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Wall Dynamics Tutorial

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Marcel Amorós-Martí – Director, California Office Lead ioMosaic Corporation

- ▶ B.S. and M.S. in Chemical Engineering
- ▶ Technical Expertise includes:
 - ▶ Pressure Relief and Flare Systems (PRFS)
 - ▶ Consequence Analysis
 - ▶ Facility Siting and Quantitative Risk Assessment (QRA)
 - ▶ Process Safety Management (PSM)
 - ▶ Process Hazard Analysis (PHA)
 - ▶ Layer Of Protection Analysis (LOPA)
 - ▶ Design and Verification of Safety Instrumented Systems (SIS)
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The purpose of this presentation is to address the following topics

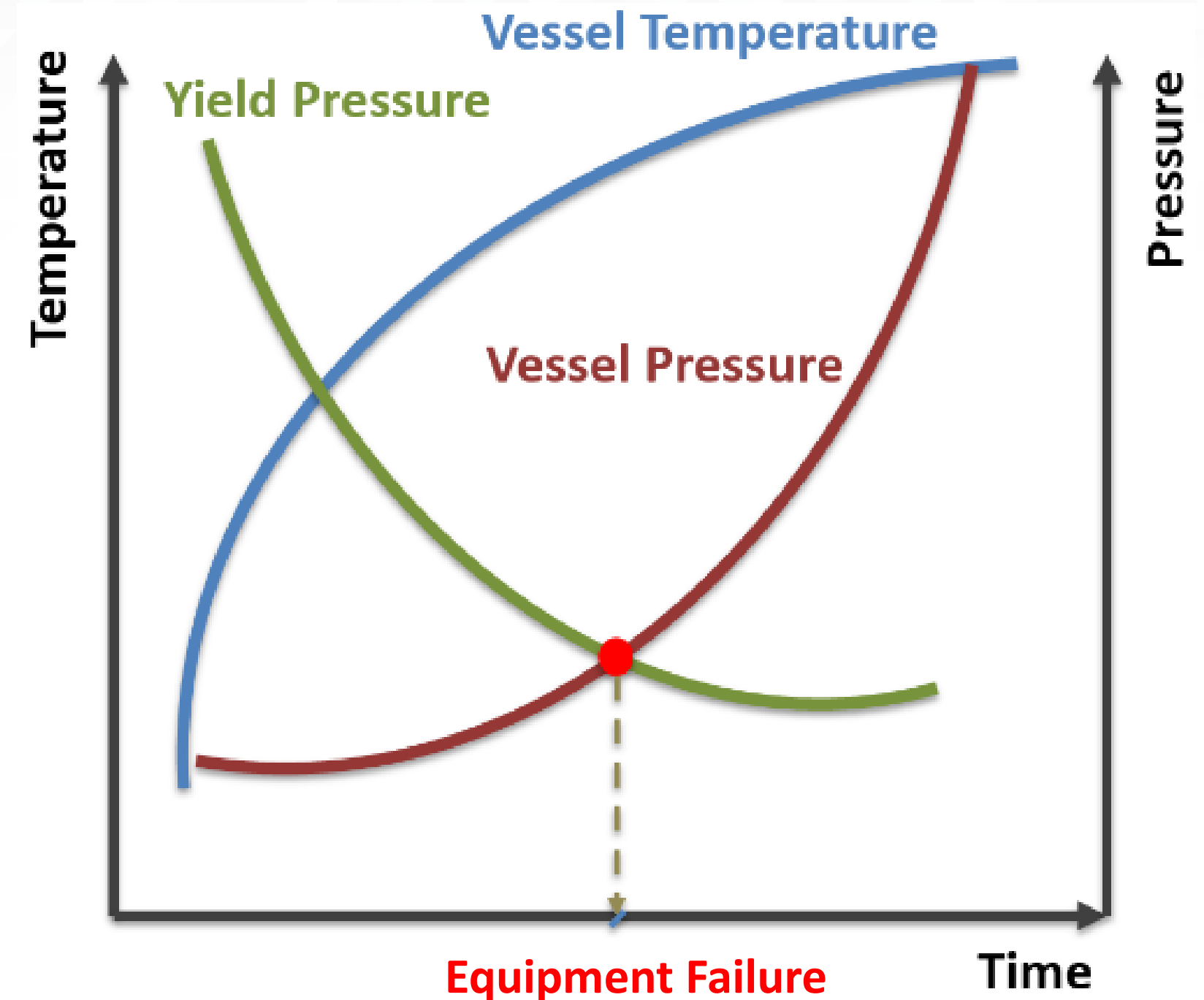
- ▶ Evaluation of vessel and piping wall temperatures using the fundamental heat transfer equation outlined in API Standard 521
- ▶ Advantages and characteristics of the wall segmentation approach implemented in Process Safety Office[®] SuperChems[™]
- ▶ Application of the wall dynamics approach in SuperChems[™] via 2 case studies
 - ▶ Case 1 – Pressure Vessel
 - ▶ Case 2 – Low-pressure Atmospheric Tank

Wall Dynamics Approach Basis



A typical scenario that is almost always considered is the exposure of an equipment to a flame jet or pool fire

- ▶ Process vessels and piping components may fail because of excessive deviations in internal or external pressure, and/or wall temperatures
 - ▶ Equipment wall temperature increases
 - ▶ Yield and tensile strength of the vessel walls decrease
 - ▶ Resistance to internal pressure decreases while pressure vessel increases



Source: ioMosaic Corporation

The fundamental heat transfer equation outlined in API Standard 521 is the basis for the wall dynamics approach

$$q_{absorbed} = \sigma(\alpha_{surface} \times \epsilon_{fire} \times T_{fire}^4 - \epsilon_{surface} \times T_{surface}^4) + h(T_{gas} - T_{surface})$$

- $q_{absorbed}$ is the absorbed heat flux from the fire, in W/m²
- σ is the Stefan-Boltzman constant, which is 5.67x10⁻⁸ W/m²K⁴
- $\alpha_{surface}$ is the equipment absorptivity, dimensionless
- ϵ_{fire} is the fire emissivity, dimensionless
- T_{fire} is the fire temperature, in K
- $\epsilon_{surface}$ is the equipment emissivity, dimensionless
- $T_{surface}$ is the equipment temperature, in K
- h is the convection heat transfer coefficient of air/fire in contact with the equipment, in W/m²K
- T_{gas} is the temperature of air/fire in contact with the equipment surface, in K

Source: API Standard 521, 2020, "Pressure-relieving and Depressuring Systems", 7th Edition

API Standard 521 provides recommended values for jet fires when data is not available

Parameter	Description	Flame Jet			
		Surface Average Heat Flux		Local Peak Heat Flux	
Leak rates		>2 kg/s (Large Jet)	≤2 kg/s (Small Jet)	>2 kg/s (Large Jet)	≤2 kg/s (Small Jet)
ϵ_f	Flame emissivity	0.33	NA	0.87	0.75
ϵ_w	Wall emissivity	0.75	NA	0.75	0.75
α_w	Wall absorptivity	0.75	NA	0.75	0.75
h	Convective heat transfer coefficient between equipment and surrounding air	40 W/m ² K	NA	100 W/m ² K	90 W/m ² K
T_g	Temperature of combustion gases flowing over the surface	1,173 K (900°C)	NA	1,473 K (1,200°C)	1,373 K (1,100°C)
T_f	Fire temperature	1,373 K (1,100°C)	NA	1,473 K (1,200°C)	1,373 K (1,100°C)
q_f	Fire heat flux	100 kW/m ²	NA	350 kW/m ²	250 kW/m ²
q_w	Absorbed heat flux	85 kW/m ²	NA	290 kW/m ²	210 kW/m ²

Source: API Standard 521, 2020, "Pressure-relieving and Depressuring Systems", 7th Edition

API Standard 521 also provides recommended values for open pool fires when data is not available

Parameter	Description	Pool Fire	
		Surface Average Heat Flux	Local Peak Heat Flux
ϵ_f	Flame emissivity	0.75	0.75
ϵ_w	Equipment emissivity	0.75	0.75
α_w	Equipment absorptivity	0.75	0.75
h	Convective heat transfer coefficient between equipment and surrounding air	20 W/m ² K	20 W/m ² K
T_g	Temperature of combustion gases flowing over the surface	873 K (600°C)	1,323 K (1,050°C)
T_f	Fire temperature	1,023 K (750°C)	1,323 K (1,050°C)
q_f	Fire heat flux	60 kW/m ²	150 kW/m ²
q_w	Absorbed heat flux	45 kW/m ²	120 kW/m ²

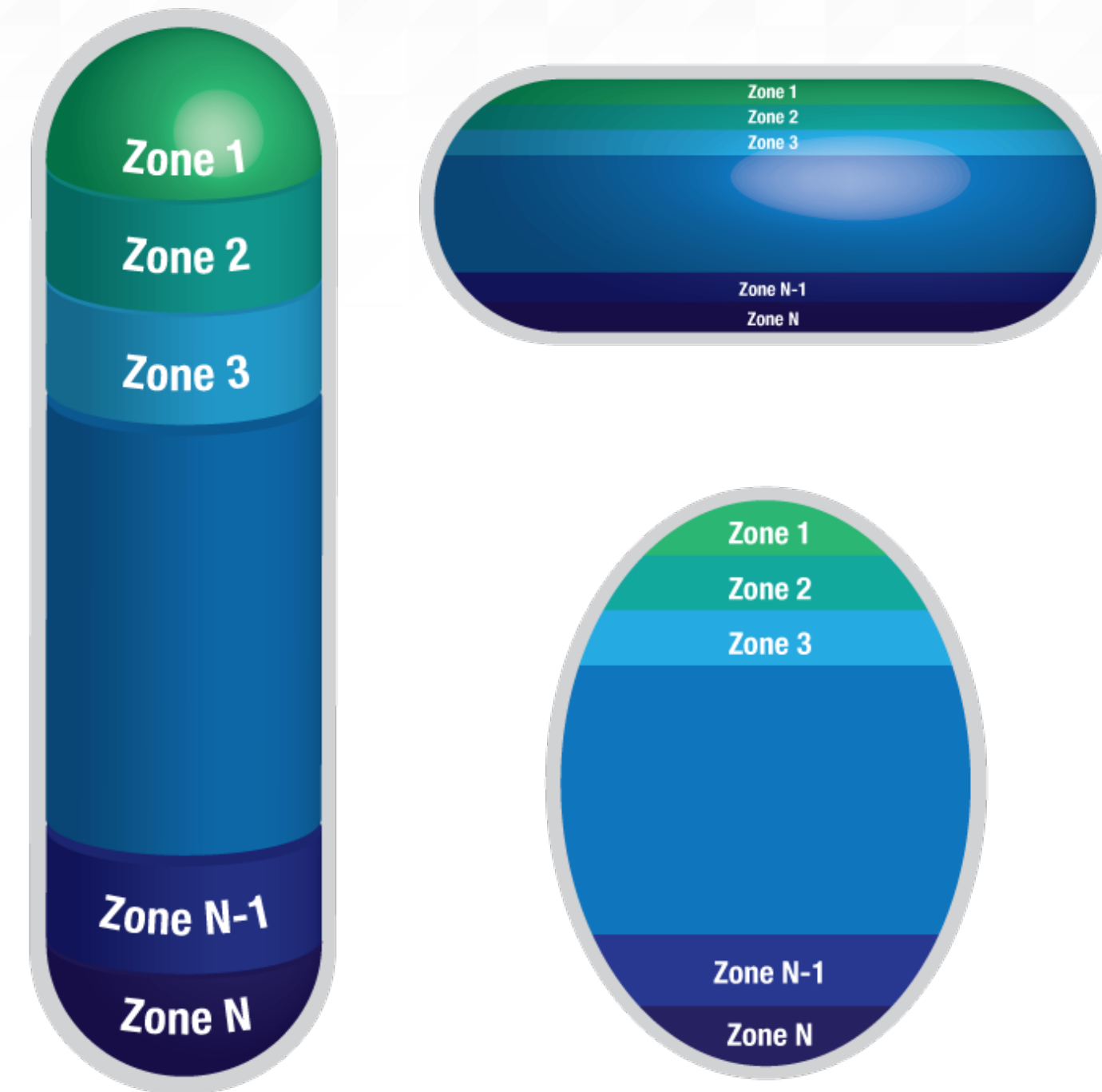
Source: API Standard 521, 2020, "Pressure-relieving and Depressuring Systems", 7th Edition

Heat transfer is calculated as a function of time and includes several options

- ▶ Heat transfer phenomena is calculated as a function of time
 - ▶ From ambient to/from wall segment
 - ▶ From wall segment to wall segment
 - ▶ From wall segment to/from fluid
- ▶ Ambient to wall segment heat transfer options include insulation, solar heating, rain, water sprays, pool fires and jet fires
- ▶ Wall segment to fluid heat transfer include radiation, natural convection, forced convection, film boiling and pool boiling

A unique aspect of SuperChems™ is how a vessel is sliced into segments

- ▶ No limit to the number of segments that the user can define
- ▶ Allows modeling flame jet impingement, and/or the effect of an open pool fire in different vessel sections / segments
- ▶ Ability to represent a wide variety of vessel shapes and heads, including composite vessels



Source: Melhem, G.A., Gaydos, D., 2014, "Properly Calculate Vessel and Piping Wall Temperatures During Depressuring and Relief", Process Safety Progress (Vol. 34, No.1)

Wall dynamics approach in SuperChems™ is a very powerful tool

- ▶ Ability to predict the fluid dynamics of equipment containing liquids, vapors, and multiphase flows with or without chemical reactions
 - ▶ Including the Design Institute for Emergency Relief Systems (DIERS) technology to estimate vapor-liquid disengagement
- ▶ Ability to specify equipment internals using a variety of materials of construction
- ▶ Ability to connect multiple equipment and connect relief and process lines to the top and/or bottom of equipment
- ▶ Ability to include incoming and outgoing fluid streams

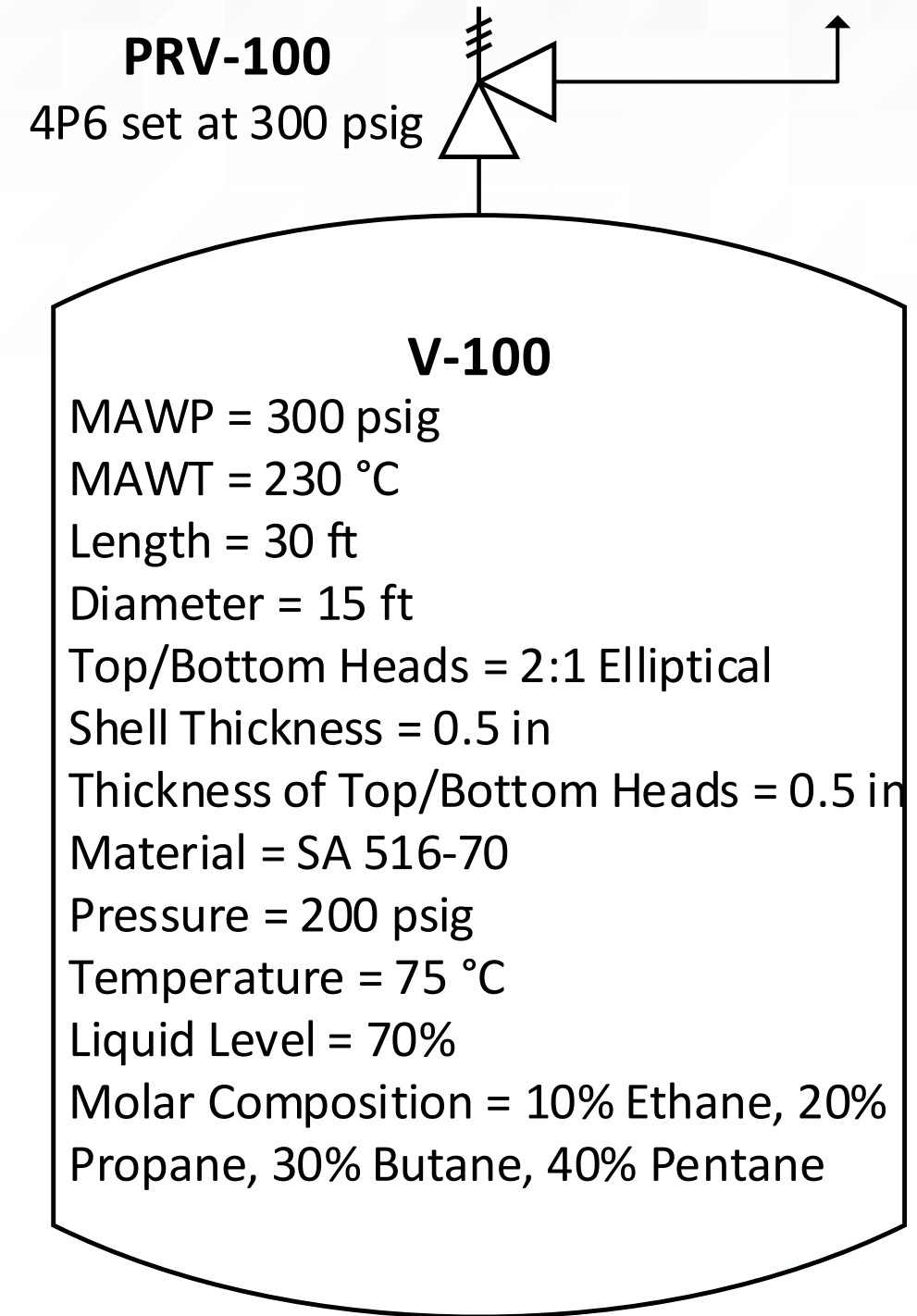
Case Studies in SuperChems™

Case 1 – Pressure Vessel



Vessel V-100 is protected by PRV-100 and exposure to an open pool fire has been identified as a contingency of concern

- ▶ Use of API Standard 521 recommended values for an open pool fire because no data is available on the pool fire characteristics
- ▶ The properties of the vessel and relief device under analysis are illustrated to the right
- ▶ SuperChems™ new visual interface is used to model this system



Source: ioMosaic Corporation

What are the necessary objects in SuperChems™?

- Under options, select the applicable “Study Type”
 - For this type of analysis, select “Pressure Relief and Flare System”
- Next, create 1 Scenario and name it appropriately
- 6 objects will appear under Case 1 scenario:
 - For this type of calculation, we only need the following objects: Mixture, Vessel, Piping Layout, and Pressure Relief Valve

Study Type

<input checked="" type="checkbox"/> Pressure Relief and Flare System	<input type="checkbox"/> Dynamic Flowsheet Simulation
<input type="checkbox"/> Consequence Modeling	<input type="checkbox"/> Quantitative Risk Analysis
<input type="checkbox"/> Reactive Modeling	<input type="checkbox"/> All

User List

- DEFAULT
- Users Group Meeting

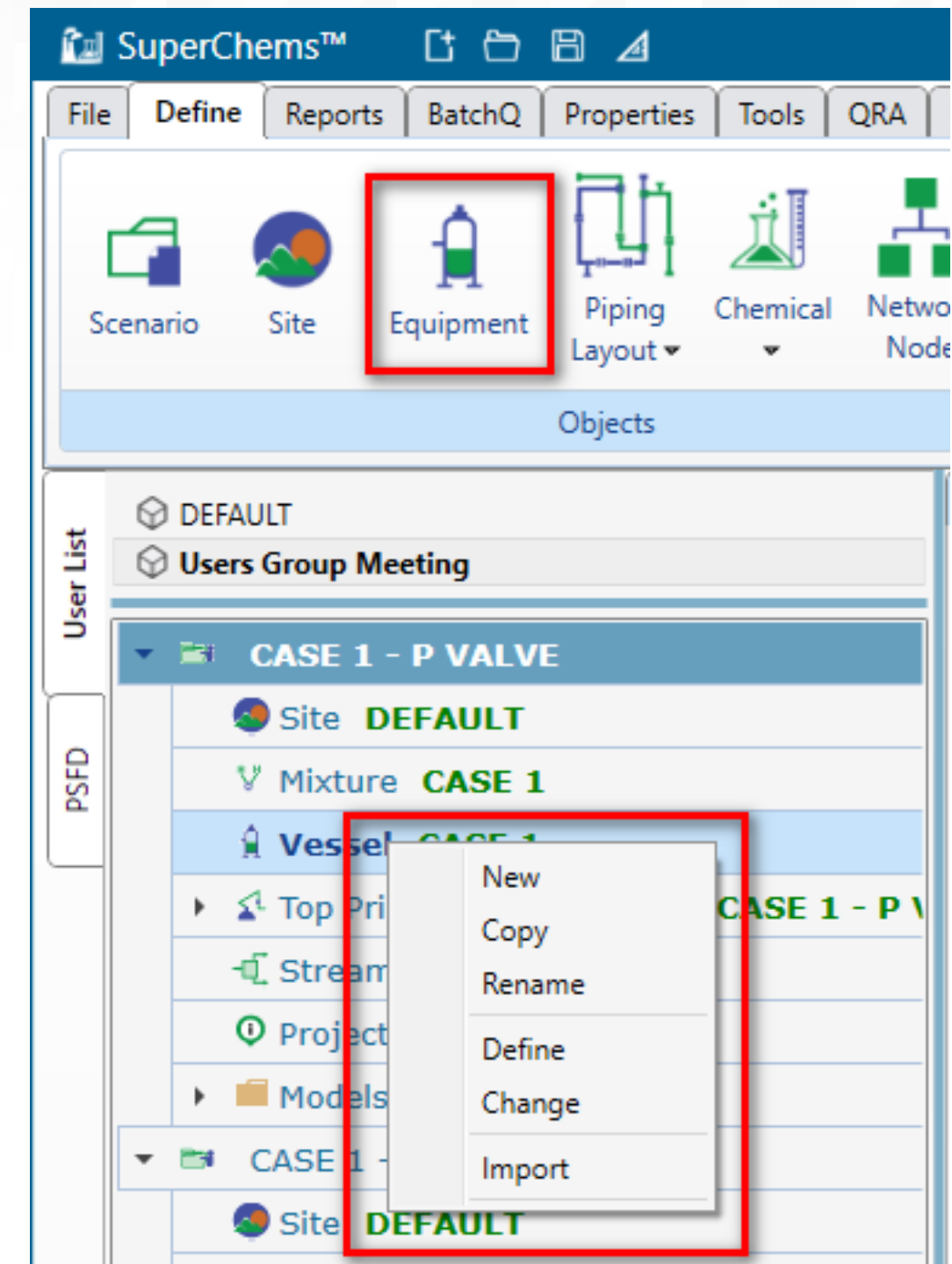
PSFD

- CASE 1
 - Site DEFAULT
 - Mixture CASE 1
 - Vessel CASE 1
 - Top Primary Piping Layout CASE 1 - P...
 - Stream [NO FLOW]
 - Project Data DEFAULT
 - Models (1)
- CASE 1 - MITIGATION

Source: Process Safety Office® SuperChems™ - ioMosaic Corporation

How should a vessel be defined?

- ▶ Right click under “Vessel”, select “New”, and name the Vessel appropriately
 - ▶ Note that SuperChems™ will automatically assign the new vessel to the scenario of interest
- ▶ Other options include:
 - ▶ Copy, Rename, Define, Change, Import
- ▶ A vessel can also be defined under “Define” tab at the top, and selecting “Equipment”



Source: Process Safety Office® SuperChems™ - ioMosaic Corporation

What are the necessary specifications?

- ▶ Design pressure
- ▶ Design Temperature
- ▶ Vessel Type
- ▶ Length
- ▶ Inside Diameter
- ▶ Shell Thickness
- ▶ Elevation
- ▶ Head Type
- ▶ Wall Thickness

CASE 1

Specification Options Report Comments Geometry and Stress Toolbox

CASE 1

Description	CASE 1 Vessel	P&IDs	NA
Location	NA	Equipment type	Vessel
Manufacturer	NA	Vessel built per	ASME Section VIII
Serial number	NA	Applicable relief code	API 520/521

Pressure

Design pressure	300	psig
Vacuum pressure	-14.7	psig
Normal operating pressure	200	psig
Maximum pressure	200	psig

Temperature

Design temperature	230	°C
Minimum temperature	-29	°C
Normal operating temperature	75	°C
Maximum temperature	75	°C

Physical Dimensions

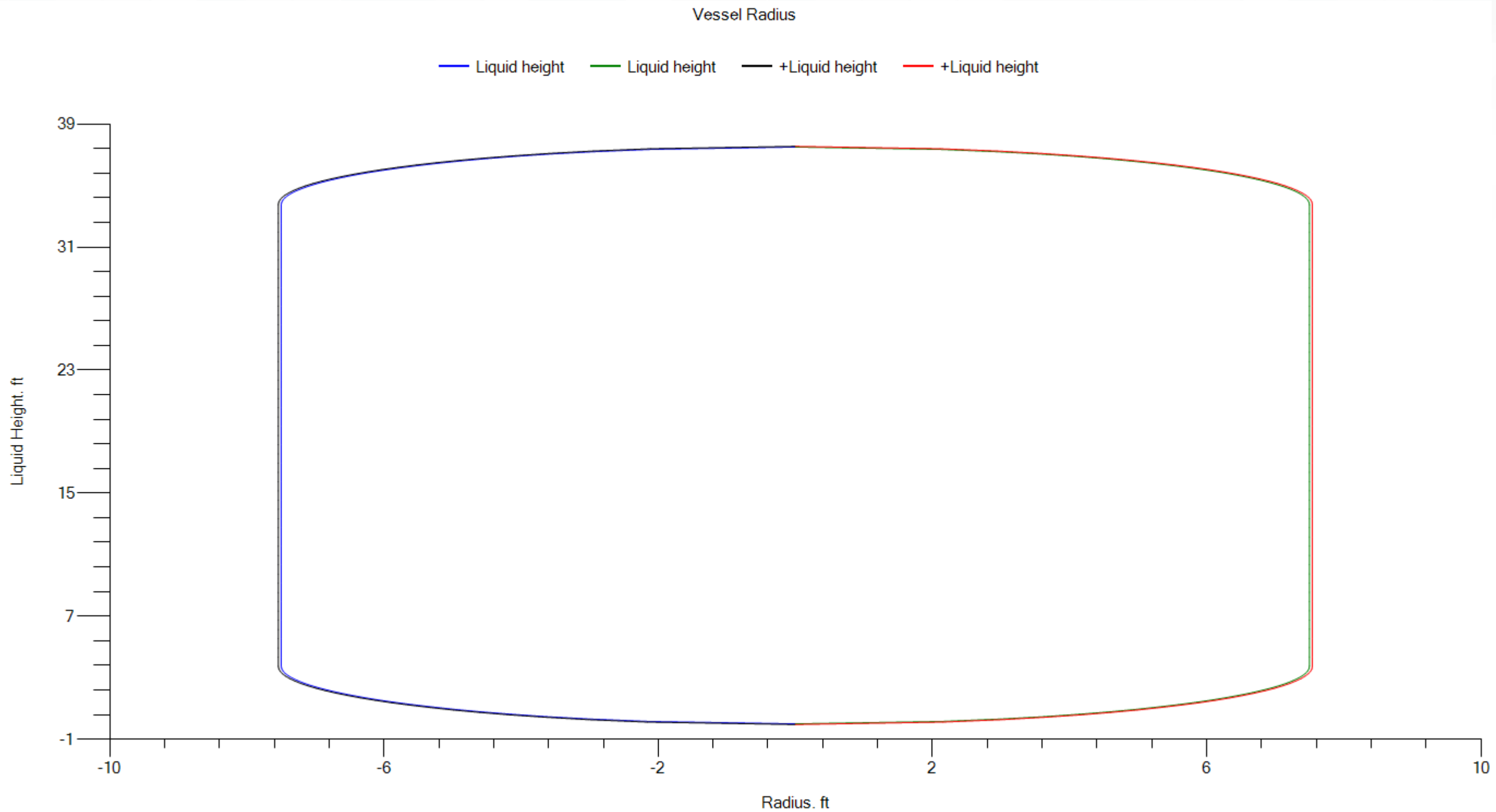
Vessel type	Vertical Cylindrical	Material of construction	STEEL
Length	30	Actual material	CARBON STEEL, C-Mn-Si
Inside diameter	15	Internals/User defined mass	0 lb
Shell thickness	0.0417	Liquid pool bottom elevation	1 ft
		Grade bottom elevation	1 ft

Head

	Top	Bottom
Type	Elliptical 2:1	Elliptical 2:1
Wall thickness	0.0417 ft	0.0417 ft

Source: Process Safety Office® SuperChems™ - ioMosaic Corporation

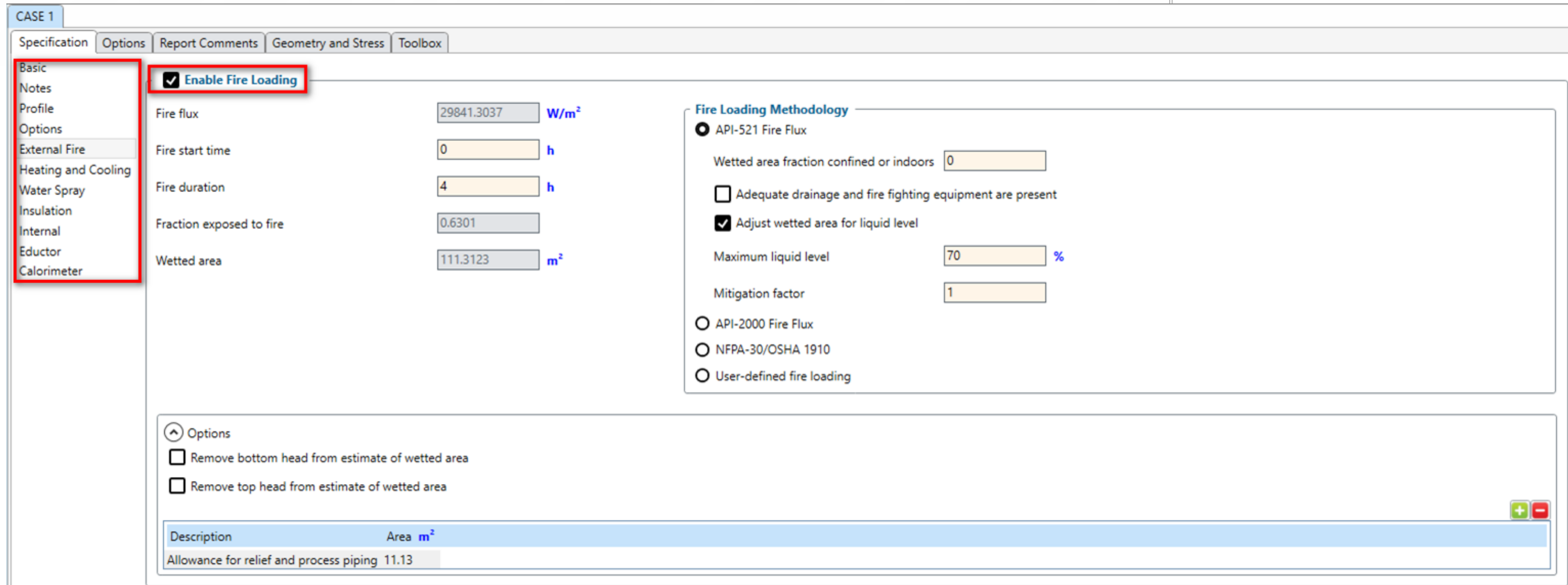
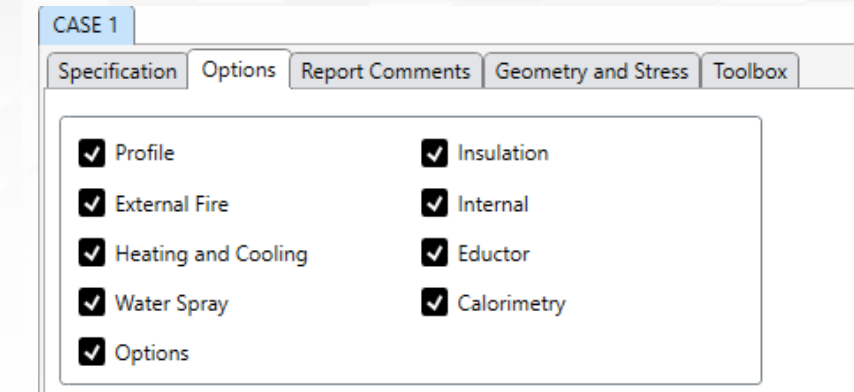
Always check the vessel geometry under “Geometry and Stress” tab to ensure the vessel dimensions



Source: Process Safety Office® SuperChems™ - ioMosaic Corporation

Vessel specification tabs appear based on the options selected

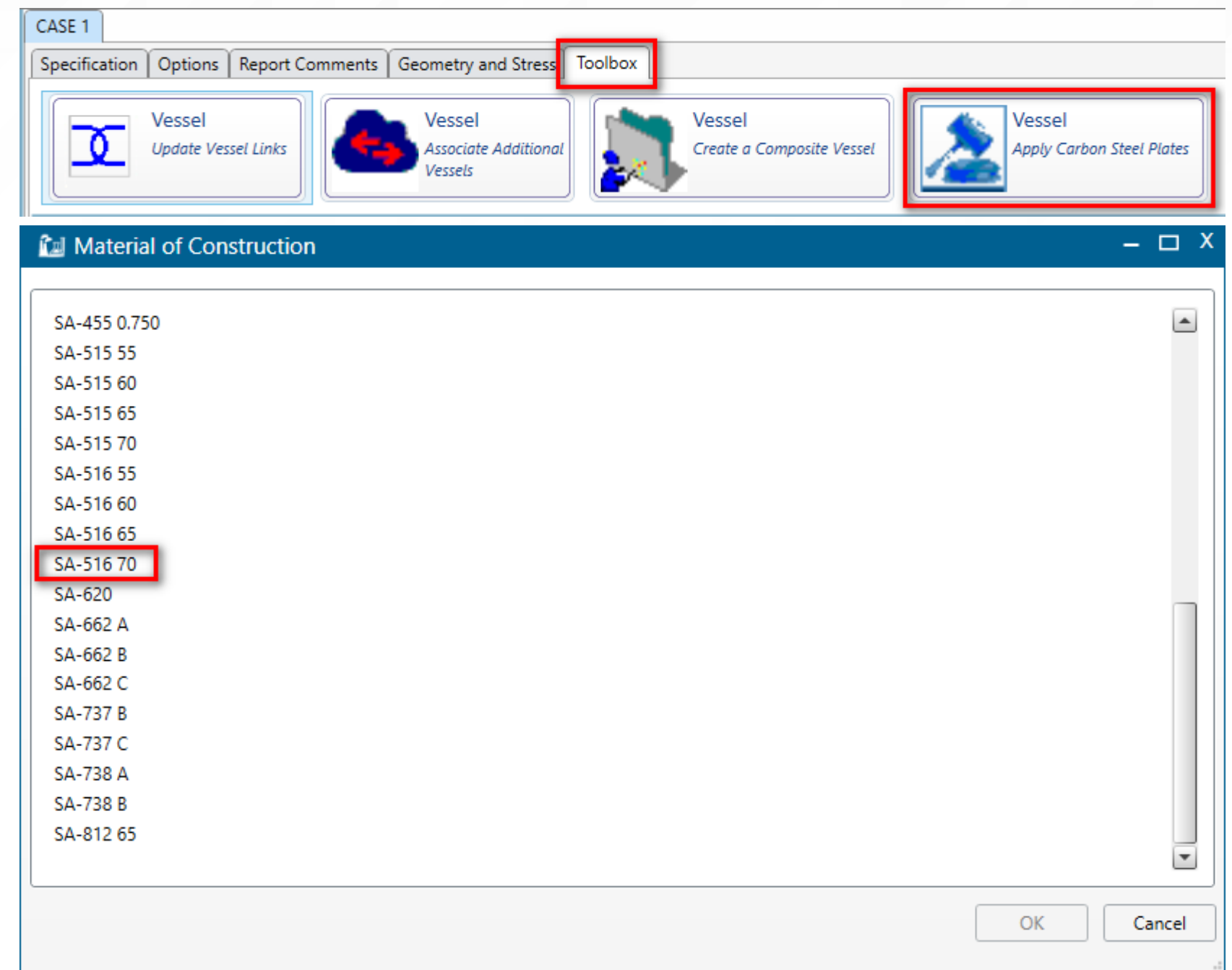
- ▶ To perform the wall dynamics, check “Enable Fire Loading”



Source: Process Safety Office® SuperChems™ - ioMosaic Corporation

Apply the appropriate Carbon Steel Plate and Allowable Stress Curve

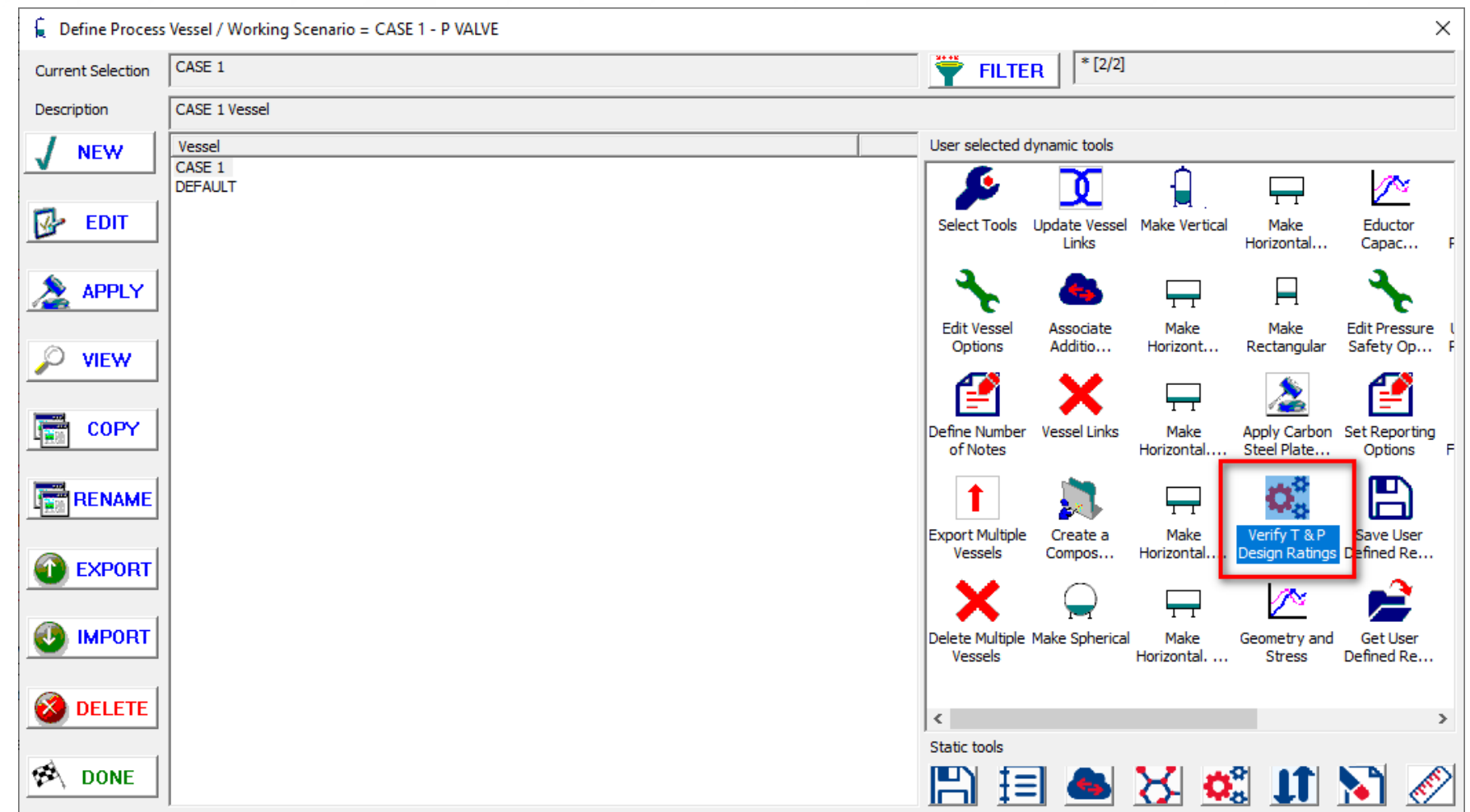
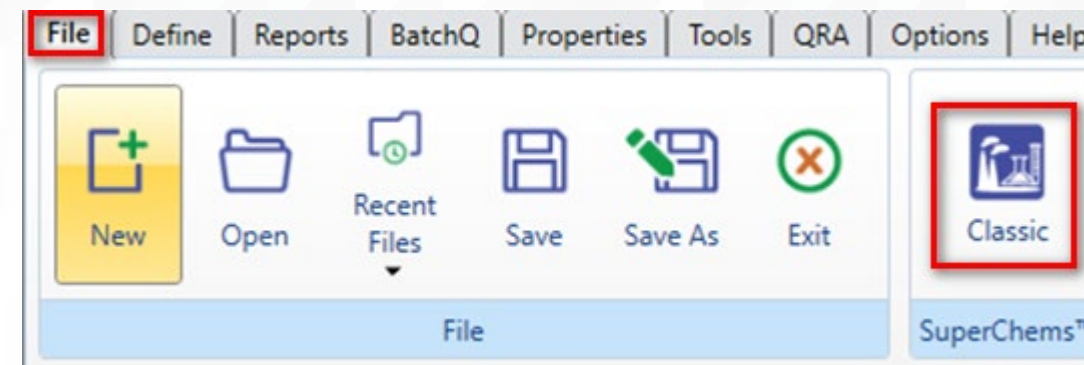
- ▶ Go to “Toolbox” tab, and click the icon “Vessel, *Apply Carbon Steel Plates*”
- ▶ SuperChems™ has prepopulated several carbon steel plate and allowable stress curves
- ▶ In this example, SA-516 Grade 70 Carbon Steel is applied based on the vessel material of construction



Source: Process Safety Office® SuperChems™ - ioMosaic Corporation

Temperature and pressure ratings can be verified by switching to SuperChems™ classic

- Under “File” tab, click the “Classic” icon
- Under the Vessel object, click the “Verify T&P Design Ratings” icon



Source: Process Safety Office® SuperChems™ - ioMosaic Corporation

ioMosaic uses 2/3 of the Ultimate Tensile Strength (UTS) as a conservative limit based on NFPA 68 Section 5.3.3.1

Vessel Name	CASE 1
Vessel Type	Vertical Cylindrical; User defined heads
Vessel Top Head Type	Elliptical 2:1
Vessel Bottom Head Type	Elliptical 2:1

** MATERIAL OF CONSTRUCTION SPECIFICATIONS. OBTAIN THIS INFORMATION FROM ASME TABLES	
Actual Material of Construction Description	CARBON STEEL, C-Mn-Si
Databank material of construction used for thermal	STEEL <input type="text" value="STEEL"/>
Specification	SA-516
P-No, G-No, or S-No	P1, G2
Product Form	Steel Plate or Sheet
Grade	70
Note 1	See Note 17 in ASME Boiler and Pressure Vessel Code. Page 280
Note 2	External pressure chart 5-UCS-28.2
Minimum Temperature. °C	-28.89
Minimum yield strength. psia	38000.00
Minimum tensile strength. psia	70000.00

Allowable Stress Basis	ASME													
Temperature. °C	-28.89	343.33	371.11	398.89	426.67	454.44	482.22	510.00	537.78					
Allowable Stress. psia	1.750E+04	1.750E+04	1.660E+04	1.480E+04	1.200E+04	9.300E+03	6.500E+03	4.500E+03	2.500E+03					
Young's Modulus of Elasticity. psia	3.410E+07	3.178E+07	3.119E+07	3.054E+07	2.985E+07	2.911E+07	2.832E+07	2.791E+07	2.748E+07	2.704E+07	2.659E+07	2.613E+07	2.565E+07	
Coefficient of Linear Thermal Expansion. /°C	7.387E-06	1.507E-05	1.590E-05	1.665E-05	1.733E-05	1.795E-05	1.850E-05	1.876E-05	1.900E-05	1.922E-05	1.943E-05	1.963E-05	1.982E-05	
Poisson's Ratio	0.290	0.290	0.290	0.290	0.290	0.290	0.290	0.290	0.290	0.290	0.290	0.290	0.290	

Failure Stress Basis	2/3 UTS													
Temperature. °C	-253.889	37.778	93.333	148.889	204.444	260.000	315.556	343.333	371.111	398.889	426.667	454.444	482.222	
Failure Stress. psia	46666.667	46666.667	46666.667	46666.667	44151.697	41357.285	39121.756	38283.433	37724.551	37165.669	36327.345	35768.463	33253.493	

Source: Process Safety Office® SuperChems™ - ioMosaic Corporation

Defining a mixture object

- Select the basis (Mass or Mole), and then add components by clicking the green button 
- Note that if the “Automatic BIPS Calculation” option is selected, SuperChems™ will automatically apply the Binary Interaction Parameters (BIPS) for us

CASE 1

Mixture Specification | Bips | Graphs | Toolbox

Basic Information


Name: CASE 1

Description: 10% Ethane, 20% Propane, 30% Butane, 40% Pentane

Mixture is soluble in water

Mixture Composition

Mass Mole

Validation Check Automatic BIPS Calculation 

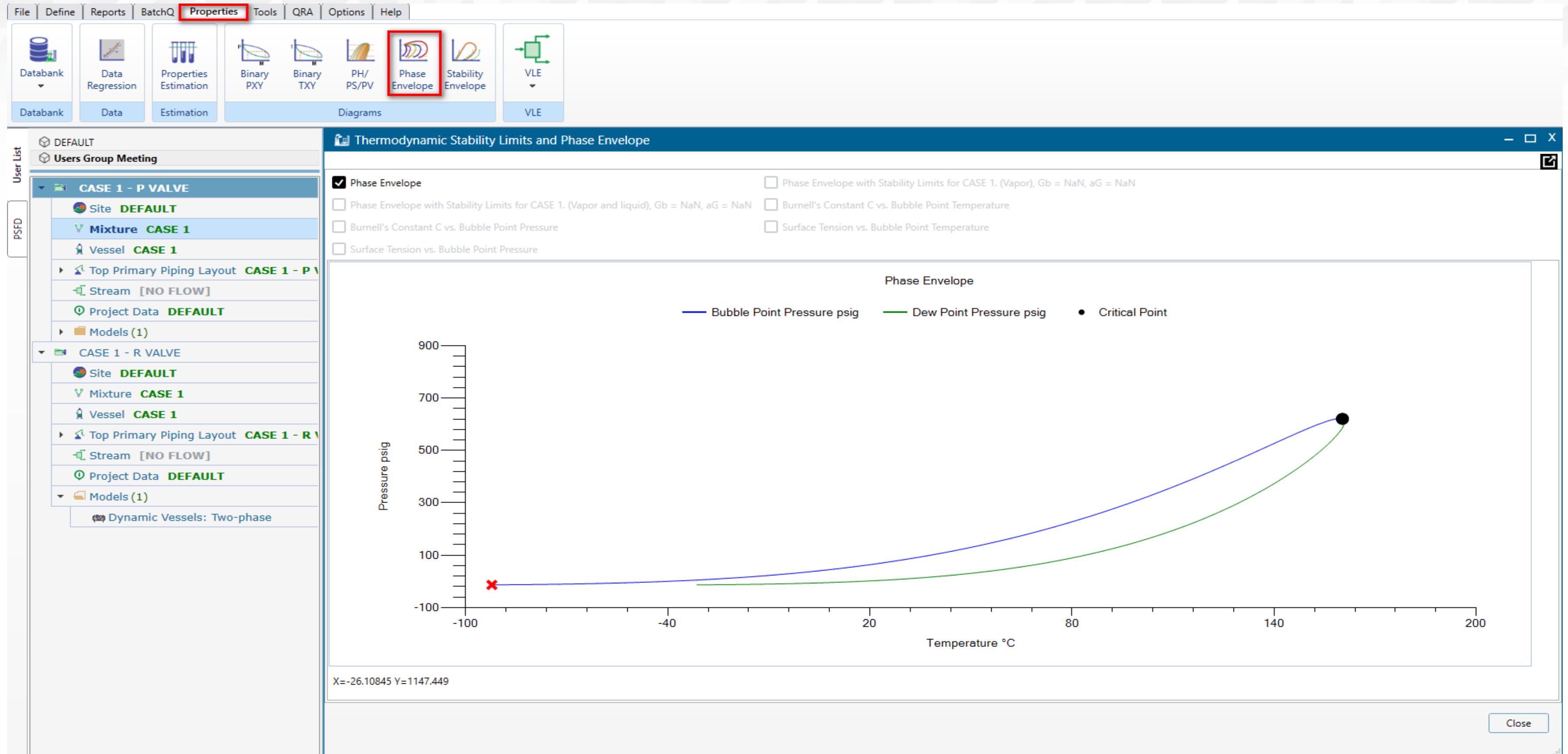
Compound	Formula	ID	MW	Mass Fraction	Mole Fraction	User Composition
ETHANE	C2H6	1	30.070	0.0517	0.1000	0.1000
PROPANE	C3H8	2	44.097	0.1517	0.2000	0.2000
n-BUTANE	C4H10	3	58.123	0.3000	0.3000	0.3000
n-PENTANE	C5H12	4	72.150	0.4965	0.4000	0.4000

Kij	ETHANE	PROPANE	n-BUTANE	n-PENTANE
ETHANE	0	0.00137	0.00706	0.0072
PROPANE	0.00137	0	0.00142	0
n-BUTANE	0.00706	0.00142	0	0
n-PENTANE	0.0072	0	0	0

Lij	ETHANE	PROPANE	n-BUTANE	n-PENTANE
ETHANE	0	-0.01489	-0.02206	0.0016
PROPANE	0.01489	0	-0.03814	0
n-BUTANE	0.02206	0.03814	0	0
n-PENTANE	-0.0016	0	0	0

Source: Process Safety Office® SuperChems™ - ioMosaic Corporation

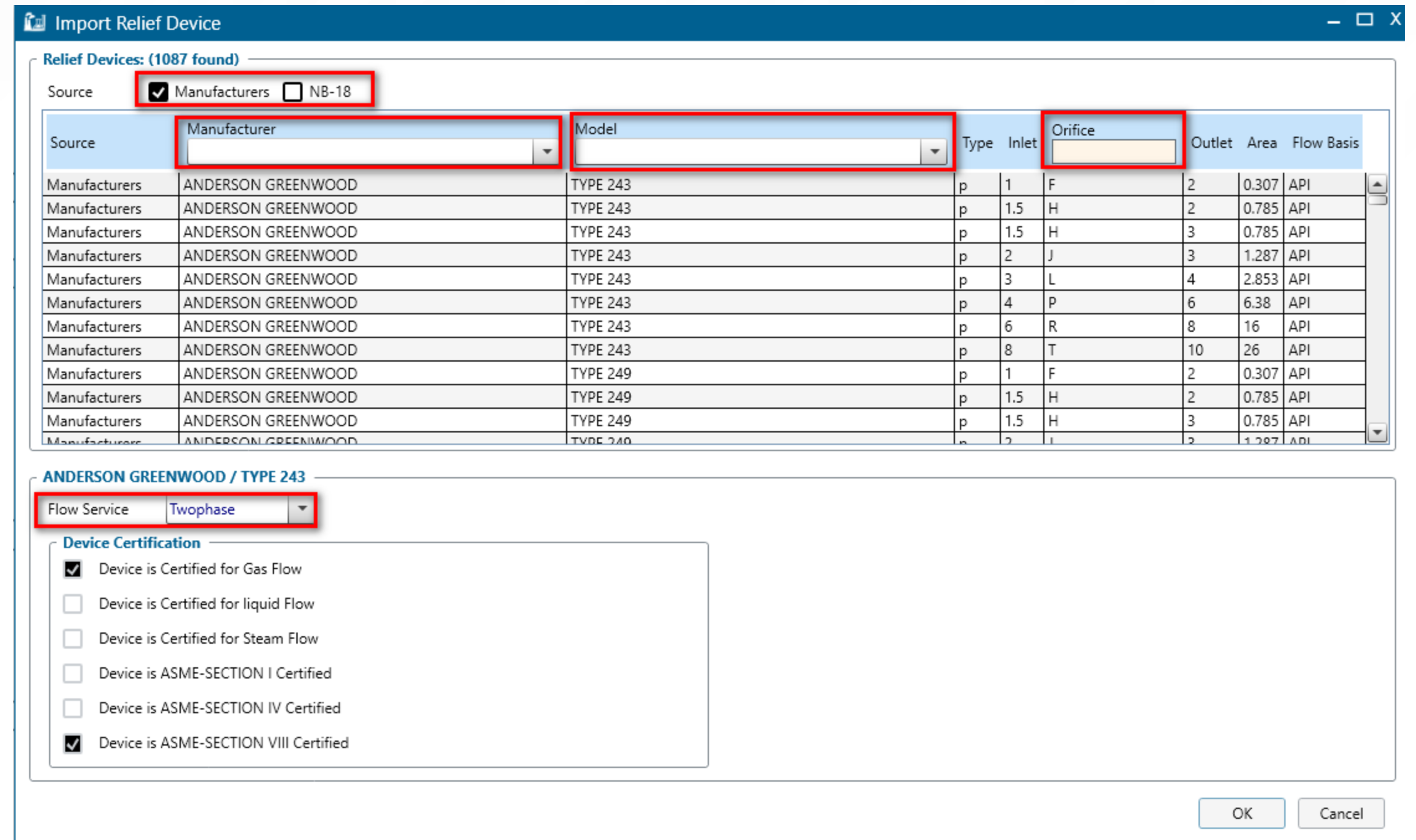
Always ensure the mixture Vapor-Liquid Equilibrium (VLE)



Source: Process Safety Office® SuperChems™ - ioMosaic Corporation

Defining the piping layout and associated pressure relief device objects

- Click on “Settings” and a new window will pop up
- SuperChems™ contains a database with thousands of relief valves to select from
- You can filter by Source, Manufacturer, Model, Orifice, or Flow Service



Source: Process Safety Office® SuperChems™ - ioMosaic Corporation

In this example, an Anderson Greenwood 4P6 pilot pressure relief valve is selected

- SuperChems™ populates almost all required fields
- You still need to specify the Set Pressure and Reseat Pressure

CASE 1 - P VALVE

PRV Specifications | Low Pressure | Lift vs. Overpressure | Lift vs. Backpressure | SDOF Parameters | Data Sheet | Cd Calculator

CASE 1 - P VALVE

Description: Anderson Greenwood Series 200/400/500/700
 Equipment protected: Case 1
 Manufacturer: ANDERSON GREENWOOD
 Location:
 Associated RD:
 PRV numeric ID: 0
 Service: Gas
 Design type: Pilot
 P & ID:
 Discharge Location:
 Model number: TYPE 243
 Serial number: NA
 Spring number: NA

Inlet Flange
 Pressure rating: 599.9977 psig Class: ANSI

Outlet Flange
 Pressure rating: 599.9977 psig Class: ANSI

Inlet Schedule

Name	Value	Unit
Nominal pipe size	4	
Piping schedule	40	
Outside Diameter	0.375	ft
Inside Diameter	0.3355	ft
Wall Thickness	0.01975	ft
Flow Area	0.00821	m ²

Pipe Info

Outlet Schedule

Name	Value	Unit
Nominal pipe size	6	
Piping schedule	40	
Outside Diameter	0.55208	ft
Inside Diameter	0.50542	ft
Wall Thickness	0.02333	ft
Flow Area	0.01864	m ²

Pipe Info

Device Certification

Certified for gas flow
 Certified for liquid flow
 Certified for steam flow
 Modulating valve
 ASME-SECTION I certified
 ASME-SECTION IV certified
 ASME-SECTION VIII certified
 Designated as spare

Lifting Characteristics

Minimum lift: 0.0083 ft Maximum lift: 0.0333 ft
 Device has a restricted lift
 Restricted lift: 0 ft Critical lift: 0.0594 ft
 Available flow area: 0 %

Use K-Based pipe solver (Advanced users only)

Flow

Flow type	Gas/Vapor	Liquid	Two phase
Discharge coefficient	0.975	0.62	0.85
Overpressure curve	OP-1	OP-1	OP-1
Backpressure curve	BP-1	BP-1	BP-1
Slip ratio multiplier			1
Slip ratio exponent			0.0001

Settings

Actual orifice flow area: 0.0041 m² Letter: P
 Design orifice flow area: 0.0041 m² Set pressure: 300 psig
 Flow area basis: API Reset pressure: 270 psig
 Maximum blowdown: 10 % Actual blowdown: 10 %

Source: Process Safety Office® SuperChems™ - ioMosaic Corporation

In the Piping Layout object, select the applicable segments

- Adjust the elevation of the “1st segment relative to vessel bottom”
 - Account for the length of top / bottom heads
- For this dynamic evaluation, we will only use the pilot 4P6 valve

The screenshot shows the 'CASE 1 - P VALVE' configuration window. The 'Properties' section includes a text field for '1st segment elevation relative to vessel bottom' with the value '37.5' and a unit dropdown set to 'ft'. The 'Available Units' list on the left includes 'PRV CASE 1 - P VALVE'. The 'Selected Units' list on the right also includes 'PRV CASE 1 - P VALVE'. The 'Coefficients' section shows 'CASE 1 - P VALVE Gas/vapor discharge coeff' as 0.975, 'CASE 1 - P VALVE Liquid discharge coefficient' as 0.62, and 'CASE 1 - P VALVE 2phase discharge coefficient' as 0.85. The 'Thermodynamic Flow Path' section has 'Isentropic' selected, and the 'Nozzle Flow Method' section has 'Use VdP integral' selected.

Property	Value
Short description	Case 1 - P Valve
PID/PFD reference	NA
Overall mass flow multiplier for flow dynamics	1
1st segment elevation relative to vessel bottom	37.5 ft
Layout is an open relief path	<input type="checkbox"/>
Layout is a header/network	<input type="checkbox"/>
Use CCF	<input type="checkbox"/>
Use design/derated flow area for PRV	<input type="checkbox"/>

Segment	DEFAULT
PRV	DEFAULT
PRV	CASE 1 - R VALVE
PRV	FLOATING ROOF
PRV	CASE 1 - P VALVE
PRV	CASE 1
Control Valve	DEFAULT
Control Valve	CV - XT 0.52
Compressor	DEFAULT
Pump	DEFAULT
Orifice	DEFAULT
Expander	DEFAULT
RD	1IN2

Property	Value
CdL = 0.62, CdV = 0.975, Cd2P = 0.85	
CASE 1 - P VALVE Gas/vapor discharge coeff	0.975
CASE 1 - P VALVE Liquid discharge coefficient	0.62
CASE 1 - P VALVE 2phase discharge coefficient	0.85

Thermodynamic Flow Path
<input checked="" type="radio"/> Isentropic
<input type="radio"/> Isenthalpic

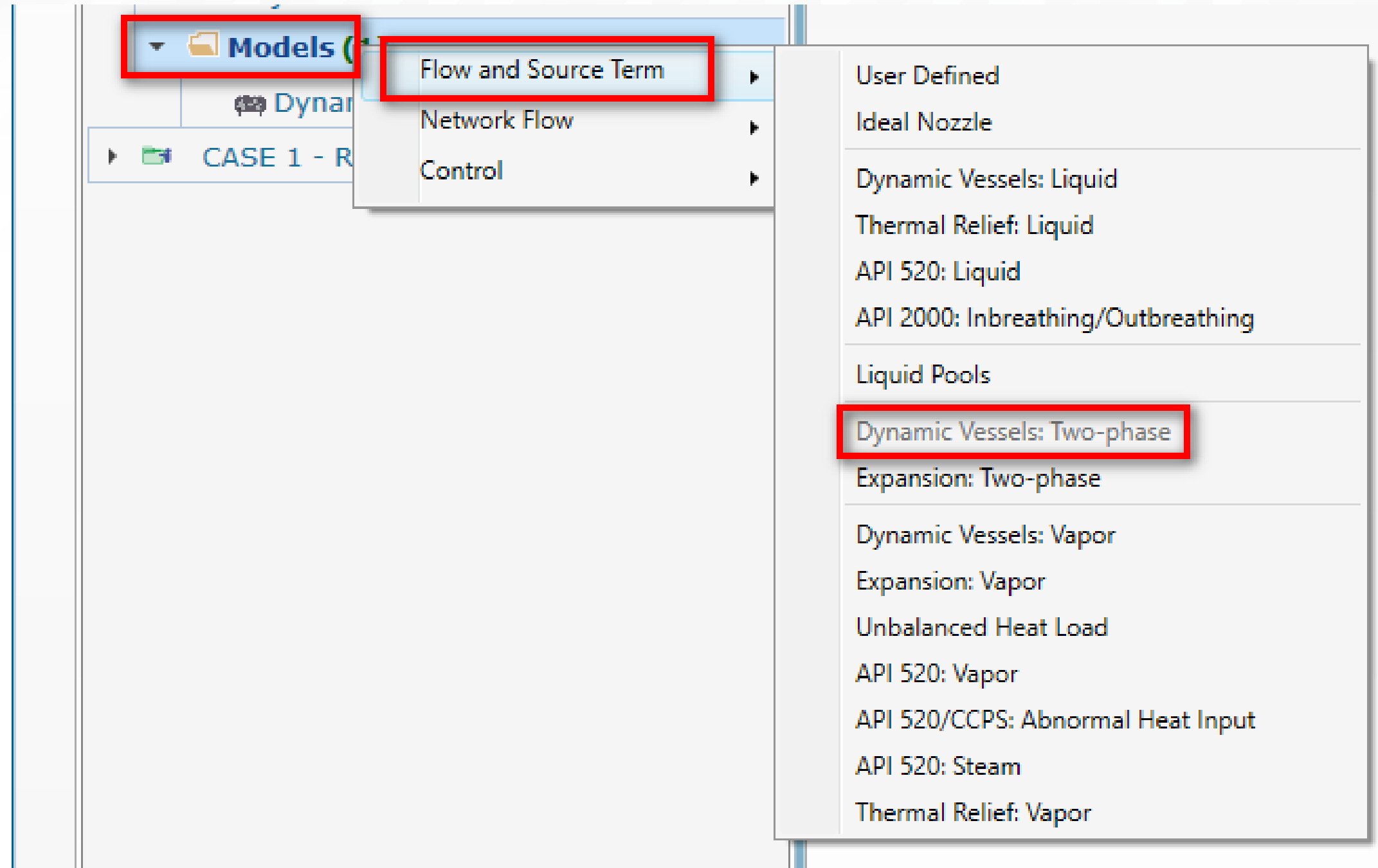
Nozzle Flow Method
<input type="radio"/> Use dH
<input checked="" type="radio"/> Use VdP integral

Selected Units
PRV CASE 1 - P VALVE

Source: Process Safety Office® SuperChems™ - ioMosaic Corporation

Next, identify and apply the correct source term model for the simulation

- ▶ Right click in “Models”
- ▶ Select “Flow and Source Term”
- ▶ Select “Dynamic Vessels: Two-phase”



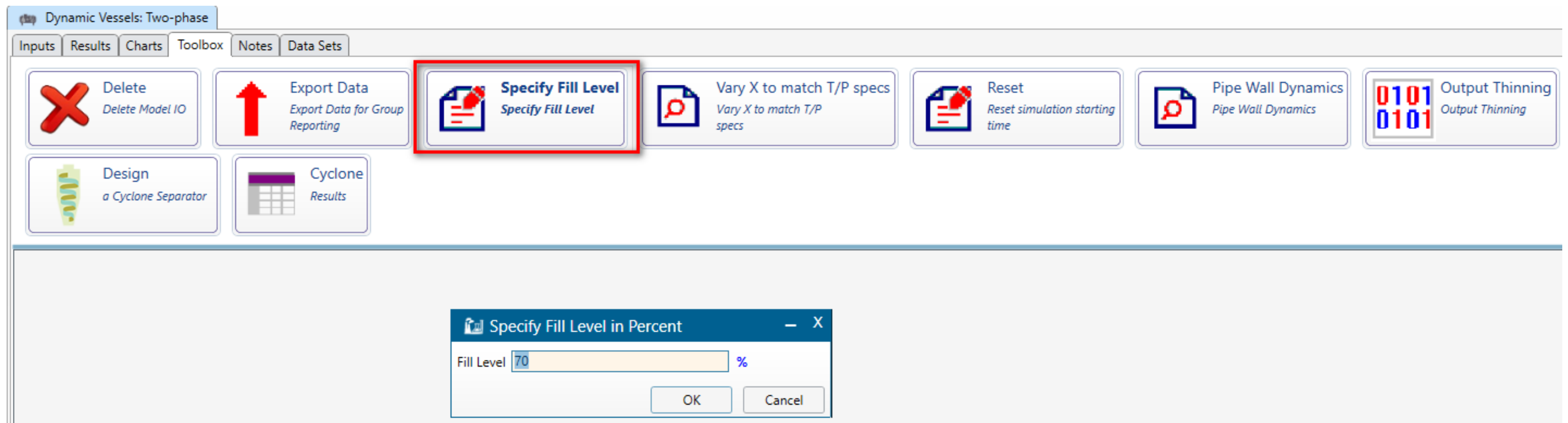
Source: Process Safety Office® SuperChems™ - ioMosaic Corporation

In the dynamic vessels two-phase model, specify initial conditions and simulation parameters

- ▶ Fluid Phase = Saturated Liquid
- ▶ Pressure = 200 psig
- ▶ Under relief piping path, specify the backpressure (0 psig) and Flow Type (Vapor)
- ▶ Starting Time = 0 hours
- ▶ Final time = 4 hours, fire duration
- ▶ Select “External fire exposure” checkbox
- ▶ Select “Perform Detailed Vessel Wall Heat Transfer Dynamics” checkbox and select the number of segments (5 in this example)

To properly calculate the mass contents, go to “Toolbox” and click “Specify Fill Level”

- In this example, the normal liquid level is 70%
- Based on the initial pressure and mixture composition, SuperChems™ will calculate the initial mass and starting temperature



Source: Process Safety Office® SuperChems™ - ioMosaic Corporation

The screenshot below shows the initial conditions and parameters for the dynamic simulation

Dynamic Vessels: Two-phase

Inputs Results Charts Toolbox Notes Data Sets

Cancel Update Run

Specifications Connectivity Run Parameters Stop Conditions Vessel Wall Dynamics Accuracy

Vessel Initial Conditions

Total volume 46267.0912 gal

Available volume 46267.0912 gal

Contents mass 135085.5188 lb

Fluid Phase

- Saturated liquid
- Liquid full
- Vapor full

	Contents	Normal operating	Maximum operating	Minimum design	Maximum design
Temperature, °C	75	75	75	-29	230
Pressure, psig	200	200	200	-14.7	300

Relief Piping Path

Flow path Backpressure, psig Piping connection Flow type

Top: primary 0 CASE 1 - P VALVE Vapor

Time Analysis

Starting time 0 h

Final time 4 h

Continue from previous simulation

Simulation Options

- Check starting conditions only
- External fire exposure

Advanced Options

- Perform Detailed Vessel Wall Heat Transfer Dynamics
- Automatically divide segments
- Number of vessel wall segments 5

Flowsheet

- Disable all incoming flow
- Disable all outgoing flow

Find Required Flow Area (Use this option with an ideal nozzle only)

Specify mixture fractions

Source: Process Safety Office® SuperChems™ - ioMosaic Corporation

Specify the vessel wall dynamics properties to use the fundamental heat transfer equation outlined in API Std 521

- Ensure that the “Fire Exposure” option is checked
- Input the correct parameters based on API Standard 521 7th edition for the “Fire/Flame Properties” and the “Wall Properties” sections

Vessel Initial Conditions

- Solar heating is not turned on for vessel
- Fire exposure
- Water exposure is not turned on for vessel
- Rain is not turned on for vessel

Fire/Flame Properties and Exposure Parameters

Fire start time	0	h
Fire duration	4	h
Emissivity	0.75	
Flame temperature	1050	°C
Gas temperature	1050	°C
Convective heat transfer coefficient	20	W/m ² /°C
Geometric view factor	1	
Atmospheric transmissivity	1	

Match fire flux data specified in vessel object

User defined fire flux	29841.3037	W/m ²
Calculated fire flux	118255.6595	W/m ²

Wall Properties

Material of construction description	CARBON STEEL, C-Mn-Si		
Databank material of construction name	STEEL		
Metal mass (Internals + User defined)	0	lb	
Outer surface emissivity	0.75		
Inner surface emissivity	1		
Absorptivity	0.75		
Wall/Vapor heat transfer Coefficient	75	W/m ² /°C	<input type="checkbox"/> Upper Limit
Wall/Liquid heat transfer coefficient	2500	W/m ² /°C	<input type="checkbox"/> Upper Limit
Wall/Condensing film heat transfer Coefficient	0	W/m ² /°C	<input type="checkbox"/> Upper Limit

Source: Process Safety Office® SuperChems™ - ioMosaic Corporation

Define the properties for all the wall segments

- Specify wall temperature equal to fluid starting temperature (75 °C) and check the applicable “Visible to fire” and “Engulfed by fire” checkboxes for all segments as applicable

The screenshot displays the 'Wall Segmentation' configuration window in ioMosaic. The interface includes a navigation bar at the top with tabs for Specifications, Connectivity, Run Parameters, Stop Conditions, Vessel Wall Dynamics, and Accuracy. The 'Wall Segmentation' tab is active, showing a list of segments on the left and detailed property settings on the right. The 'Heat Transfer Segment' section is expanded, showing two segments: 'Bottom Segment 0 -> 1' and 'Top Segment 4 -> 5'. The 'Bottom Segment 0 -> 1' properties are highlighted with a red box, showing checked boxes for 'Visible to fire' and 'Engulfed by fire', and input fields for 'Insulation layer thickness' (0 ft), 'Initial insulation temperature' (75 °C), and 'Initial wall temperature' (75 °C). The 'Top Segment 4 -> 5' properties are also highlighted with a red box, showing unchecked boxes for 'Visible to fire', 'Engulfed by fire', 'Protected by water spray', 'Visible to solar heating', 'Exposed to rain', and 'Buried in semi-infinite material', and input fields for 'Insulation layer thickness' (0 ft), 'Initial insulation temperature' (75 °C), and 'Initial wall temperature' (75 °C). A 'Maximum Do/t' field is set to 212.6299 with a 'User override' checkbox. The 'Associated/Calculated Data' section shows 'Bottom segment elevation' (31.1406 ft) and 'Top segment elevation' (37.5417 ft). The site ambient temperature is 25 °C and the initial vessel contents temperature is 75 °C.

Source: Process Safety Office® SuperChems™ - ioMosaic Corporation

Click “Run” and wait for the dynamic simulation to finish

Dynamic Vessels: Two-phase

Inputs Results Charts Toolbox Notes Data Sets

Summary Flows Profiles Detailed Profiles Composition

Export

Vessel Options & Considerations

External fire exposure

Relief Piping

Vessel Connection	Relief Piping	Backpressure psig	Flow type
TOP: Primary Piping	CASE 1 - P VALVE	0	Vapor

Overall Balance

		Initial	Final	Final - Initial
Time	h	0.0000	4.000	4.000
Temperature	°C	74.892	947.7	872.8
Pressure	psig	200.0	271.3	71.327
Vapor mass	lb	3,353	4,921	1,568
Vapor volume	gal	13,895	48,337	34,442
Liquid mass	lb	1.31732E+05	0.0000	-1.31732E+05
Liquid volume	gal	32,372	0.0000	-32,372
Total mass	lb	1.35086E+05	4,921	-1.30164E+05
Total volume	gal	46,267	48,337	2,070
Volume Full of Liquid	%	69.968	0.0000	-69.968

Design Boundaries

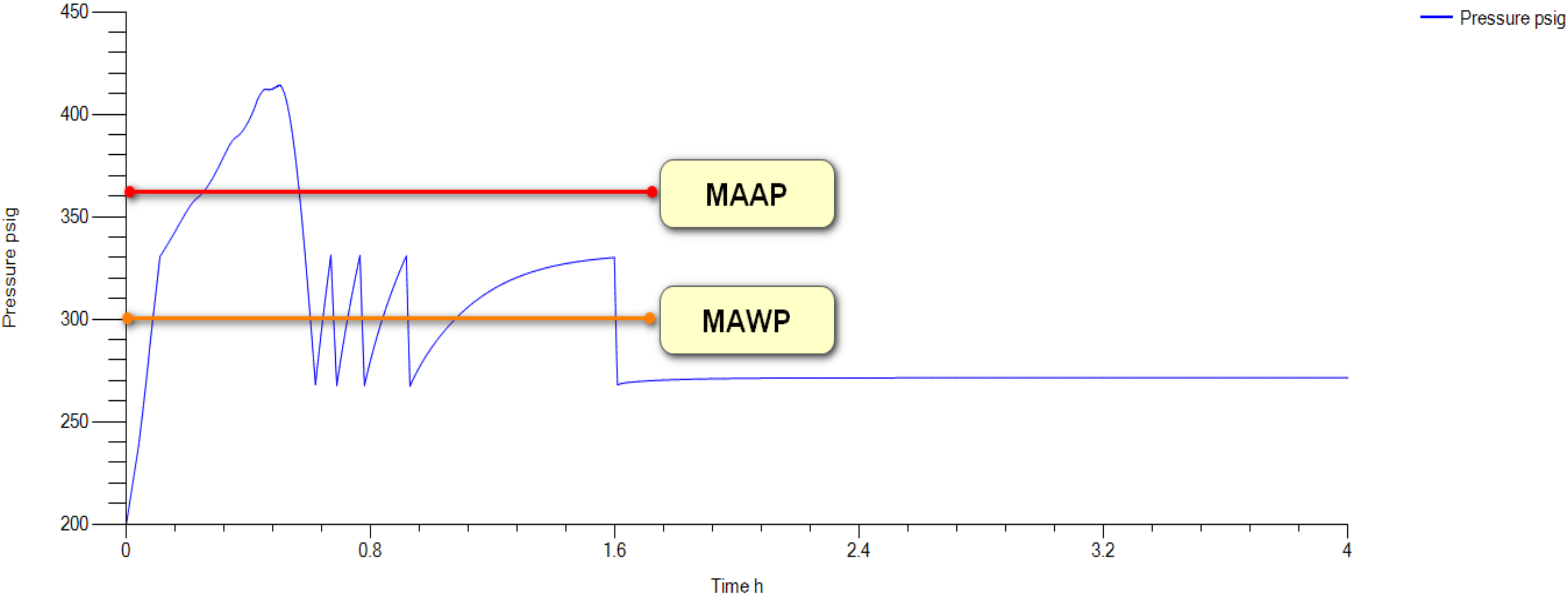
		Maximum	Time h	Point	
Pressure	psig	414.1	0.5020	173	1.38 x DESIGN P
dP/dt	psig/h	1,904	0.0760	34	
Temperature	°C	947.7	4.000	716	3.90 x DESIGN T
dT/dt	°C/h	2,108	0.6200	287	
Impulse	lbf	3,163	0.5020	171	
Fire heating input	W	1.60372E+07	0.0000	0	

Composition Balance

		Initial Liquid	Final Liquid	Initial Vapor	Final Vapor	Initial Total	Final Total	Change Total
ETHANE	lb	6,225	0.0000	763.5	79.491	6,989	79.491	-6,909
PROPANE	lb	19,478	0.0000	1,019	430.8	20,497	430.8	-20,066
n-BUTANE	lb	39,635	0.0000	890.9	1,343	40,526	1,343	-39,183
n-PENTANE	lb	66,394	0.0000	680.1	3,068	67,074	3,068	-64,006
Totals		1.31732E+05	0.0000	3,353	4,921	1.35086E+05	4,921	-1.30164E+05

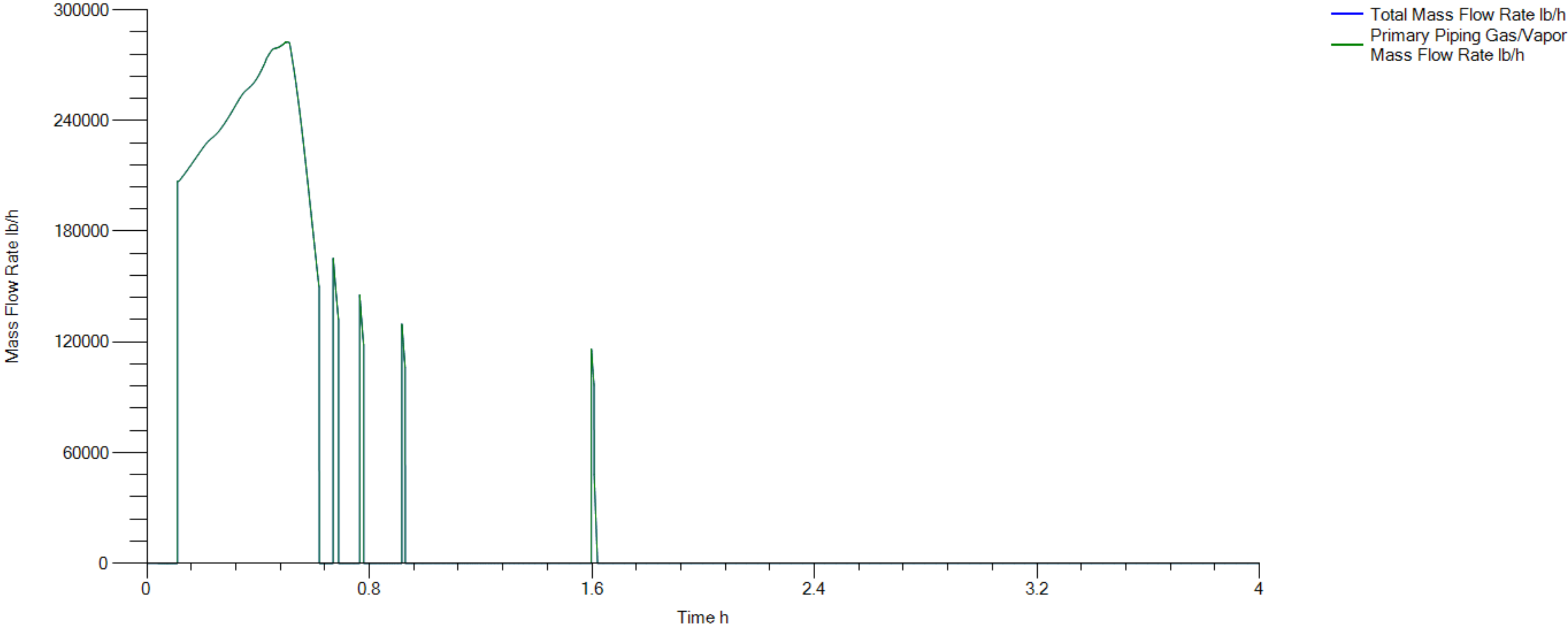
Source: Process Safety Office® SuperChems™ - ioMosaic Corporation

Under “Charts” tab, the user can illustrate several types of dynamic results such as pressure profile



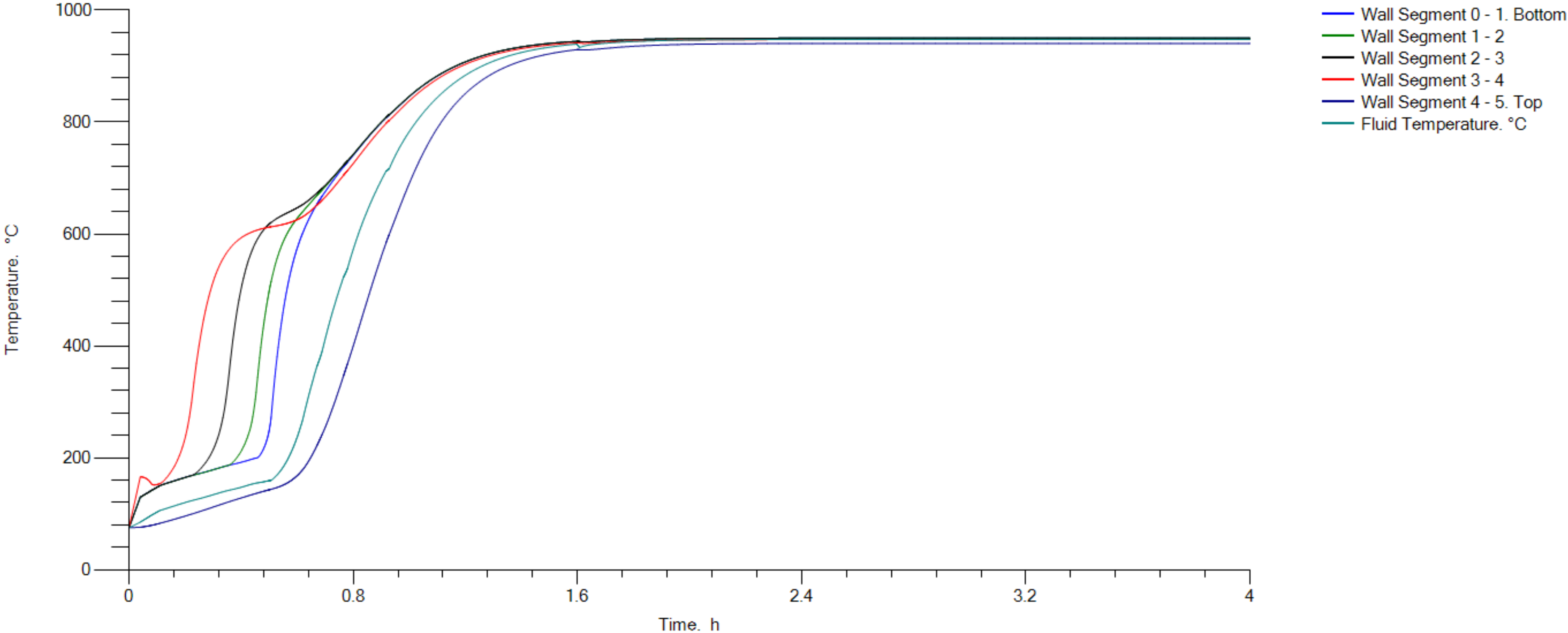
Source: Process Safety Office® SuperChems™ - ioMosaic Corporation

The user can also illustrate other results such as venting history profile



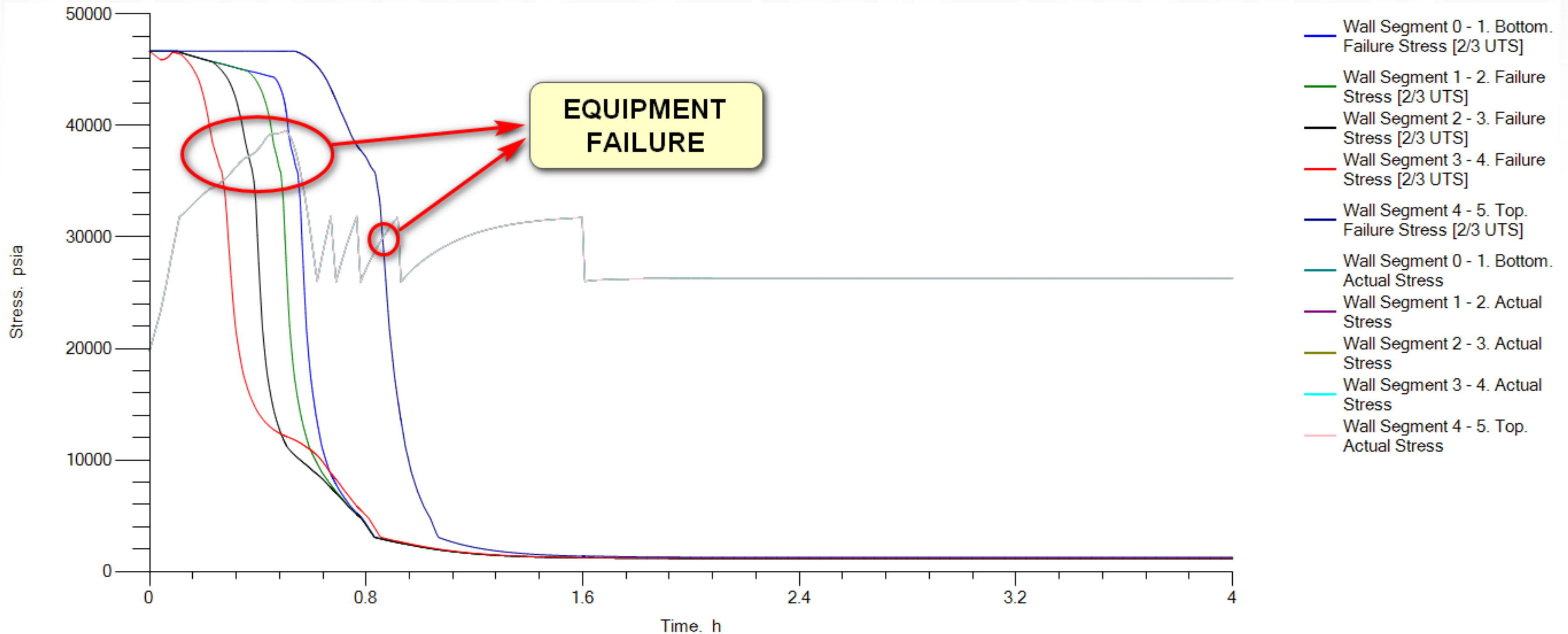
Source: Process Safety Office® SuperChems™ - ioMosaic Corporation

Under “Wall Dynamics” tab, the user can illustrate wall segment temperature profiles



Source: Process Safety Office® SuperChems™ - ioMosaic Corporation

Based on the wall failure stress profiles, V-100 stress exceeds 2/3 of the Ultimate Tensile Strength (UTS)

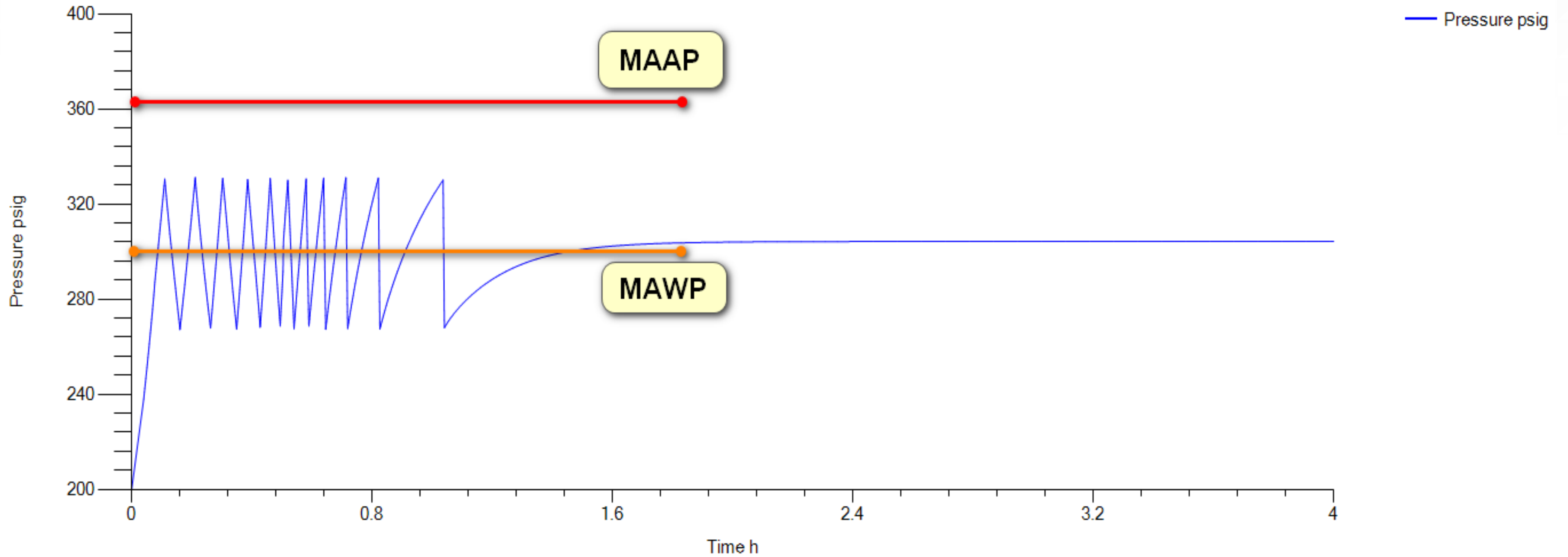


Source: Process Safety Office® SuperChems™ - ioMosaic Corporation

PRV-100 may not adequately protect V-100 in the event of exposure to an open pool fire

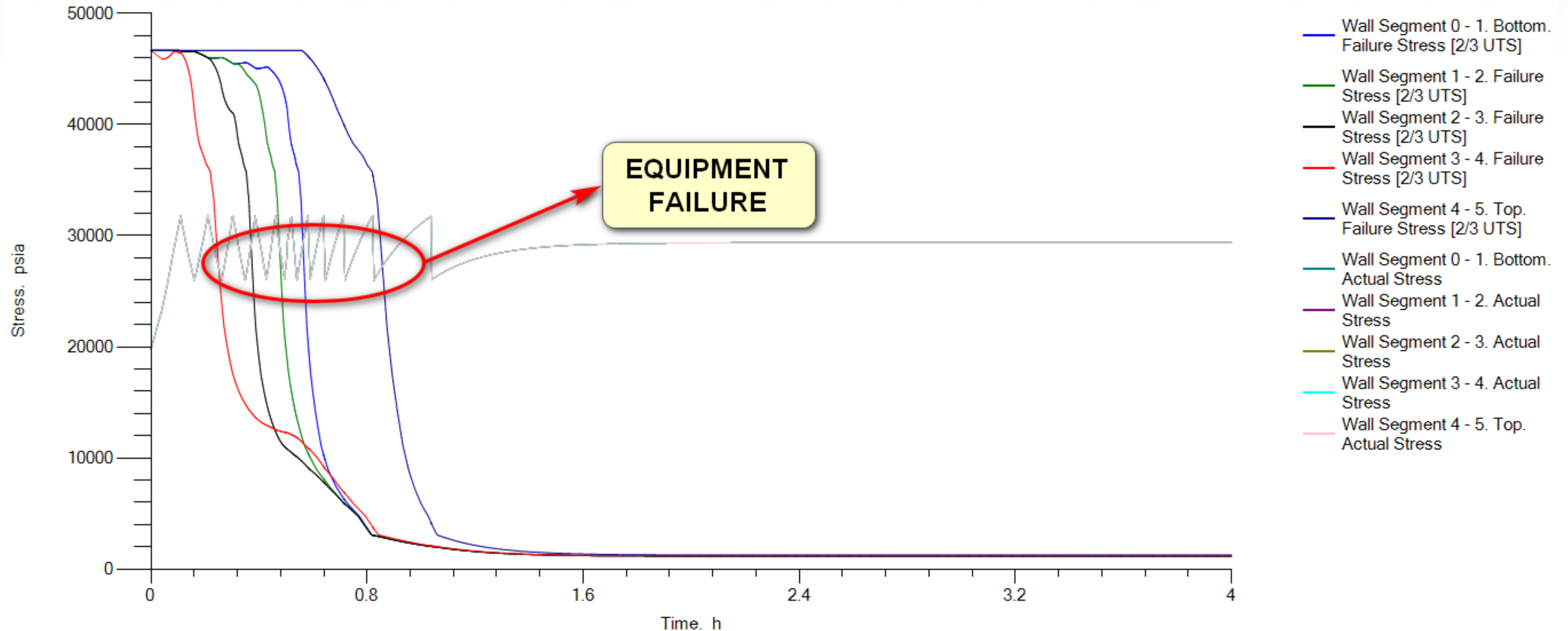
- ▶ The pressure relief system may be inadequate because the expected vessel pressure is above the Maximum Allowable Accumulated Pressure (MAAP = 1.21 x MAWP)
- ▶ Additionally, the vessel stress exceeded 2/3 of the UTS, so the equipment is expected to fail before 4 hours
- ▶ Next, we investigate the impact of installing a larger relief device (6R8)
- ▶ Note that valid mitigation solutions are typically the following:
 - ▶ Install fire-proof insulation
 - ▶ Replace the pressure relief valve for an emergency depressuring system
 - ▶ Use of water sprays

From the overpressure point of view, the system seems adequate because maximum pressure is below MAAP (1.21 x MAWP)



Source: Process Safety Office® SuperChems™ - ioMosaic Corporation

However, V-100 is still expected to fail after 15 minutes of fire exposure because the vessel stress exceeds 2/3 of the UTS



Source: Process Safety Office® SuperChems™ - ioMosaic Corporation

Case Studies in SuperChems™

Case 2 – Low-Pressure Atmospheric Tank



Atmospheric Storage Tank T-100 has been identified to be exposed to thermal radiation due to a nearby pool fire

- ▶ A nearby loss of containment scenario results in leakage of a flammable material resulting in a pool fire
- ▶ Using SuperChems™, it is estimated that T-100 is exposed to a heat flux of 25 kW/m² with a duration of 5 minutes
- ▶ The properties of the vessel under analysis are illustrated to the right

Floating Roof
T-100
MAWP < 15 psig
MAWT = 250 °C
Length = 35 ft
Diameter = 100 ft
Bottom Head = Flat
Top Head = Floating Roof
Shell Thickness = 0.5 in
Thickness of Top/Bottom Heads = 0.5 in
Material = SA 516-70
Pressure = 0 psig
Temperature = 25 °C
Liquid Level = 85%
Molar Composition = 100% Decane

Source: ioMosaic Corporation

API Standard 650 may be used to define the failure criterion for low-pressure atmospheric storage tanks

- ▶ The goal is to identify whether the mechanical integrity of the tank would be compromised, resulting in potential equipment failure
- ▶ Evaluation of T-100 mechanical integrity needs to account for the tank wall temperatures and heat radiation received
- ▶ Based on API Standard 650 12th Edition, the failure temperature of a carbon steel storage tank is indicated as 93 °C, and for well-maintained and inspected storage tanks, the failure temperature is indicated as 250 °C

Source: API Standard 650, 2013, "Welded Tanks for Oil Storage", 12th Edition

The image below illustrates simulation initial conditions and parameters when tank T-100 is exposed to 25 kW/m²

Dynamic Vessels: Two-phase

Inputs Results Charts Toolbox Notes Data Sets

Cancel Update Run

Specifications Connectivity Run Parameters Stop Conditions Vessel Wall Dynamics Accuracy

Vessel Initial Conditions

Total volume ft³

Available volume ft³

Contents mass lb

Fluid Phase

Saturated liquid

Liquid full

Vapor full

	Contents	Normal operating	Maximum operating	Minimum design	Maximum design
Temperature, °C	<input type="text" value="25"/>	25	25	-29	230
Pressure, psig	<input type="text" value="0"/>	0	0	-14.7	14.7

Relief Piping Path

Flow path Backpressure, psig Piping connection Flow type

Top: primary FLOATING ROOF No flow

Time Analysis

Starting time min

Final time min

Continue from previous simulation

Simulation Options

Check starting conditions only

External fire exposure

Advanced Options

Perform Detailed Vessel Wall Heat Transfer Dynamics

Automatically divide segments

Number of vessel wall segments

Flowsheet

Disable all incoming flow

Disable all outgoing flow

Find Required Flow Area (Use this option with an ideal nozzle only)

Specify mixture fractions

Mixture Composition

Mass Mole

Compound	Formula	ID	MW	Mass Fraction	Mole Fraction	User Composition
n-DECANE	C10H22	9	142.285	0.9993	0.9965	0.9993
NITROGEN	N2	980	28.014	0.0007	0.0035	0.0007

Source: Process Safety Office® SuperChems™ - ioMosaic Corporation

Wall dynamics parameters and properties are properly specified for this scenario

Vessel Initial Conditions

- Solar heating
- Fire exposure
- Water exposure is not turned on for vessel
- Rain is not turned on for vessel

Fire/Flame Properties and Exposure Parameters

- Fire start time: 0 min
- Fire duration: 5 min
- Emissivity: 0.75
- Flame temperature: 750 °C
- Gas temperature: 600 °C
- Convective heat transfer coefficient: 20 W/m²/°C
- Geometric view factor: 1
- Atmospheric transmissivity: 0.387
- Match fire flux data specified in vessel object
- User defined fire flux: 25000 W/m²
- Calculated fire flux: 25026.1371 W/m²

Wall Data Wall Segmentation

Heat Transfer Segment

- Bottom Segment 0 -> 1
- Segment 1 -> 2
- Segment 2 -> 3
- Segment 3 -> 4
- Segment 4 -> 5
- Segment 5 -> 6
- Segment 6 -> 7
- Segment 7 -> 8
- Segment 8 -> 9
- Segment 9 -> 10
- Segment 10 -> 11
- Segment 11 -> 12
- Segment 12 -> 13
- Segment 13 -> 14
- Segment 14 -> 15
- Segment 15 -> 16
- Segment 16 -> 17
- Segment 17 -> 18
- Segment 18 -> 19
- Top Segment 19 -> 20

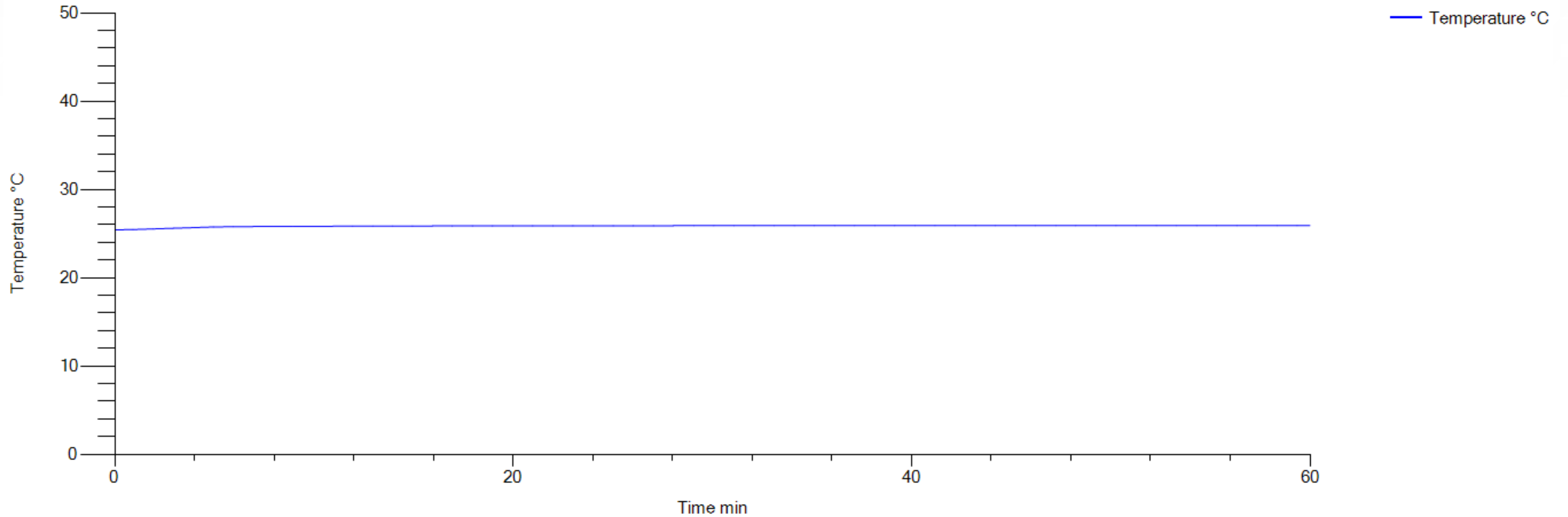
Site Ambient Temperature = 25 °C. Initial Vessel Contents Temperature = 25 °C

Bottom Segment 0 -> 1

- Visible to fire
- Engulfed by fire
- Protected by water spray
- Visible to solar heating
- Exposed to rain
- Buried in semi-infinite material
- Insulation layer thickness: 0 ft
- Initial insulation temperature: 25 °C
- Initial wall temperature: 25 °C
- Maximum Do/t: 212.6299 User override
- Associated/Calculated Data

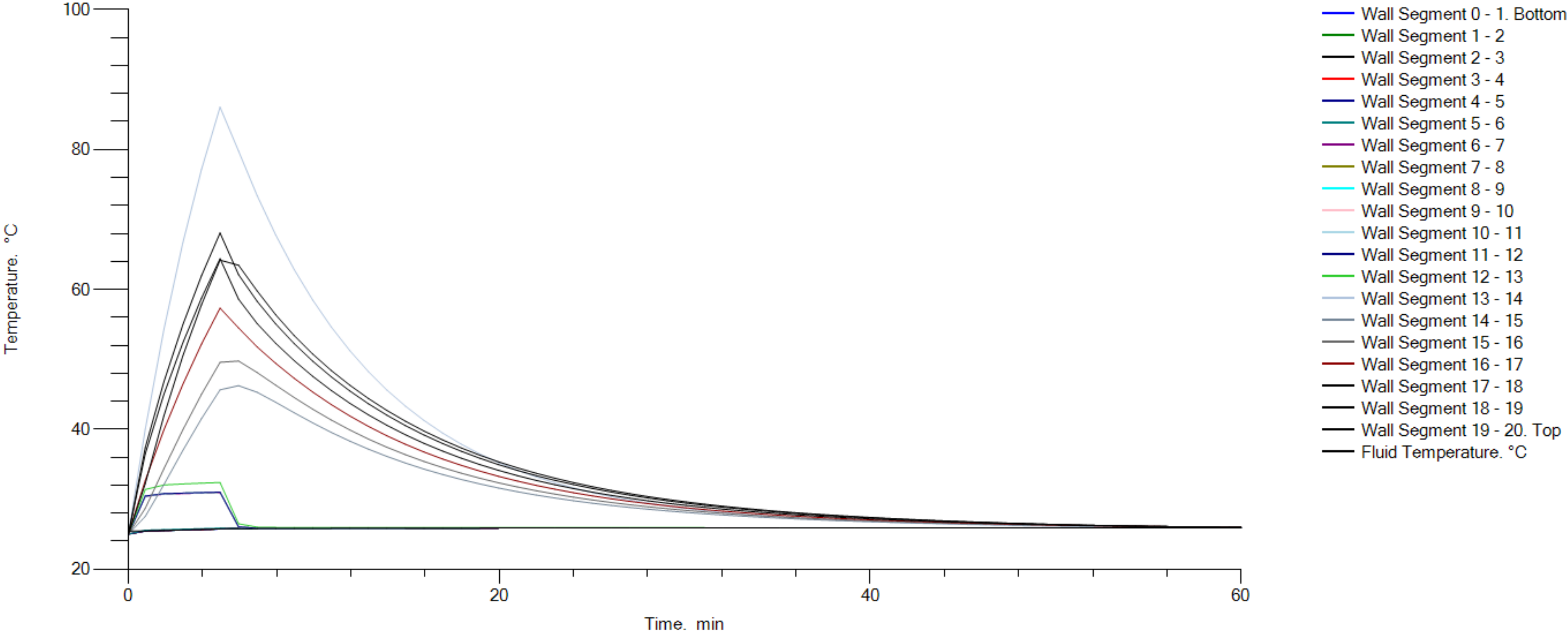
Source: Process Safety Office® SuperChems™ - ioMosaic Corporation

Based on the dynamic simulations results, it can be observed that T-100 fluid temperature stays reasonably constant



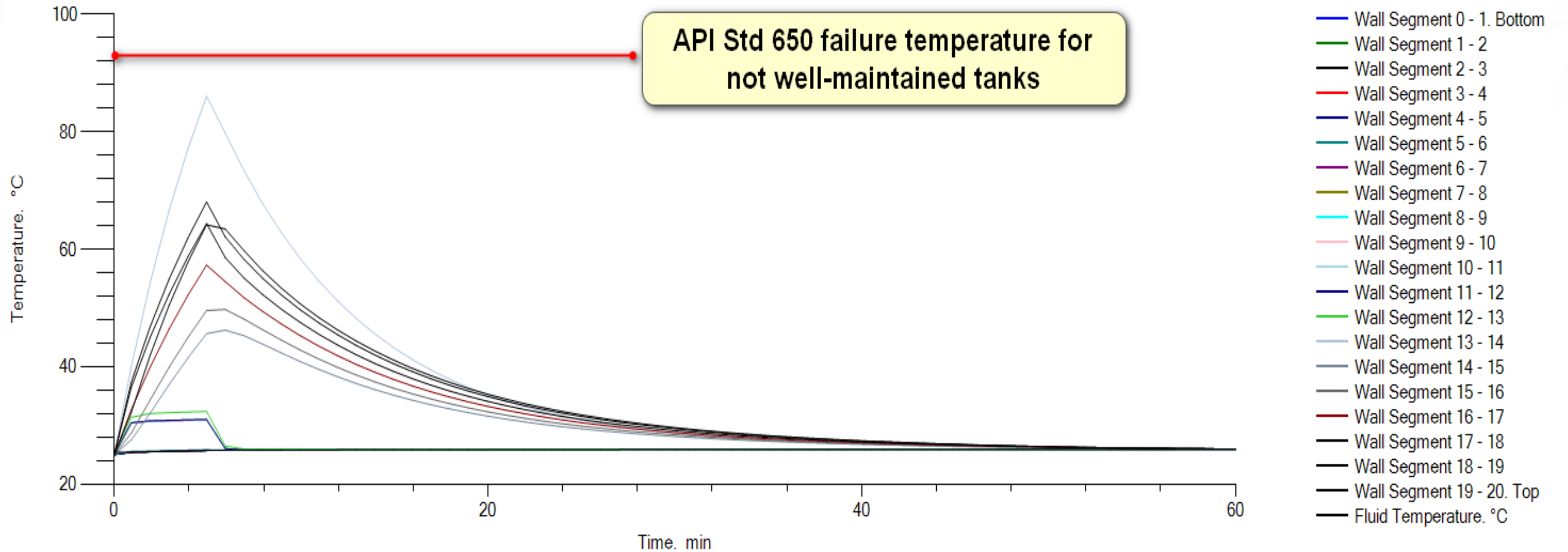
Source: Process Safety Office® SuperChems™ - ioMosaic Corporation

Wall temperature profiles indicate that segments not covered by liquid get hotter sooner and then cool down after 5 minutes



Source: Process Safety Office® SuperChems™ - ioMosaic Corporation

T-100 mechanical integrity is not expected to be compromised based on the detailed wall dynamics results



Source: Process Safety Office® SuperChems™ - ioMosaic Corporation

Wall Dynamics Tutorial Summary



The following topics have been addressed during today's presentation

- ▶ Evaluation of vessel and piping wall temperatures using the fundamental heat transfer equation outlined in API Standard 521
- ▶ Advantages and characteristics of the wall segmentation approach implemented in SuperChems™
- ▶ Application of the wall dynamics approach in SuperChems™ via 2 case studies: (1) evaluation of a pressure vessel, and (2) evaluation of a low-pressure atmospheric tank

Thank you very much!
Questions?



About ioMosaic Corporation

Through innovation and dedication to continual improvement, ioMosaic has become a leading provider of integrated process safety and risk management solutions. ioMosaic has expertise in a wide variety of areas, including pressure relief systems design, process safety management, expert litigation support, laboratory services, training, and software development.

ioMosaic offers integrated process safety and risk management services to help you manage and reduce episodic risk. Because when safety, efficiency, and compliance are improved, you can sleep better at night. Our extensive expertise allows us the flexibility, resources, and capabilities to determine what you need to reduce and manage episodic risk, maintain compliance, and prevent injuries and catastrophic incidents.

Our mission is to help you protect your people, plant, stakeholder value, and our planet.

For more information on ioMosaic, please visit: www.ioMosaic.com