment
Scenarios
PRD Data
Rating
Line Sizing
Unit Op Protected
V-100
Operating Temperature
257.0 ºC
Reference
Design Temperature
290.0 ºC
Manual
Operating Pressure
43.50 barG
Reference
Design Pressure
52.00 barG
Manual

Step 3:


Equipment
Scenarios
PRD Data
Rating
Line Sizing
Create Scenario
Open Scenario
Duplicate & Rename
Delete Scenario
Sizing Case
Scenario
Name
Type
Stream
Name
MW
Phase - Method
Flow Rate [kg/h]
Required
Rated
Orifice Area [cm²]
Calculated
Selected
Capacity Used [%]
Pressure Drop [% of Set]
Inlet
Outlet
Notes
Scenario100
Fire
2 @Main
18.02
Vapor
Direct Integra
511.7
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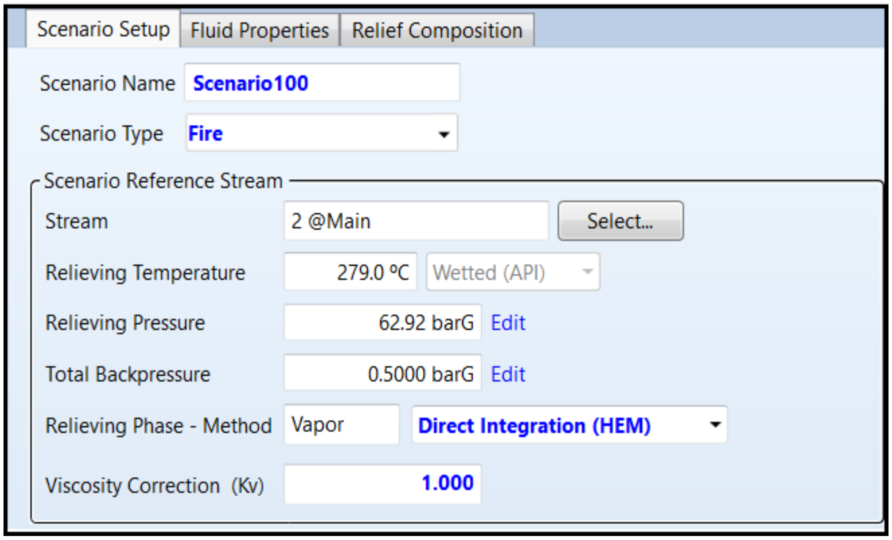
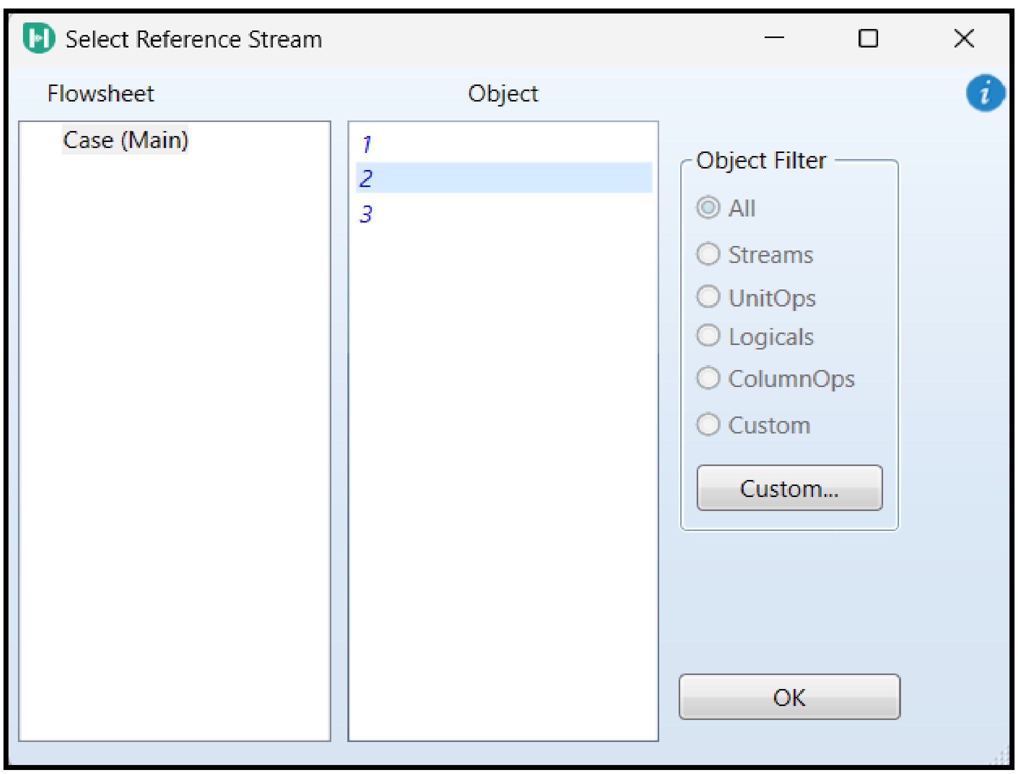
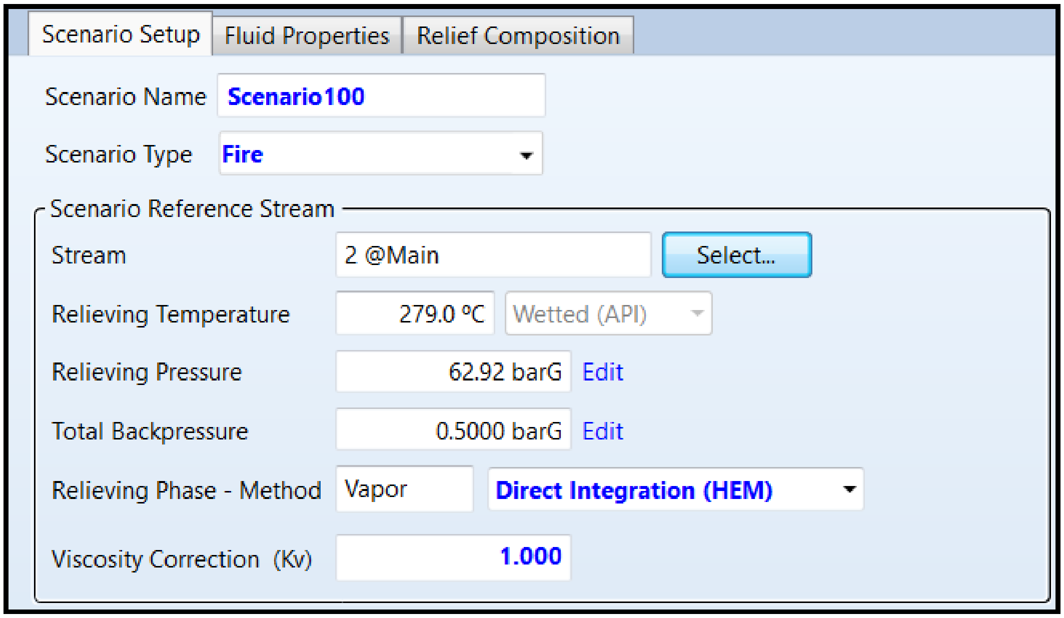
General
Control Valve Related
Heaters and Coolers
Fire
Blocked Outlet
Exch. Tube Rupture
Thermal Expansion
Control Valve Failure
Cold Side of Exchanger Blocked-In
Overfilling
Abnormal Flow through Valve
Blocked-In Fired Heater
User Defined
Failure of Automatic Controls
Fan Failure
Flare
Reaction/Mixing
Distillation Column/Tower
General Power Failure
Chemical Reaction
Reflux Failure
Local Power Failure
Accidental Mixing
Reflux Failure (Side Stream)
Cooling Water Failure
Inadvertent Loss of Segregation
Abnormal Heat or Vapor Input
Coolant Failure (Other than CW)
Pressure Surge or Internal Explosion
Accumulation of Non-Condensables
Loss of Heat
Loss of Absorbent
100 PSV 001: Please select a Sizing Case

Step 4:


Scenario Setup
Fluid Properties
Relief Composition
Scenario Name
Scenario100
Scenario Type
Fire
Scenario Reference Stream
Stream
2 @Main
Select...
Relieving Temperature
279.0 °C
Wetted (API)
Relieving Pressure
62.92 barG
Edit
Total Backpressure
0.5000 barG
Edit
Relieving Phase - Method
Vapor
Direct Integration (HEM)
Viscosity Correction (Kv)
1.000


Select Reference Stream
Flowsheet
Object
Case (Main)
1
2
3
Object Filter
All
Streams
UnitOps
Logicals
ColumnOps
Custom
Custom...
OK


Scenario Setup
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Relief Composition
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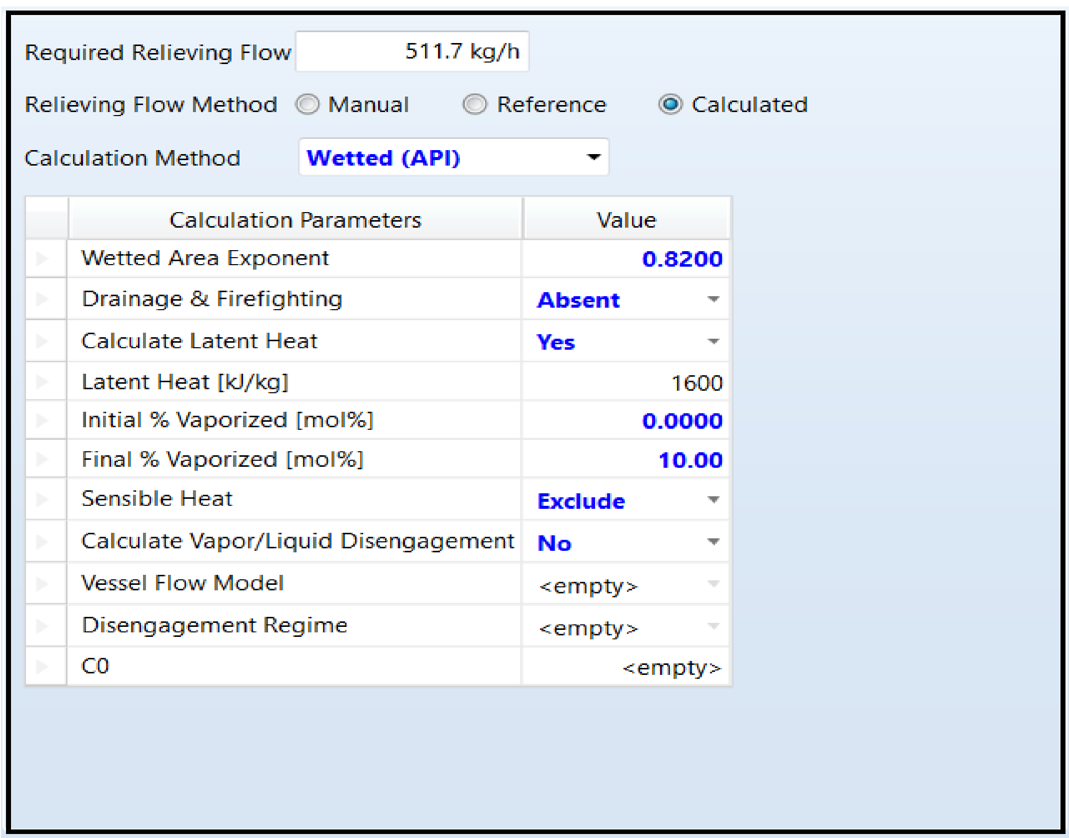
Scenario100
Scenario Type
Fire
Scenario Reference Stream
Stream
2 @Main
Select...
Relieving Temperature
279.0 °C
Wetted (API)
Relieving Pressure
62.92 barG
Edit
Total Backpressure
0.5000 barG
Edit
Relieving Phase - Method
Vapor
Direct Integration (HEM)
Viscosity Correction (Kv)
1.000

Step 5:


Required Relieving Flow
511.7 kg/h
Relieving Flow Method
Manual
Reference
Calculated
Calculation Method
Wetted (API)
Calculation Parameters
Value
Wetted Area Exponent
0.8200
Drainage & Firefighting
Absent
Calculate Latent Heat
Yes
Latent Heat [kJ/kg]
1600
Initial % Vaporized [mol%]
0.0000
Final % Vaporized [mol%]
10.00
Sensible Heat
Exclude
Calculate Vapor/Liquid Disengagement
No
Vessel Flow Model
<empty>
Disengagement Regime
<empty>
C0
<empty>

Step 6:

Number of Vessels: 1

Vessel Parameters	Vessel 1
Specify Equipment Dimensions?	Yes
Exposed Area [m^2]	4.138
Vessel Type	Vertical (incl. bot
Head Type	2:1 Ellipsoidal
Diameter [m]	0.7000
Vessel Tan/Tan [m]	3.275
Liquid Level [m]	1.640
Elevation [m]	0.0000
Maximum Flame Height [m]	7.620
Additional Area %	0.0000
Calculate F Factor?	No
Environment Factor F	1.000
Insulation k [W/m/ºC]	<empty>
Insulation Thickness [mm]	<empty>
Heat Input [kJ/h]	8.186E+005
Relieving Flow [kg/h]	511.7

4.PSV-2121/2122

The rated capacity of FT-2002 is 27180 kg/h, so the relief load is 27180 kg/h.

5.PSV-2171/2172

The rated capacity of FT-2001 is 48000 kg/h, so the relief load is 48000 kg/h.

6.PSV-2354/2360

Heat Exchanger E-2020 tube rupture

Please check Appendix A.

7.PSV-2485

1. Heat Exchanger Data Input

High pressure side	Reformed Gas
Low pressure side	DMW
Design Pressure of high-pressure side	29 barg
Design Pressure of low-pressure side	14 barg
Operating Pressure	24.5 barg
M	12.06
Cp/Cv	1.36
Z	1
Relieving Temperature	138
Tube OD	25.4
Tube Thk.	1.65

2. Check if a PSV is needed

In order to perform this step, do the calculation below:

multiply design pressure of high-pressure side by 10/13:
29 * 10/13 = 22.3 barg
So, design pressure of low-pressure side should be at least 22.3 brag in order not to need a PSV. Here it is 7.5 bars, thereby requiring a PSV.

3. Use the formula below to calculate Relief Load

K_G : 2.93 (Metric), 385 (USC)

K_L : 1.77 (Metric), 2645 (USC)

Vapors $$W_G = K_G d^2 P_1 \sqrt{\frac{M}{zT}}$$

Liquids $$W_L = K_L d^2 \sqrt{\rho_L (P_1 - P_2)}$$

W_G	:	gas flow through tube break, kg/hr or lb/hr
W_L	:	liquid flow through tube break, kg/hr or lb/hr
d	:	tube inside diameter, mm or inch
P_1(*)	:	HP side normal pressure, bara or psia (alternatively the HP side design pressure may be considered for P_1, as required by some clients).
P_2(*)	:	relieving pressure of the low pressure side, usually 1.1 x gauge set pressure, bara or psia
M	:	molecular weight
z	:	compressibility factor
T(*)	:	vapor temperature, °K or °R
ρ_L(*)	:	liquid density, kg/m3 or lb/ft3

4. Relief Load Result

$$W_s = KG \times (d\^{}2) \times P1 \times ((M/ZT)\ \^{}0.5)$$

$$W_s = 2.93 \times (22.1\ ^2) \times (24.5 + 1.013) \times \frac{12.06}{1 \times 411} = 6254.12 \text{ kg/hr.}$$

PSV 2376/2377/2378/2379/2380

The total capacity is 430000kg/h (Normal capacity is388329 considering 1.1 times) which is shared by PSV-2376, PSV-2377, PSV-2378, and PSV-2379; PSV-2380 is spare and its capacity is the same as PSV-2376~79.

PSV-2494

1. Heat Exchanger Data Input

High pressure side	Reformed Gas
Low pressure side	CW
Design Pressure of high-pressure side	29 barg
Design Pressure of low-pressure side	7.5 barg
Operating Pressure	24.2 barg
M	11.24
Cp/Cv	1.39
Z	1
Relieving Temperature	56.4
Tube OD	19.05
Tube Thk.	1.65

2. Check if a PSV is needed

In order to perform this step, do the calculation below:

multiply design pressure of high-pressure side by 10/13:

29 * 10/13 = 22.3 barg

So, design pressure of low-pressure side should be at least 22.3 barg in order not to need a PSV. Here it is 7.5 bars, thereby requiring a PSV.

3. Use the formula below to calculate Relief Load

K_G : 2.93 (Metric), 385 (USC)
K_L : 1.77 (Metric), 2645 (USC)

Vapors $$W_G = K_G\, d^2\, P_1 \sqrt{\frac{M}{zT}}$$

Liquids $$W_L = K_L\, d^2 \sqrt{\rho_L (P_1 - P_2)}$$

W_G	:	gas flow through tube break, kg/hr or lb/hr
W_L	:	liquid flow through tube break, kg/hr or lb/hr
d	:	tube inside diameter, mm or inch
P_1(*)	:	HP side normal pressure, bara or psia (alternatively the HP side design pressure may be considered for P_1, as required by some clients).
P_2(*)	:	relieving pressure of the low pressure side, usually 1.1 x gauge set pressure, bara or psia
M	:	molecular weight
z	:	compressibility factor
T(*)	:	vapor temperature, °K or °R
ρ_L(*)	:	liquid density, kg/m3 or lb/ft3

4.Relief Load Results

W_s = KG × (d^2) × P1 × ((M/ZT) ^0.5)

$$W_s = 2.93 \times (15.75^{2}) \times (24.2 + 1.013) \times \frac{11.24}{1 \times 329} = 3387.18 \text{ kg/hr.}$$

PSV-2494

1.Heat Exchanger Data Input

High pressure side	Syngas
Low pressure side	CW
Design Pressure of high-pressure side	99 barg
Design Pressure of low-pressure side	7.5 barg
Operating Pressure	83.7 barg
M	10.07
Cp/Cv	1.37
Z	1
Relieving Temperature	43.6
Tube OD	25.4
Tube Thk.	1.65

2. Check if a PSV is needed

In order to perform this step, do the calculation below:
multiply design pressure of high-pressure side by 10/13:
99 * 10/13 = 76.15 barg
So, design pressure of low-pressure side should be at least 76.15 barg in order not to need a PSV. Here it is 7.5 bars, thereby requiring a PSV.

3. Use the formula below to calculate Relief Load

K_G : 2.93 (Metric), 385 (USC)
K_L : 1.77 (Metric), 2645 (USC)

Vapors $$W_G = K_G d^2 P_1 \sqrt{\frac{M}{zT}}$$

Liquids $$W_L = K_L d^2 \sqrt{\rho_L (P_1 - P_2)}$$

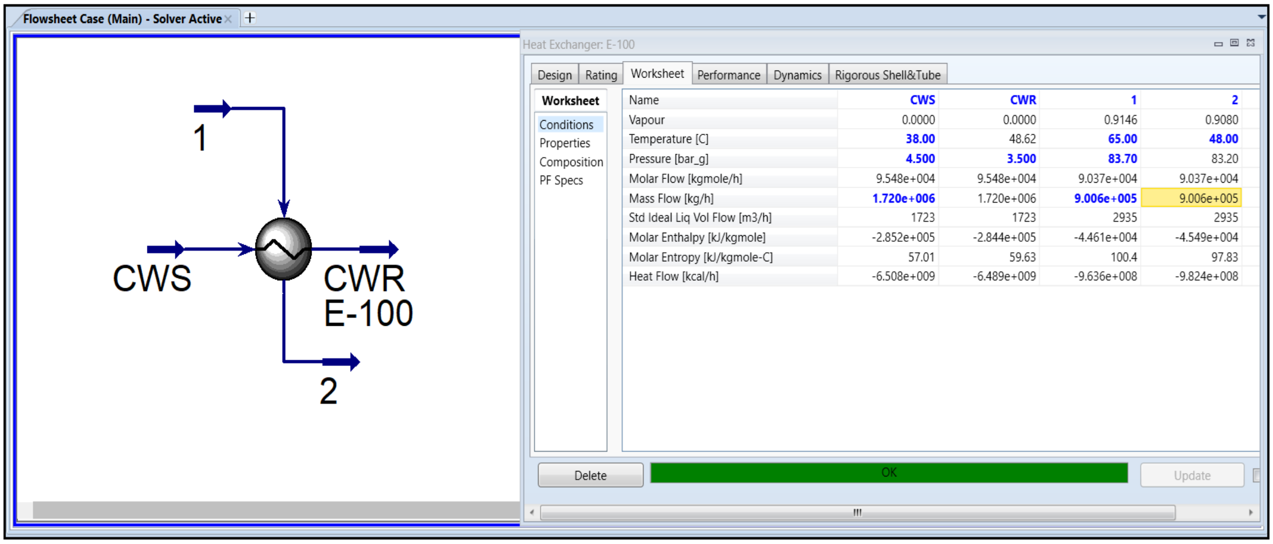
W_G	:	gas flow through tube break, kg/hr or lb/hr
W_L	:	liquid flow through tube break, kg/hr or lb/hr
d	:	tube inside diameter, mm or inch
P_1(*)	:	HP side normal pressure, bara or psia (alternatively the HP side design pressure may be considered for P_1, as required by some clients).
P_2(*)	:	relieving pressure of the low pressure side, usually 1.1 x gauge set pressure, bara or psia
M	:	molecular weight
z	:	compressibility factor
T(*)	:	vapor temperature, °K or °R
ρ_L(*)	:	liquid density, kg/m3 or 1b/ft3

4. Relief Load Result

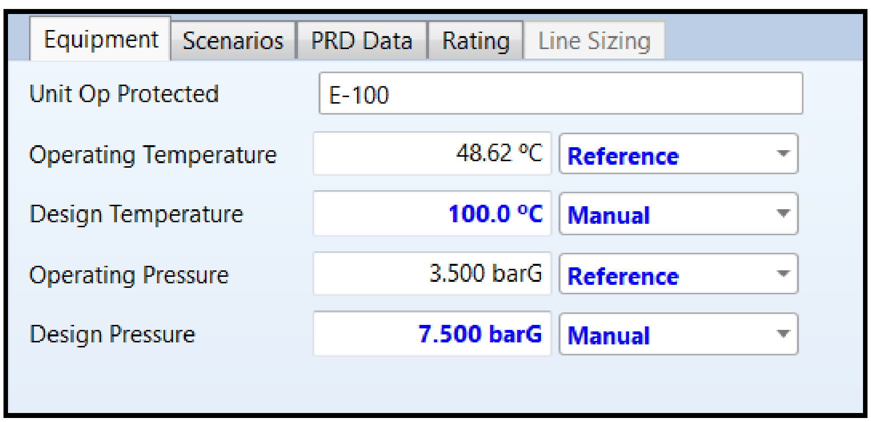
$$W_s = KG \times (d\text{^}2) \times P1 \times ((M/ZT)\text{^}0.5)$$

$$W_s = 2.93 \times (22.1^{2}) \times (83.7 + 1.013) \times \frac{10.07}{1 \times 323} = 21620 \text{ kg/hr.}$$

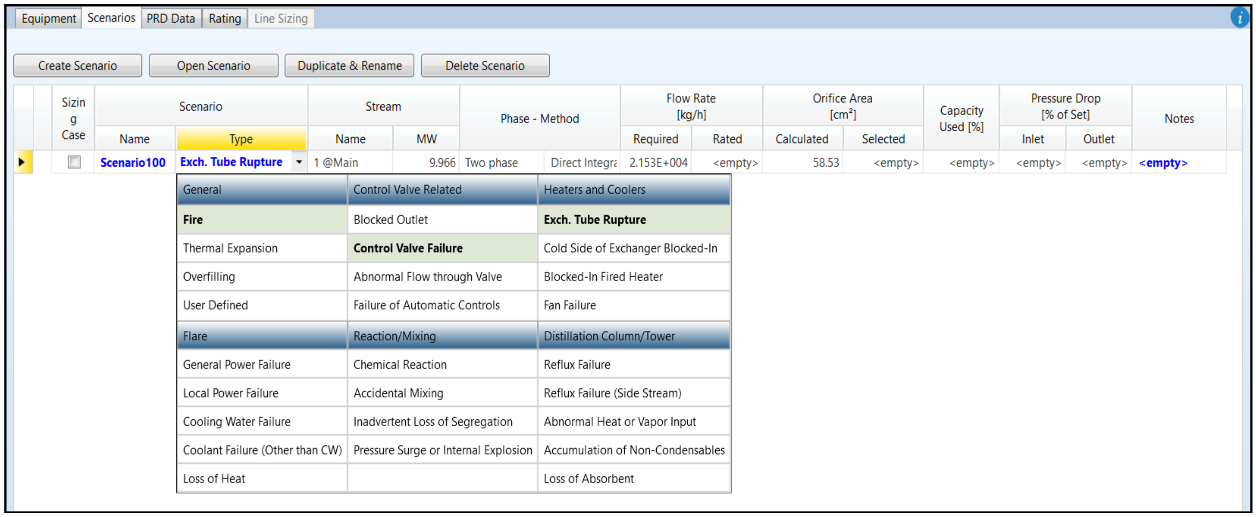
Simulation



Step 1:



Step 2: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PRD Data
Rating
Line Sizing
Create Scenario
Open Scenario
Duplicate & Rename
Delete Scenario
Sizing Case
Scenario
Name
Type
Stream
Name
MW
Phase - Method
Flow Rate [kg/h]
Required
Rated
Orifice Area [cm²]
Calculated
Selected
Capacity Used [%]
Pressure Drop [% of Set]
Inlet
Outlet
Notes
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Exch. Tube Rupture
1 @Main
9.966
Two phase
Direct Integr
2.153E+004
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58.53
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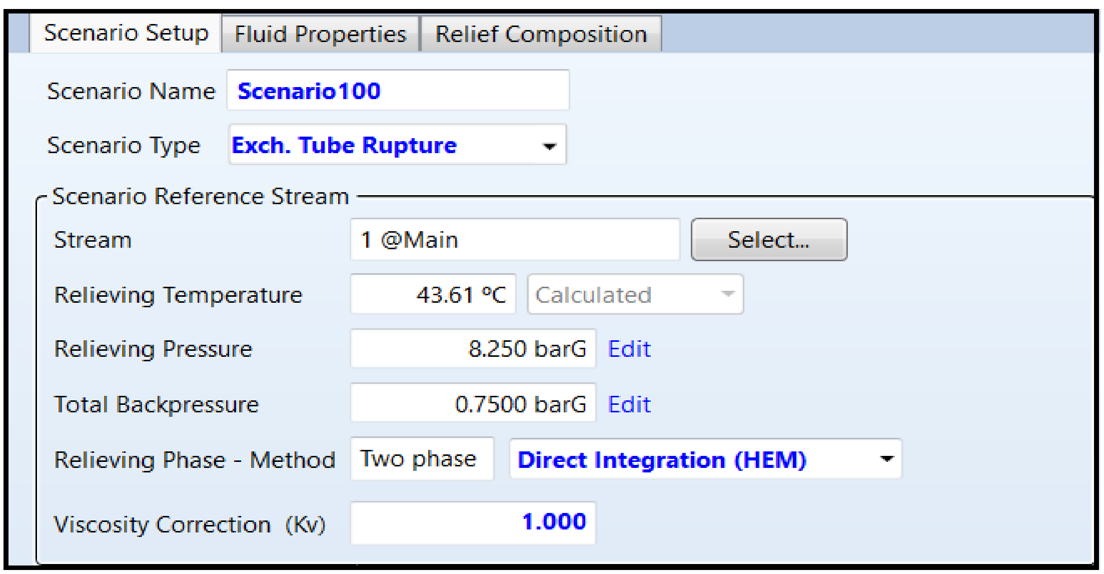
Fire
Blocked Outlet
Exch. Tube Rupture
Thermal Expansion
Control Valve Failure
Cold Side of Exchanger Blocked-In
Overfilling
Abnormal Flow through Valve
Blocked-In Fired Heater
User Defined
Failure of Automatic Controls
Fan Failure
Flare
Reaction/Mixing
Distillation Column/Tower
General Power Failure
Chemical Reaction
Reflux Failure
Local Power Failure
Accidental Mixing
Reflux Failure (Side Stream)
Cooling Water Failure
Inadvertent Loss of Segregation
Abnormal Heat or Vapor Input
Coolant Failure (Other than CW)
Pressure Surge or Internal Explosion
Accumulation of Non-Condensables
Loss of Heat
Loss of Absorbent

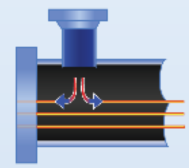
Step 3:


Scenario Setup
Fluid Properties
Relief Composition
Scenario Name
Scenario100
Scenario Type
Exch. Tube Rupture
Scenario Reference Stream
Stream
1 @Main
Select...
Relieving Temperature
43.61 °C
Calculated
Relieving Pressure
8.250 barG
Edit
Total Backpressure
0.7500 barG
Edit
Relieving Phase - Method
Two phase
Direct Integration (HEM)
Viscosity Correction (Kv)
1.000

Step 4:

Required Relieving Flow	2.153E+004 kg/h
Relieving Flow Method	◯ Manual ◯ Reference ◉ Calculated
Direction of Flow	◯ From Tube to Shell ◉ From Shell to Tube

	High Pressure Side	High Pressure Side Method	Choking Condition	Low Pressure Side @ Relief
Pressure	83.70 barG	**Reference**	43.97 barG	8.250 barG
Temperature	65.00 ºC	**Reference**	60.40 ºC	43.61 ºC
Phase	Two phase		Two phase	Two phase



Tube I.D.	**25.40 mm**	
Flow Coefficient (C)	**0.4000**	
ΔP	39.73 bar	(choked flow)
Vapor Density (ρV)	24.13 kg/m³	
Vapor k	1.384	
Liquid Density (ρL)	768.4 kg/m³	
Vapor Ratio (R)	0.7641	

Step 5:

PSV Results	Value
Calculated Orifice [cm²]	58.53
Selected Orifice [cm²]	**71.290 (Q)**
Fraction of Full Lift	1.000
Rated Capacity [kg/h]	2.622E+004
Capacity Used [%]	82.10
Orifice Designation	6 Q 8
In/Out Flanges	150 x 150
Discharge Coefficient (Kd)	**0.8500**

Here is all we have obtained:

Parameters	Values	Units
Relief Load-API	21620	kg/hr.
Relief Load-Hysys	21530	kg/hr.
Selected Orifice	71.29	Cm^2
Orifice Designation	6Q8	

PSV-3047/3048/3057

Steam Drum D-3003

The normal capacity of steam is about 251000 kg/h and the rated capacity is achieved by multiplying the normal capacity by 1.1 which equals to 276000 kg/h.

PSV-3163

1.Determine the scenario, using API-521

Since it is D-3001 and exposed to fire then a fire scenario is defined.

Parameters	Value	Parameters	Value
Diameter	4.9 m	M	9.37
Height	4.8 m	Set Pressure	99 barg
Fluid	Methanol + Syng	Relieving Pressure	120.79 bara
Z		Accumulation	0.21
Cp/Cv	1.37	Material	SS

2.Calculate the relief load, using API-520 Part1

$$A = \frac{F' \times A'}{\sqrt{p_1}} \quad (9)$$

where

A is the effective discharge area of the valve, expressed in mm^2 (in.^{2});

A' is the exposed surface area of the vessel, expressed in m^2 (ft^2);

p_1 is the upstream relieving absolute pressure, expressed in kPa (psi);

NOTE p_1 is the set pressure plus the allowable overpressure plus the atmospheric pressure.

F' can be determined using Equation (10). If calculated using Equation (10) and the result is less than 182 in SI units (<0.01 in USC units), then use a recommended minimum value of F' = 182 in SI units (F' = 0.01 in USC units). If insufficient information is available to use Equation (10), then use F' = 821 in SI units (F' = 0.045 in USC units).

$$F' = \frac{C_9}{C \times K_D}\left[\frac{(T_W - T_1)^{1.25}}{T_1^{0.6506}}\right] \quad (10)$$

where

C_9 is a constant [= 0.2772 in SI units (0.1406 in USC units)];

K_D is the coefficient of discharge (obtainable from the valve manufacturer);

NOTE A K_D value of 0.975 is typically used for preliminary sizing of PRVs (see API 520, Part 1).

T_W is the maximum wall temperature of vessel material, expressed in K (°R);

T_1 is the gas absolute temperature, at the upstream relieving pressure, determined from Equation (12), expressed in K (°R).

The coefficient, C, is given by Equation (11):

$$C = C_{10}\sqrt{k\left(\frac{2}{k+1}\right)^{\frac{k+1}{k-1}}} \quad (11)$$

where

C_{10} is a constant {= 0.0395 (kg-mole-K)$^{0.5}$/(mm^2-kPa-h) in SI units [520 (lb-mole-°R)$^{0.5}$/(lbf-h) in USC units]};

k is the ideal gas specific heat ratio (C_p/C_v) of gas or vapor at relieving temperature.

$$T_1 = \frac{p_1}{p_n} \times T_n \quad (12)$$

where

p_n is the normal operating gas absolute pressure, expressed in kPa (psia);

T_n is the normal operating gas absolute temperature, expressed in K (°R).

The recommended maximum vessel wall temperature, T_w, for the usual carbon steel plate materials is 593 °C (1100 °F). If vessels are fabricated from alloy materials, the value for T_w should be based on the stress rupture data for that material. See 4.4.13.2.3, 4.4.13.2.6, 4.6.1, and Annex A for guidance on the potential for vessel failure from overtemperature due to fire exposure.

If $F' \geq 182$ in SI units ($F' \geq 0.01$ in USC units), the relief load, $q_{m,\text{relief}}$, expressed in kg/h (lb/h), can be calculated directly by rearranging the critical vapor equation and substituting Equation (9) and Equation (10), which results in Equation (13):

$$q_{m,\text{relief}} = C_{12}\sqrt{M \times p_1}\left[\frac{A'(T_w - T_1)^{1.25}}{T_1^{\,1.1506}}\right] \quad (13)$$

where

M is the relative molecular mass of the gas;

C_{12} is a constant [= 0.2772 in SI units (0.1406 in USC units)].

The minimum relief load recommended for sizing where $F' < 182$ in SI units ($F' < 0.01$ in USC units) is calculated by setting $F' = 182$ in SI units ($F' = 0.01$ in USC units), which results in Equation (14):

$$q_{m,\text{relief}} = C_{13} C A' \sqrt{\frac{M p_1}{T_1}} \quad (14)$$

where

C_{13} is a constant [= 182 in SI units (0.01 in USC units)].

NOTE To derive Equation (13) and Equation (14), Z, K_b, and K_c in API 520, Part 1, Equation (3) have each been assumed to have a value of 1. For Equation (14), K_D is conservatively assumed to have a value of 1.

Calculation

Parameters	Value	Parameters	Value
Aw	100 m2	KD	0.975
C9	0.2772	F’	328
C10	0.0395	Tw	593C
C	0.026	Relief Load	13236 kg/hr

$$\mathrm{Ws} = \frac{2.722 \times (\mathrm{Tw} - \mathrm{T})^{1.25} \times \mathrm{A} \times \sqrt{\mathrm{MP}}}{\mathrm{T}^{1.1506}}$$

$$\mathrm{Ws} = \frac{2.722 \times (866.5 - 478.6)^{1.25} \times 100 \times \sqrt{(120.7 \times 100 \times 9.37}}{478.6^{1.1506}} = 13236 \frac{\mathrm{kg}}{\mathrm{hr}}$$

Note: Relieving temperature calculation:

$$\mathrm{T} = \frac{\text{Relieving Pressure}}{\text{Operating Pressure}} \times \text{Operating Temperature}$$

$$\mathrm{T} = \frac{120.79}{81} \times (48 + 321) = 478.7\ \mathrm{C}$$

PSV-5370

Use the formula below to calculate Relief Load

$$q = \frac{\alpha_V \cdot \phi}{1\,000 d \cdot c}$$

q is the volume flow rate at the flowing temperature, expressed in cubic metres per second;

α_V is the cubic expansion coefficient for the liquid at the expected temperature, expressed in 1/°C;

ϕ is the total heat transfer rate, expressed in watts;

NOTE For heat exchangers, this can be taken as the maximum exchanger duty during operation.

d is the relative density referred to water (d = 1,00 at 15,6 °C), dimensionless;

NOTE Compressibility of the liquid is usually ignored.

c is the specific heat capacity of the trapped fluid, expressed in J/kg·K.

1.PSV-5370

Parameters	value
av (1/k)	0.000454
duty (watts)	160000
specific gravity	0.99
c (J/kg.C)	4176

Q (lit/m)	1.05
Q (kg/h)-API521	63

$$q = \frac{av \times \emptyset}{1000 \times d \times C}$$

$$q = \frac{0.000454 \times 160000 \times 60000}{1000 \times 0.99 \times 4176} = 1.05 \text{ lit/min}$$

2.PSV-5339

Use the formula below to calculate Relief Load

$$q = \frac{\alpha_V \cdot \phi}{1\,000 d \cdot c}$$

q is the volume flow rate at the flowing temperature, expressed in cubic metres per second;

α_V is the cubic expansion coefficient for the liquid at the expected temperature, expressed in 1/°C;

ϕ is the total heat transfer rate, expressed in watts;

NOTE For heat exchangers, this can be taken as the maximum exchanger duty during operation.

d is the relative density referred to water (d = 1,00 at 15,6 °C), dimensionless;

NOTE Compressibility of the liquid is usually ignored.

c is the specific heat capacity of the trapped fluid, expressed in J/kg·K.

Parameters	value
av (1/k)	0.000454
duty (watts)	3600000
specific gravity	0.99
c (J/kg.K)	4176

Q (lit/m)	23.71
Q (kg/h)-API521	1422

$$q = \frac{av \times \emptyset}{1000 \times d \times C}$$

$$q = \frac{0.000454 \times 3600000 \times 60000}{1000 \times 0.99 \times 4176} = 23.71 \text{ lit/min}$$

PSV-5058

Heat Exchanger E-2024 Tube Rupture

Venting Required (Ws) = 2.463× (d ^ 2) × (ΔP × ρV/10) ^ 0.5

Parameter	Unit	Value
Tube ID (d)	mm	28.5
ΔP	bar	9.5
Gas Density (ρV)	Kg/m^3	20.47

Ws = 2.463× (28.5 ^ 2) × (9.5 × 20.47/10) ^ 0.5 = 8822.15 kg/hr.

PSV-5058

Heat Exchanger E-5001 Tube Rupture

Venting Required (Ws) = 2.463× (d ^ 2) × (ΔP × ρV/10) ^ 0.5

Parameter	Unit	Value
Tube ID (d)	mm	27.53
ΔP	bar	2.44
Gas Density (ρV)	Kg/m^3	3.37

Ws = 2.463× (27.53 ^ 2) × (2.44 × 3.37/10) ^ 0.5 = 1692.73 kg/hr.

PSV-5179/5180

Heat Exchanger E-5002 Tube Rupture

Venting Required (Ws) = 2.463× (d ^ 2) × (ΔP × ρV/10) ^ 0.5

Parameter	Unit	Value
Tube ID (d)	mm	21.18
ΔP	bar	1.71
Gas Density (ρV)	Kg/m^3	7.35

Ws = 2.463× (21.18 ^ 2) × (1.71 × 7.35/10) ^ 0.5 = 1239 kg/hr.

PSV-5250/5261

Heat Exchanger E-5023 Tube Rupture

Venting Required (Ws) = 2.463× (d ^ 2) × (ΔP × ρV/10) ^ 0.5

Parameter	Unit	Value
Tube ID (d)	mm	22.1
ΔP	bar	18.84
Gas Density (ρV)	Kg/m^3	9.74

Ws = 2.463× (22.1 ^ 2) × (18.84 × 9.74/10) ^ 0.5 = 5153 kg/hr.

PSV-5250/5261

Heat Exchanger E-5003 Tube Rupture

Venting Required (Ws) = 2.463× (d ^ 2) × (ΔP × ρV/10) ^ 0.5

Parameter	Unit	Value
Tube ID (d)	mm	14.83
ΔP	bar	0.5
Gas Density (ρV)	Kg/m^3	3.99

Ws = 2.463× (14.83 ^ 2) × (0.5 × 3.99/10) ^ 0.5 = 242 kg/hr.

Governing Scenarios

PSV-5058/5059/5060/5061

1. The overall relieve amount of the T5001 overhead is equal to the amount into condenserAE5004 which is 112490kg/h.
2. Tube rupture scenario for both heat exchangers E-5001 and E-5024 would result in venting flowrate of 8822 + 1692 = 10514 kg/hr.
3. By comparison between the relief load of these scenarios, the governing scenario is reflux failure.

PSV-5179/5180

1. The overall relieve amount of the T5002 overhead is equal to the amount into condenser AE5005 which is 418559kg/h,
2. Tube rupture scenario for heat exchangers E-5002 would result in venting flowrate 1239 kg/hr.
3. By comparison between the relief load of these scenarios, the governing scenario is reflux failure.

PSV-5250/5251/5261

1. The overall relieve amount of the T5003 overhead is equal to the amount into condenser E5002 1/2/3/4 which is 440751kg/h.
2. Tube rupture scenario for both heat exchangers E-5023 and E-5003 would result in venting flowrate of 242 + 5153 = 5395 kg/hr.
3. By comparison between the relief load of these scenarios, the governing scenario is reflux failure.

PSV-2494

1. The relief load for tube rupture scenario is 3387.18 kg/hr.
2. Also, the hydraulic expansion is an applicable scenario. Here is the calculation for the hydraulic expansion scenario.

Parameters	value
av (1/k)	0.000454
duty (watts)	6500000
specific gravity	0.99
c (J/kg.K)	4176

Q (lit/m)	42.82
Q (kg/h)-API521	

3. By comparison between the relief load of these scenarios, the governing scenario is tube rupture.

PSV-3143/3146/3149

1. The relief load for tube rupture scenario is 24000 kg/hr.
2. Also, the hydraulic expansion is an applicable scenario. Here is the calculation for the hydraulic expansion scenario.

Parameters	value
av (1/k)	0.000454
duty (watts)	44300000
specific gravity	0.99
c (J/kg.K)	4176

Q (lit/m)	291.88
Q (kg/h)-API521	

3. By comparison between the relief load of these scenarios, the governing scenario is tube rupture.

Practice

In a HAZOP meeting tube rupture scenario was suggested for methanol reactors. Causes could be pressure drop differences, leak as a result of corrosion, or both. Investigate the matter and check if the existing PSVs could handle such relief load as a result of tube rupture.

Let's check if this scenario is applicable.

High-pressure operating pressure is 79.5 barg

Low-pressure operating pressure is 33.7 barg

Required Pressure = 79.5 × 10/13 = 61.15 barg , So the low-pressure side pressure should be minimum 61.15 barg so that tube rupture does not occur. So this scenario is applicable.

Parameter	Value	Unit
Tube Inner Diameter (ID)	57.5	
Differential pressure of high-pressure side and low side (△P)	45.8	
Gas density (ρV)	17.9	Kg/m^3

Ws = 2.463× (d ^ 2) × (ΔP × ρV/10) ^ 0.5

Ws = 2.463× (57.5 ^ 2) × (45.8 × 17.9/10) ^ 0.5 = 73732 kg/hr.

So the PSVs which are designed for blocked outlet with venting capacity of 281000 kg/hr. can handle such relief load and is in fact the governing scenario.

Appendix A

The equation for heat exchanger tube rupture for liquid is as follows:

$$Ws = 1.68 \times \rho \times d^2 \times \sqrt{\frac{\Delta P}{\rho}}$$

Parameter	Value	Unit
Heat Exchanger Inner tube Diameter (d)	48.26	mm
Liquid Density (ρ)	683	Kg/m^3
Differential pressure of high-pressure side and low-side (△P)	74.7	bar

$$Ws = 1.68 \times \rho \times d^2 \times \sqrt{\frac{\Delta P}{\rho}} = 1.68 \times 683 \times 48.26^2 \times \sqrt{\frac{74.7}{683}} = 883601 \frac{kg}{hr}$$