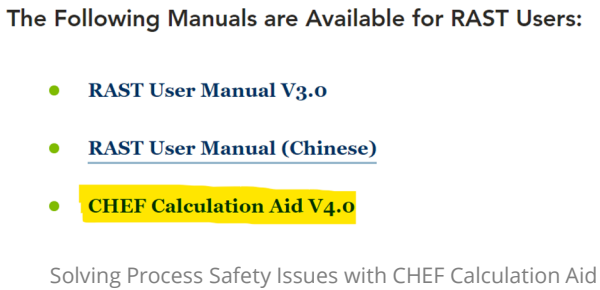
Solving Process Safety Issues with CHEF Calculation Aid

Enter Name Here

About CHEF

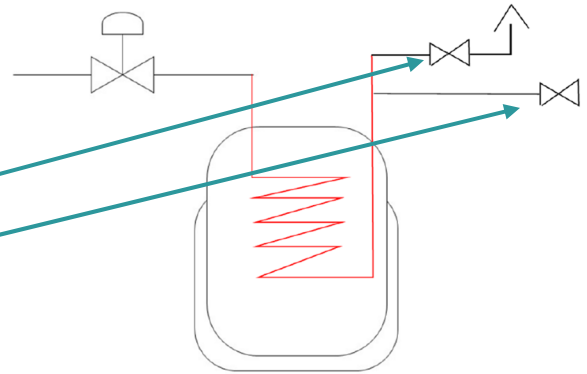
- Chemical Hazard Engineering Fundamentals Screening Tool (CHEF)
- Published by Center for Chemical Process Safety (CCPS)
- Requires minimal inputs to obtain the results
- Source models, vapor dispersion, explosion, and impact assessments can be done
- Free excel and can be downloaded from CCPS
  - https://www.aiche.org/ccps/resources/tools/risk-analysis-screening-tool-rast-and-chemical-hazard-engineering-fundamentals-chef/rast-user-and-chef-manuals



Solving Process Safety Issues with CHEF Calculation Aid

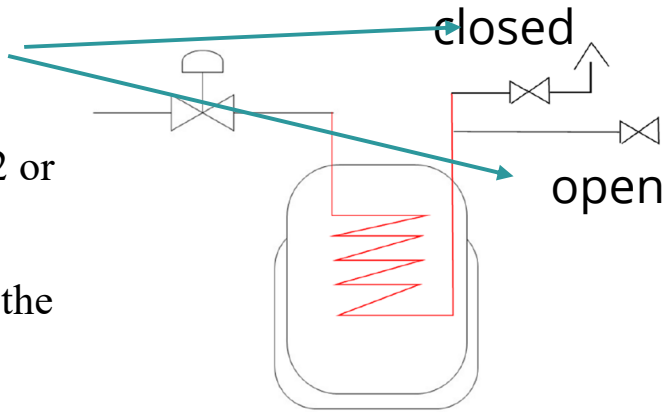
Example-1 - Periodic reactor internal coil failure

- An internal coil is used to cool reactor contents where a desired reaction is completed at
  - atmospheric pressure
  - operating temperature of 250 °C
  - thermic fluid in the jacket is closed
- During the reaction stage (stage prior use of internal coil)
  - the return line of the internal coil is closed, however,
  - the vent line is open and discharges to the top of the building with a weather hood.
- Normal cooling water is used for the cooling process.



Example-1 - Periodic reactor internal coil failure

- Once the reaction is complete
  - an internal coil is used for reducing the temperature of the reactor contents
- Interview - Approximately 10 reactors out of which there are 2 or 3 reactor internal coil failure per year
- Failures range from pin hole leaks to a guillotine break across the welded sections of the pipe
- In 2020 HAZOP, reactor node considered an internal failure of the internal coil but considered the relief system in the reactor as a safeguard



CHEF Screening tool to address the internal coil failure

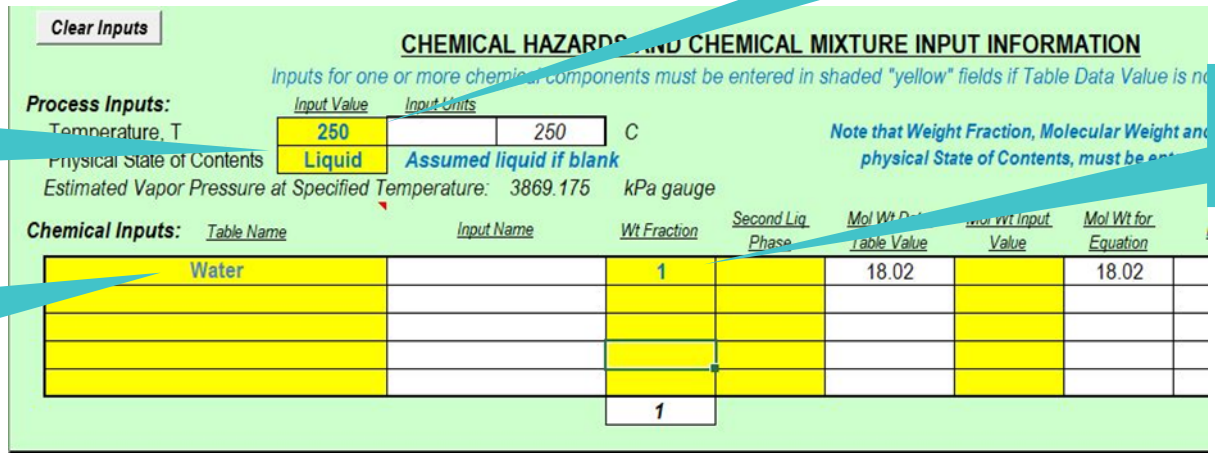
- Design pressure of the internal coil-5 $kg_f/cm2$ (g)
- Design pressure of the reactor -3 $kg_f/cm2$ (g)
- Volume of the reactor-10 m^3
- Volume of internal coil - 0.25 m^3
- Vapor pressure of water - 39.5 $kg_f/cm2$ (g) at 250 °C

Operating Temperature

Physical State

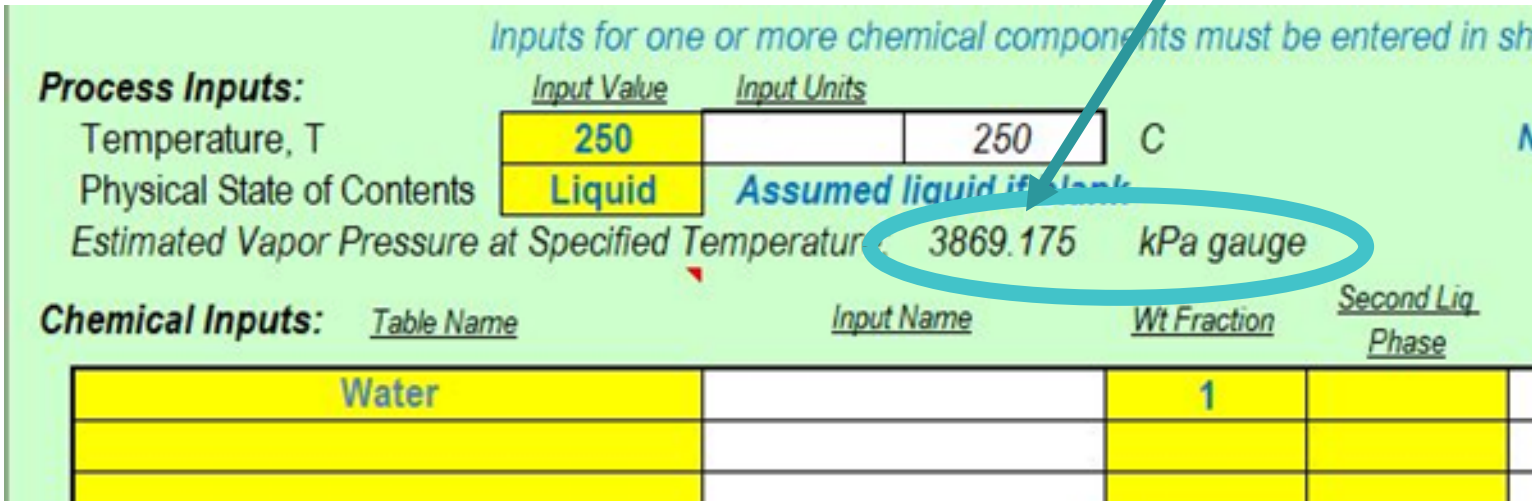
Chemical Input

Weight fraction



CHEF Screening tool to address the internal coil failure

- Design pressure of the internal coil-5 $kg_f/cm2$ (g)
- Design pressure of the reactor -3 $kg_f/cm2$ (g)
- Volume of the reactor-10 m^3
- Volume of internal coil - 0.25 m^3
- Vapor pressure of water - 39.5 $kg_f/cm2$ (g) at 250 °C



Deficiencies and failure modes Identified

- The cooling water is of low quality that will result in scaling of the pipe and these deposits can result in further deterioration of piping
- The pipe can catastrophically rupture
- Estimate the hazard distances due to an overpressure excursion
- Thermal stress cracking when cooling water is introduced as part of the cooling process (Temperature above Leidenfrost temperature > 200 °C)
- Vibration fatigue due to overpressurization during cooling
- Process Hazard Analysis ranks the blocked cooling water outlet with a low consequence

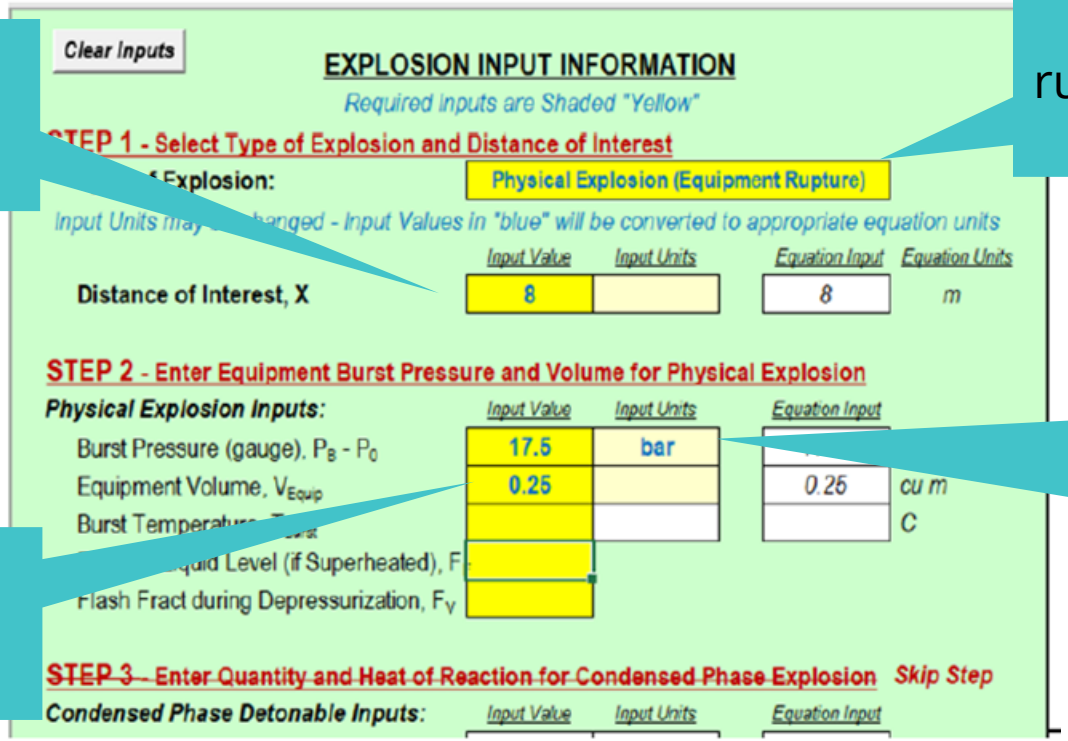
Estimate the hazard distances

Cabin and break room at a distance of 8 m

Equipment rupture – internal coil damage

Settle out pressure - ASME Safety Factor of 3.5

Volume of the internal coil



Estimate the hazard distances

SIMPLE TNT MODEL per Section 13.4

Physical Explosion

Note: P_A = 101.3 kPa

Equivalent Vapor Volume, $V^* = V_V + V_L F_V (\rho_L/\rho_V)$ (equation 13-2)

= (0.25) [ ] ( ) (/ ( ) + (1 -)] = **0.25** m^3

Physical Explosion Energy (equation 13-1), $Q_{PV} = V^* P_B [\ln (P_B / P_A) + (P_A / P_B) - 1]$

= (0.25) (1851.3) [LN (1851.3 / 101.3) + (101.3 / 1851.3) - 1] = **907.3** kJ

$kg_{TNTeq} = Q_{PV} / 4600$ = **0.2** kg

Scaled Overpressure at 1 psi = 0.068

Scaled Distance = 18 = X / $kg_{TNTeq}^{1/3}$

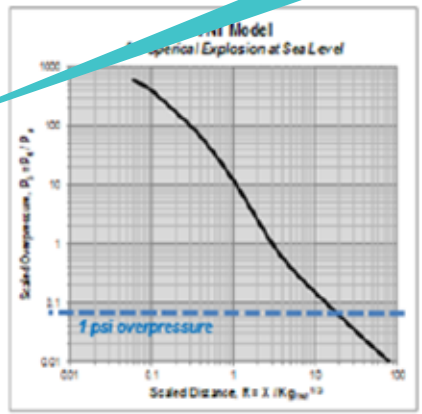
Distance to 1 psi = 18 (0.2)^1/3 = 10.5 m

From Graph, Scaled Distance, R = X / $kg_{TNTeq}^{1/3}$ =

8 / (0.2)^1/3 = 13.67

Scaled Overpressure = 0.096

Overpressure at 8 m = 1.4 psi or 9.7 kPa



Distance to 1 psi is 10.5 m

Overpressure at 8 m is 1.4 psi

Conclusions

- CHEF calculation aid helps in estimating process safety consequence
- A useful tool to determine thermo-physical properties
- Damage mechanisms were highlighted and requested team to revisit the design or find other suitable alternatives to prevent or mitigate internal coil failures

Re-use of tank for storage of IPA

- 2-propanol, commonly referred as IPA, was subject to many accidents in 2020. Many small and medium scale chemical industries were affected due to either direct or indirect manufacturing of sanitizers
- The following example shows how the CHEF calculation aid was used for storage and handling of IPA
- An existing storage tank was re-purposed for their specific application

Example-2 – IPA Storage Tank

$$V_i = P_i \times \frac{10^6}{101.3}$$

Physical State

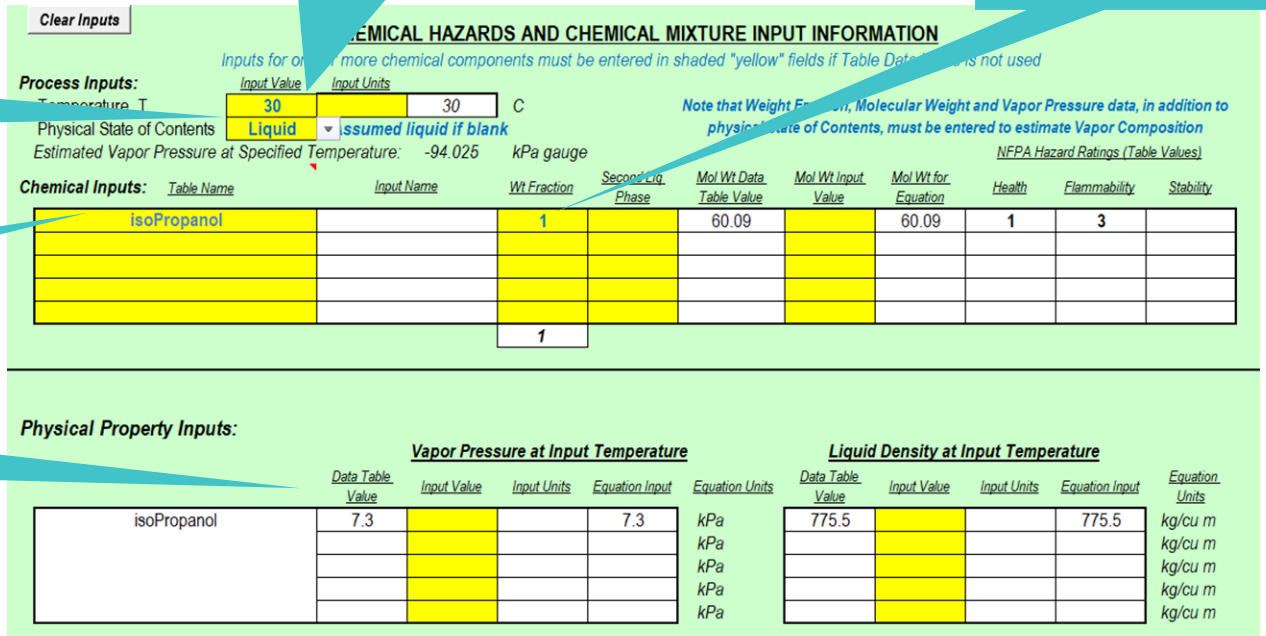
At 30 °C IPA 7.2% [vol basis] in air

Isopropanol (IPA) – Input chemical

Vapor pressure at input temperature

Temperature and physical state

Weight fraction



Example-2 – IPA Storage Tank

- Obtaining chemical properties

Lower Explosive Limit (LEL): 2 % (NTP, 1992)
Upper Explosive Limit (UEL): 12 % (NTP, 1992)

Source: Cameo Chemicals

Flammability property – Flash Point

Flammability property – LEL

Toxicity property – ERPG-2 and ERPG-3

Flammability Property Inputs:

	Flash Point (Liquid)					Lower Flammable Limit				
	Data Table Value	input Value	input Units	Equation input	Equation Units	Data Table Value	input Value	input Units	Equation input	Equation Units
ropanol	12			12	C	2			2	vol %
					C					vol %
					C					vol %
					C					vol %
					C					vol %

Toxicity Property Inputs:

	input Value	input Units	Equation input	Equation Units
Exposure Duration, t			60	min

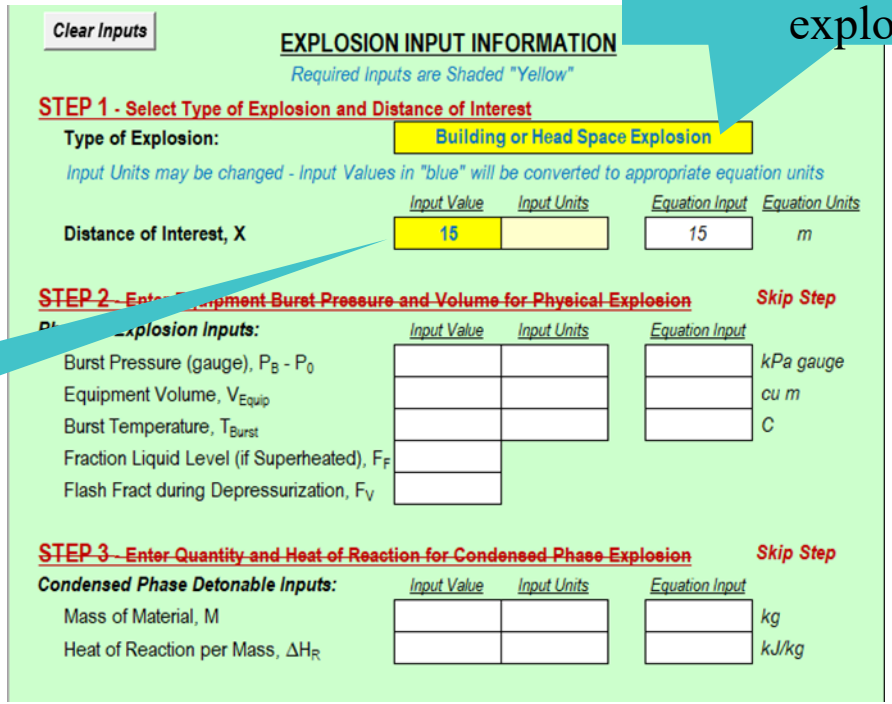
	One-Hour ERPG-2				One-Hour ERPG-3					
ERPG-2	Data Table Value	input Value	input Units	Equation input	Data Table Value	input Value	input Units	Equation input	Equation Units	Dose Exponent, n
isoPropanol	400			400	12000			12000	ppm	
									ppm	
									ppm	
									ppm	
									ppm	

Estimating Internal deflagration of IPA storage tank

- 50 m^3 storage tank volume
- Average void space volume of 15 m^3

Nearby high foot traffic area.

Internal Deflagration – Building or head space explosion



Clear Inputs

EXPLOSION INPUT INFORMATION

Required Inputs are Shaded "Yellow"

STEP 1 - Select Type of Explosion and Distance of Interest

Type of Explosion: Building or Head Space Explosion

Input Units may be changed - Input Values in "blue" will be converted to appropriate equation units

	Input Value	Input Units	Equation Input	Equation Units
Distance of Interest, X	15		15	m

STEP 2 - Enter Equipment Burst Pressure and Volume for Physical Explosion — Skip Step

Physical Explosion Inputs:

	Input Value	Input Units	Equation Input	
Burst Pressure (gauge), $P_B - P_0$				kPa gauge
Equipment Volume, V_{Equip}				cu m
Burst Temperature, T_{Burst}				C
Fraction Liquid Level (if Superheated), F_F				
Flash Fract during Depressurization, F_V				

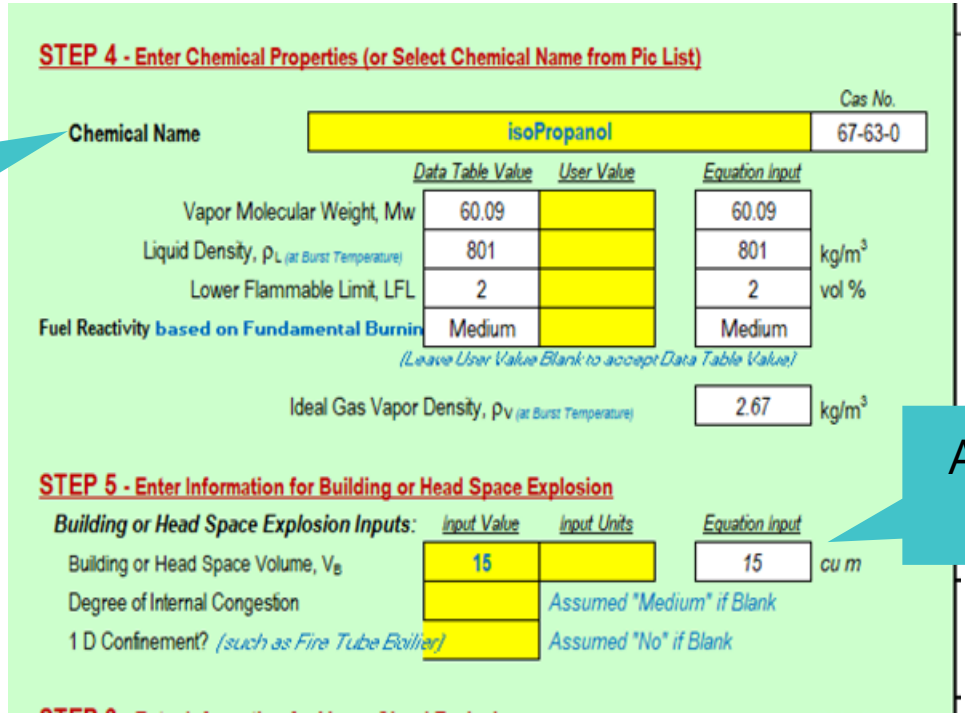
STEP 3 - Enter Quantity and Heat of Reaction for Condensed Phase Explosion — Skip Step

Condensed Phase Detonable Inputs:

	Input Value	Input Units	Equation Input	
Mass of Material, M				kg
Heat of Reaction per Mass, ΔH_R				kJ/kg

Estimating Internal deflagration of IPA storage tank

Chemical of interest



STEP 4 - Enter Chemical Properties (or Select Chemical Name from Pic List)

			Cas No.
Chemical Name	isoPropanol		67-63-0

	Data Table Value	User Value	Equation input	
Vapor Molecular Weight, Mw	60.09		60.09	
Liquid Density, ρ_L (at Burst Temperature)	801		801	kg/m^3
Lower Flammable Limit, LFL	2		2	vol %
Fuel Reactivity based on Fundamental Burnin	Medium		Medium	

(Leave User Value Blank to accept Data Table Value)

Ideal Gas Vapor Density, ρ_V (at Burst Temperature) 2.67 kg/m^3

STEP 5 - Enter Information for Building or Head Space Explosion

Building or Head Space Explosion Inputs:	Input Value	Input Units	Equation input	
Building or Head Space Volume, V_B	15		15	cu m
Degree of Internal Congestion		Assumed "Medium" if Blank		
1 D Confinement? *(such as Fire Tube Boiler)*		Assumed "No" if Blank		

Average void space volume

Estimating Internal deflagration of IPA storage tank

BAKER-STREHLOW-TANG MODEL per Section 13.5

Building or Head Space Explosion

Fuel Reactivity	Obstacle Density or Congestion: Low	Medium	High
High	0.5	>1	>1
Low-Medium	0.35	0.5	1
Class I Dust		0.35	0.5

Use Mach 0.5 for Low-Medium Fuel Reactivity and Medium Confinement

Potential Explosion Site (PES) Volume, $V_{PES} = V_B =$ 15 m^3

Explosion Energy (equation 13-3), $Q_E = 3500\ V_{PES} =$

3500 (15) = 52500 kJ

Overpressure at 1 psi = 0.068

Scaled Distance $X / (2\ Q_E / P_0)^{1/3} =$ 2.5

Distance to 1 psi = $R\ (2\ Q_E / P_0)^{1/3} =$

2.5 [2 (52500) / 101.3]^1/3 = 25.2 m

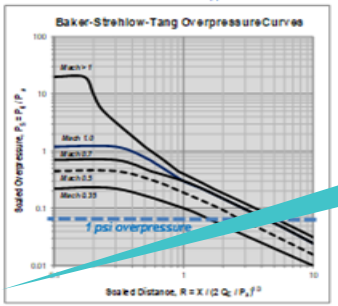
From Graph, Scaled Distance, $R = X / (2\ Q_E / P_0)^{1/3} =$

15 / [2 (52500) / 101.3]^1/3 = 1.486

Scaled Overpressure = 0.118

Overpressure at 15 m = 1.7 psi or 12 kPa

Note: P_A = 101.3 kPa



Distance to 1 psi

Overpressure at distance of interest

Summary

- CHEF Calculation aid is versatile and essential tool for Process Safety and Risk Management professionals.
- List of 222 chemicals and pre-defined process safety models
- Inputs are clearly highlighted and can override as per use case
- Requires limited process safety information for screening purposes
- Identify the hazards and potential consequence to troubleshoot process safety issues


THANK
YOU
Photo by Caleb Chen - Creative Commons null