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STORAGE TANK PROTECTION USING ASPEN HYSYS

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Abstract

This work determines the normal and emergency venting requirements for atmospheric storage tank in a gas plant using ASPEN HYSYS Safety environment. Pressure relief sizing calculations are performed for fire case scenario. Since Aspen HYSYS safety environment is provided with updated industrial design standard codes like API 650, API 620 and API 2000, the results of this study are reliable and accurate. The methodology developed in this work is useful to process design engineers to quickly analyze the low-pressure storage tank protection.

Keywords: Storage tank; Emergency venting; Vacuum relief; Pressure relief device.

1. Introduction

Storage tanks are used to store huge amounts of chemicals. Storage tank pressures are in the range of +56 mbar to -6 mbar and +140 mbar to -10 mbar [1]. Due to condensation or evaporation storage tank pressure may decrease or increase. To protect storage tank in-breathing and out-breathing are necessary. According to [2] in-breathing for a storage tank is defined as the required flow rate of ambient air entering into the tank through the vacuum valve and out-breathing is defined as the flow rate of air or chemicals stored in the tank passed out from the tank through the pressure relief valve to compensate for pressure changes within the tank. Breathing capacities of low pressure storage tanks are available in [2-3, 5]. The decrease in pressure results collapse of the tank and increase in pressure results to the blasting of the tank. Atmospheric pressure and temperature changes, fire exposures, equipment failures and operating errors are some of the reasons for the in-breathing and out-breathing of storage tanks. This kind of situations needs the design of pressure relief systems. The pressure relieving mechanism ejects mass, containing energy, so removal of energy reduces the pressure in the process [6]. Explained how to locate, select, design and maintain pressure relief devices in a process. In relief sizing calculations relief device discharge area and diameter of the inlet piping are calculated [7]. Mathematical models are available to calculate the in-breathing capacity of storage tank filled with low-pressure gas and cooled by rainfalls [8]. Modelling studies explained the effect of temperature and pressure on vent sizing calculations. These studies helped in sizing new vents and to evaluate the risk of already build structures. Giving time to time temperature distribution of liquid phase is another advantage of this model [9]. Protection from vacuum collapse is explained by [10], the approach used simple heat and mass balance equations. Maintaining pressure relief systems for tanks exposed to fire discussed by [11]. The mass discharged through relief system may be liquid, gas or combination of both. If the mass is in either completely liquid or completely vapour then the system is in single phase system and the relief design is simple. If the mass is a combination of liquid and gas it is a two-phase system and designing relief system for the two-phase system is difficult [12] and [13]. For two-phase nonreactive systems to design pressure relief systems, short cut techniques are proposed by [14]. The safety and integrity of storage tanks can be improved by installing the pressure protection system on the tank. This is explained with a case study, i.e. protection ammonia storage tank [15].

Causes of overpressure for process equipment are discussed in API 2008 manual [4]. According to the ASME boiler and pressure vessel code section VIII, all pressure vessels are to have protection from overpressure scenarios irrespective of their credibility of overpressure [20]. The different types of relief devices and their advantages and disadvantages are discussed in [12] and [17]. For sizing, selection and installation of pressure relieving systems in refineries API 520 part-I [4] is the most widely used manual in the chemical process industries. Emergency relief requirements are necessary in the case of fire or low or high-pressures for reactive chemical storage tanks. Protection of reactive storage tanks is explained with a case study, i.e., with hydrogen cyanide by [18]. Results of this case study can be extended to other reactive systems.

The objective of the present work is to propose atmospheric storage tank protection containing hydrocarbons in a gas plant using Aspen HYSYS safety environment. Aspen HYSYS safety environment is provided with storage tank protection and design of pressure relief system. Aspen plus vent sizing program is provided with a solution of the integral equation for vent flow. This equation is available in Design Institute for Emergency Relief Systems (DIERS) project manual [13]. This equation is helpful in predicting the flow rate through the vent at each time increment [19]. Designing reliable and accurate pressure relief system mitigates the damage to personnel, equipment and production schedule. Pressure relief system design needs the information of physical properties of the components, flow rates of all streams, properties of the metals used for the design of tanks. Pressure relief system design can be divided into a number of scenarios. Each scenario is analyzed for calculation of pressure relief loads and orifice size of pressure relief device, the rate of discharge of relieving fluid to a flare system. The designing pressure relief system is a complex task. This complex task gets simplified by using Aspen HYSYS safety environment.

Aspen HYSYS safety environment is provided with calculation methodology to give quantitative values for normal and emergency venting requirements for atmospheric storage tanks. During calculations, Aspen HYSYS gives warnings when the inlet pressure drop exceeds 3% of the specified constraints and for outlet pressure losses exceeds 10%. These warnings are helpful in customizing the inlet line loss criteria to select line design preferences. Storage tank venting requirements in Aspen HYSYS are based on the standards of API 2000. Normal operations for storage tanks are pumping fluids in and out, temperature changes inside of the tank or atmosphere. In these situations, the tank needs pressure and vacuum relief. In emergency situations like tank exposed to fire, control valve failure, the tank needs emergency venting requirements. The storage tank protection procedure available from previous works in literature is a complex task. However, using Aspen HYSYS safety environment, this task is simplified.

2. Material and methods

2.1. In-breathing and out-breathing calculations

For storage tank protection Aspen HYSYS safety analysis environment is used. Aspen HYSYS storage tank protection environment is provided with normal venting and emergency venting calculations for low pressure storage tank. Storage tank protection module follows the API 650, API 620 and sizing pressure relief device follows API 2000 standards.

Feed stream to the storage tank contains nitrogen 0.72%, carbon dioxide 0.01%, methane 89.45%, ethane 7.26%, propane 2.02%, isobutane 0.24%, n-butane 0.29% and i-pentane 0.01%. This mixture is to be stored in an atmospheric storage tank shown in figure1. The temperature of the tank is 25^0C and pressure is 1 bar. The first step in storage tank protection is doing steady state simulations for the specified storage tank. Peng-Robinson thermodynamic package is used for property calculations of hydrocarbons present in the system. The simulated storage tank is shown in figure1. The second step is exporting simulated tank information to Aspen

Safety analysis environment. Aspen HYSYS safety analysis environment contains storage tank protection, depressurizing, flare system design and blowdown analysis modules.

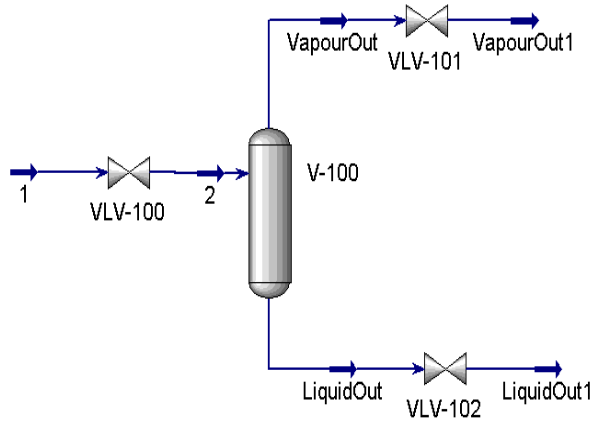

Figure 1. Storage tank

The present study deals with the protection of low pressure storage tank, so add storage tank option is selected. Storage tank protection tabs contain: Tank design tab (for specifying storage tank design input values), normal venting tab (to calculate normal breathing device specifications), emergency venting tab (to calculate emergency breathing device specifications). In the third step tank design information is filled based on the codes of standards. Tank design information is tank design code is API 620, tank type is vertical with no bottom head, tank design inputs are pressure 14.7 Psi, latitude is below 42^0 and 58^0, vapour pressure option is higher than Hexane or unknown, evaporation rate is 15 Nm^3/hr, uncontained area fraction 1 m, insulation area fraction 1m, insulation thickness 25.4 mm, thermal conductivity 0.5674 kcal/m/^{0}C.

Tank design specifications are used to calculate normal vent sizing and emergency vent sizing. In the fourth step, under normal venting tab, the necessary input information is provided. Breathing device types available are pressure and vacuum relief, open vent, blanketing system and pressure vacuum valve. Here pressure vacuum relief device is selected because it is appropriate for low storage tank protection. API2000 edition types are 6th edition, 7th edition and 7th edition extended. API 7th edition is selected for this case. Normal venting input information is set to pressure, vacuum set pressure, maximum liquid inflow and maximum liquid outflow. In the fifth step, required data for emergency venting is entered. Emergency venting tab needs the information of emergency device type (open vent, Manhole cover, Man way/ Emergency vent, Pressure vacuum valve, Pilot operated pressure relief, Gauge Hatch. For the current study pressure vacuum valve is selected), set pressure, bottom tank above grade, flame height from grade in meters, calculation of environmental factor, fluid latent heat. Tank design input information, normal venting information and emergency venting input information are shown in tables 1, 2, and in 3 respectively.

Table 1. Tank design inputs

Tank Design inputs	Values
Barometric pressure [bar]	1.01325
Design pressure [barG]	1
Vacuum design pressure [mbarG]	-1
Operating pressure [barG]	0
Diameter [m]	1.524
Height [m]	9.144
Maximum operating temperature [^{o}C]	65.55
Latitude	Between $42^0$and 58^0
Vapor pressure	More than Hexane or Unknown
Evaporation rate [Nm^3/h]	15
Uncontained area fraction	1
Insulation area fraction	1
Insulation thickness [mm]	25.4
Thermal conductivity (Normal), kcal/hr/m/^{0}C	0.5674
Thermal conductivity (Fire), kcal/hr/m/^{0}C	0.5674

Table 2. Normal venting inputs

Normal venting inputs	Values
Set pressure [mbarG]	3.73
Vacuum set pressure [mbarG]	-3.73
Maximum liquid Inflow [m^3/h]	2.27
Maximum liquid Outflow [m^3/h]	11.35
Tank vapor molecular weight	17.94
Volatile liquid	True

Table 3. Emergency venting inputs

Emergency inputs	Values
Set pressure [mbarG]	3.73
Bottom tan above grade [m]	0.91
Flame height from grade [m]	9.14
Calculate environment factor?	True
Environment factor, F	0.35
Relieving gas temperature [^oC]	24.43
Relieving gas molecular weight	17.94
Fluid latent heat [kJ/kg]	116.3

2.2. Pressure relief

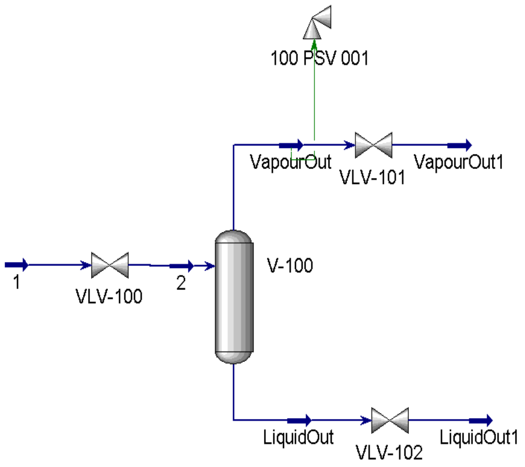

Figure 2. Storage tank with Pressure Relief Valve

Aspen HYSYS pressure relief (over-pressure protection and vacuum protection) calculations fall under the scope of API 2000. Defining the system to be protected is the first step for the preparation protective system design. Once the protective system is defined, then the identifying the location of pressure relief devices is the second step. In this step pressure relief valve is selected from the Aspen HYSYS safety environment and it is placed at the top of the storage tank, and it is connected with the vapour stream leaving the tank. A storage tank with pressure relief valve is shown in figure 2.

The selection of the pressure relieving device depends on the type of the scenario.

The information or data for relief system is gathered from standard codes, i.e., API 520, API 521and API 2000. Here phase behaviour of the system is considered, next design basis is specified. Finally, relief system is defined. Aspen HYSYS is provided with various overpressure scenarios. The list of overpressure scenarios in Aspen HYSYS is high pressure scenario, reaction scenario, thermal expansion of liquid scenario, external fire scenario, two-phase scenario. Various scenarios available in Aspen HYSYS are given in table 6. Credible scenarios are considered for size relief systems. Credible scenarios involve single failure. Care is taken in selecting the minimum allowable working pressure, maximum allowable temperature, and minimum design metal temperature. Set pressure is selected at which the device operates. Relief device is placed on the top of the storage tank. Since our system is low pressure storage tank, it requires both vacuum and pressure relief devices. For a fire scenario to vent to the flare, pilot operated relief valve is selected to compensate the backpressure from the downstream system. When the discharge is to the atmosphere spring relief valve is selected. For each scenario required relief flow rate and required relief area be determined. To calculate the required relief area, Aspen HYSYS uses the physical property data from thermodynamic property packages. The present system contains hydrocarbons Peng-Robinson model is selected for predicting properties. For a fire case scenario and high velocities of fluid two-phase flow calculations are considered. Next design basis is defined. The design basis for sizing pressure relief device needs the information of mass discharge rate, set pressure, overpressure, backpressure, temperature. For this study, there is a possibility of storage tank may expose to fire. Because of that sizing calculation for pressure relieving device are performed based on fire case scenario equations from API 2000 using Aspen HYSYS safety analysis environment.

3. Theory

This section discusses the equations used for normal venting, emergency venting, and pressure relief calculations for fire case scenario. All calculations are based on API Standard 2000/ISO 28300.

3.1. Normal venting equations

The thermal rate for heating up (thermal out-breathing) or cooling down (thermal inbreathing) is reduced by insulation. HYSYS calculates the reduction factor, for a fully insulated tank using Equation (1).

$$R_{in} = \frac{1}{1 + \frac{h.l_{in}}{\lambda_{in}}} \tag{1}$$

For partially insulated tanks reduction factor is given by equation (2)

$$R_{inp} = \frac{A_{inp}}{A_{TTS}}.R_{in} + \left(1 - \frac{A_{inp}}{A_{TTS}}\right) \tag{2}$$

Double walled insulation reduction factor is calculated by using equation (3)

$$R_c = 0.25 + 0.75\frac{A_c}{A_w} = 0.25 + 0.75f_c \tag{3}$$

In equation (3) uncontained area fraction f_c *is* specified. In this study, the storage tank is fully insulated so equation (1) can be used. Thermal out-breathing (i.e., the maximum thermal flow rate for heating up, due to atmospheric heating) and inbreathing (maximum thermal flow rate during cooling down, due to atmospheric cooling) of the external surfaces of the tank shell are calculated by using equation (4) and equation (5)

$$V_{OT} = Y.V_{tk}^{0.9}.R_i \tag{4}$$

The volume of the tank is equal to πDH. The Y-factor for the latitude in equation (4) is taken from Appendix-A. Latitude for the tank is between $42^0$and 58^0. So Y-factor is 0.25.

$$V_{IT} = C.V_{tk}^{0.7}.R_i \tag{5}$$

C is a function of vapor pressure, average storage temperature, and latitude. When using API 2000 7th Ed. Annex A, the thermal inbreathing requirements are determined from interpolation values between tank capacity volume and inbreathing capacity as shown in Appendix - B. From the Appendix-B, C factor value is 5.

The out-breathing volumetric flow rate is calculated by equation (6), and it is equal to the maximum volumetric filling rate. The maximum volumetric filling rate is calculated based on API2000, 7th edition standards.

$$V_{op} = V_{pf} \tag{6}$$

For more volatile components or dissolved gases, HYSYS performs flash calculations to increase the out-breathing venting requirements. For products stored above 40°C or for vapor pressure greater than 5 kPa, the out-breathing rate is increased by the evaporation rate. The inbreathing venting requirement will be the maximum specified liquid discharging capacity for the tank, as shown in Equation (7) and it is equal to the maximum rate of liquid discharging.

$$V_{ip} = V_{pe} \tag{7}$$

Venting capacity (i.e., V_{pf} and V_{pe}) calculations are based on API 2000, 7th edition standards. HYSYS uses the equation (8) to calculate the coefficient of discharge, *K*.

$$K_d = \frac{q_a}{q_{th}} \tag{8}$$

Test flow rate and theoretical flow rate uses test medium flow rate values. Generally, test medium is air only.

$$q_{th} = 125.15p_iA_{min}\sqrt{\left[\frac{1}{M.Z_i.T_i}\right]\left[\frac{k}{k-1}\right]\left[\left(\frac{p_0}{p_i}\right)^{\frac{2}{k}} - \left(\frac{p_0}{p_i}\right)^{\frac{k+1}{k}}\right]} \tag{9}$$

Equation (9) is used to calculate the theoretical flow rate.

3.2. Emergency venting equations

The wetted exposed surface area of a storage tank is calculated using equation (11). Exposed surface area equation for vertical tank needs the parameter wetted height. Wetted height is calculated using equation (10).

$$W = F_G - E \tag{10}$$

Equation (10) is valid for if H+E > F_G otherwise W = H.

$$A = \pi DW \tag{11}$$

Required venting capacity is calculated based on wetted area, design pressure, and environmental factor F. If the tank area <2800 ft^2 case, required venting capacity be calculated from equation (12).

$$q = 906.6\frac{QF}{L}\sqrt{\frac{T}{M}} \tag{12}$$

The heat input from fire *Q* is calculated based on the wetted area (A_{TWS}) and the design pressure. Heat input values are given in Appendix-D. Required venting capacities based on the wetted area are given in Appendix-E.

The volume of the storage tank depends on the tank type. Here the tank type is vertical and no bottom head. The volume of the storage tank is calculated from equation (13). Where D is the diameter of the tank and "H" is the height of the tank.

$$V = \frac{\pi D^2 H}{4} \tag{13}$$

Environmental Factors for Non-Refrigerated Aboveground Tanks are shown in Appendix -F. Environmental factor values are available for various types of tanks in design guidelines. All calculations are based on API Standard 2000/ISO 28300, 7th edition. For fire relief scenarios, the same calculations are used as for wetted surface area calculations for storage tanks. Additional venting requirements are latent heat of vaporization of hexane, equal to 334,900 J/kg at atmospheric pressure, and the relative molecular mass of hexane (86.17) and assuming a vapor temperature of 15.6°C. This method provides accurate results for many fluids with similar properties. Emergency venting requirements for storage tanks exposed to fire is shown in Appendix-G.

3.3. Pressure relief equations

Aspen HYSYS Safety Analysis environment has built-in tools to calculate the required relieving load for a subset of overpressure contingencies: Fire, Tube Rupture, Control Valve Failure, Thermal Expansion, Reflux Failure, and Fan Failure. This study deals with fire case scenario. For fire case scenario pressure relief load is calculated from equation (14) and equation (15).

$$Q = C_{DF} F A_{WS}^{0.82} \tag{14}$$

$$W = 3.6Q/\lambda \tag{15}$$

The rate of heat load added to the tank contents for the presence or absence of adequate draining for fire fighting is given by equations (16) and (17).

$$\mathrm{Q_{fire}} = 21000\mathrm{FA_e^{0.82}}\ \text{if adequate drainage} \tag{16}$$

$$\mathrm{Q_{fire}} = 34500\mathrm{F\ A_e^{0.82}}\ \text{, if inadequate drainage} \tag{17}$$

Environment factor is to account for the presence of fire proof insulation, with a value of 1. The environmental factor is given by equation (18).

$$F = \frac{k(1660 - T_{relief})}{21000\delta_{ins}} \tag{18}$$

If the total backpressure (pressure downstream of the nozzle) is greater than the critical flow pressure, then the subcritical flow will occur. Critical flow pressure is given by equation (19)

$$\frac{P_{cf}}{P_1} = \left[\frac{2}{k+1}\right]^{\frac{k}{k-1}} \tag{19}$$

As per API 520, 8th edition, calculation of PSV orifice size under subcritical flow conditions can be calculated using equation (20).

$$A_o = \frac{W}{735 * F_2 * K_d * K_c}\sqrt{\frac{T * Z}{M * P_1(P_1 - P_2)}} \qquad (20)$$

4. Results and discussion

Storage tanks may expose to various hazardous conditions. Each hazard case is considered as a scenario. Various scenarios and the reasons for the occurrence of scenarios are shown in detail in table 6. In most cases, low-pressure storage tanks will face hazard from fire. Because of that in this study fire case scenario is considered for pressure relief calculations.

Normal venting requirements are in breathing or vacuum relief and out-breathing. For these two cases, pressure relief must satisfy the maximum requirements for liquid flows into and out of the tanks as well as thermal breathing caused by changes in atmospheric temperature. Normal venting calculations are completed using equations (1) to equation (9). Emergency venting calculations are completed using the equation (10) to equation (13). Input values required are set pressure, vacuum set pressure, maximum liquid inflow, and maximum liquid outflow and vapour molecular weight. Normal venting input conditions are shown in table 2. Corresponding results for inbreathing and out-breathing results are shown in table 4. Breathing device type is pressure and vacuum relief and API2000, 7th edition standards. From the results, it is evident that the calculated size of pressure and vacuum device is for in-breathing 3.499 cm and out-breathing 3.276 cm.

Table 4. Normal venting results

Results	In-breathing	Out-breathing
Liquid movement [Nm³/h]	11.36	34.54
Thermal [Nm³/h]	31.07	2.727
Total [Nm³/h]	42.42	37.27
Preliminary device area [cm²]	9.613	8.427
Preliminary calculated size [cm]	3.499	3.276

Table 5. Emergency venting results

Results	value
Calculated Exposed Area [m²]	39.40
Calculated Heat Input [Kcal/h]	1.542E+006
Calculated Relieving Flow [Nm³/h]	2.008E+004
Preliminary Device Area [cm²]	4256
Preliminary Calculated Size [cm]	73.62

Emergency venting input values are shown in table 3. Emergency venting type is Man way/Emergency Vent. Flame height from grade 30 ft, environment factor (F) is 1. Fluid latent heat is 50 Btu/lb. Set pressure 5.42×10^{-2} mbarG, Bottom Tan above grade 3 feet, flame height from grade 30 feet. Emergency venting results are given in table 5. Calculated size for emergency venting is 73.62 cm.

Table 6. Various scenarios

Scenario Name	Sub Scenarios
General	Fire Thermal Expansion Overfilling User Defined
Control Valve related	Blocked Outlet Control Valve Failure Abnormal Flow through valve Failure of Automatic Controls
Heaters and Coolers Scenario	Exchanger Tube Rupture Cold Side of Exchanger Blocked-In Blocked-In Fired Heater Fan Failure

Scenario Name	Sub Scenarios
Flare Scenario	General Power Failure Local Power failure Cooling Water Failure Coolant Failure (Other than Cooling Water) Loss of Heat
Reaction/Mixing Scenario	Chemical Reaction Accidental Mixing Inadvertent Loss of Segregation Pressure Surge or Internal Explosion
Distillation Column/Tower Scenario	Reflux Failure Reflux Failure (Side Stream) Abnormal Heat or Vapor Input Accumulation of Non- Condensable Loss of Absorbent

For fire scenario, the vapour outlet stream from the tank is considered as the reference stream. The scenario set up values are relieving temperature 24.4^0C, relieving pressure is 4.522×10^{-3} mbarG. Total back pressure is 3.737×10^{-4} mbarG. Relieving phase is vapour. Line sizing input data and line sizing results are shown in table 7 and in table 8. For line sizing calculations PSV inline size is 2 inch, outline size 2 inches. The nominal diameter of the inline and outline is 2 inches. Schedule for inline and outline is 80. The inner diameter of both inline and outline is 1.939 inch, and roughness of the pipe for both inline and outline is 0.04572 mm. Average velocities required, through the inline stream is 1.188 m/s and through the outline are 1.196 m/s. Pressure relief sizing calculations are given table 9. The required flow rate is 4.536 kg/hr to meet this criterion required a diameter of the orifice is 0.523 cm^2. Selected orifice size is 0.709 cm^2. Allowable overpressure is 21%.

Table 7. Line sizing input

Line sizing inputs	InLine	OutLine
PSV flange size [in]	1	2
N.D. [in]	2	2
Schedule	80	80
I.D. [in]	1.939	1.939

Table 8. Line sizing results

Line sizing results	InLine	OutLine
Calculated DP [bar]	1.352E-5	1.360E-5
Maximum DP [bar]	1.121E-4	3.737E-4
Average velocity [m/s]	1.188	1.196
Average Rho*v^2 [kg/m/s²]	1.065	1.072

Table 9. Sizing results for fire case scenario

PSV results	Values
Calculated Orifice [cm²]	0.523
Selected Orifice [cm²]	0.709(D)
Rated Capacity [kg/h]	6.14
Capacity Used [%]	73.78
In/Out Flanges	150 x 150
Noise Level	48.44
Noise Height [m]	30
Discharge Coefficient (Kd)	0.975

5. Conclusions

The industrial atmospheric storage tank protection using Aspen HYSYS safety analysis is explained. Normal venting and emergency venting calculation procedure are explained. Pressure relief calculation procedure explained for fire case scenario. This methodology is time-saving and cost saving. Oversizing of the relief systems and repeated readjustments of the process, equipment can be avoided by following this approach. The methodology developed here can be used internationally for similar kind of storage tank in other chemical industries.

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Nomenclature

A	*Total tank surface area (shell and roof), m²*
A_c	*Tank surface area not inside the containment tank, m²*
A_e	*Calculated tank exposed Area, m²*
A_{inp}	*Insulated surface area of the tank, m²*
A_{min}	*Minimum flow area of the device, expressed in cm²*
A_o	*Orifice area, m²*
A_w	*Vessel wetted surface area for double-walled insulation, m²*
A_{WS}	*Exposed wetted surface area of the vessel, m²*
C	*Factor that depends on vapor pressure, average storage temperature, and latitude*
C_{DF}	*Constant to account for the presence or absence of adequate draining*
D	*Diameter of tank, m*
E	*Bottom Tan above Grade,*
f_c	*Fraction of the tank surface area not inside the containment tank*
F	*Environmental factor*
F_G	*Flame height from grade, m*
H	*Height, m*
h	*Inside heat-transfer coefficient, W/m².K*
k	*Ratio of specific heats of the test medium at the test conditions*
K_d	*Coefficient of discharge*
K_c	*Combination correction factor for installations with a rupture disk upstream of pressure safety valve*
k_{ins}	*Insulation thermal conductivity, Watt/h. m.K*
L	*Latent heat of vaporization of the stored liquid at the relieving temperature and pressure, J/kg*
l_{in}	*Wall thickness of the insulation, m*
M	*Relative molecular mass of the vapour, kg/kmol*
M_T	*Relative molecular mass of the test medium, kg/kmol*
p_i	*Absolute pressure at device inlet, kPa*
p_o	*Absolute pressure at device outlet, kPa*
P_{cf}	*Critical flow pressure, kPa*
q	*Required venting capacity, m³/hr*
q_a	*Test flow rate when the test medium is air, m³/hr*
q_{th}	*Theoretical flow rate when the test medium is air, m³/hr*
Q	*Heat input, Watt*
Q_{fire}	*Total heat absorption to the wetted surface, Watt/h*
T	*Absolute temperature, K*
T_i	*Absolute temperature at device inlet, K*
T_{relief}	*Fluid relieving temperature, °C*
V	*Storage tank volume, m³*
V_{op}	*Out-breathing volumetric flow rate, m³/hr of air*
V_{ip} *of air*	*Inbreathing venting requirement, m³/hr*
V_{pf}	*Maximum volumetric filling rate, m³/hr*
V_{pe}	*Maximum rate of liquid discharging, m³/hr*
V_{IT}	*Inbreathing of the external surfaces of the tank shell, Nm³/h*
V_{OT}	*Thermal out-breathing of the external surface of the tank shell, Nm³/h*
R_c	*Reduction factor for tank containing partial or complete double walls*
R_i	*Reduction factor for insulation*
R_{in}	*Reduction factor for fully insulated tanks*
R_{inp}	*Reduction factor for partially insulated tanks*
V_{tk}	*Tank volume, m³*
W	*Wetted height, m*
Y	*Factor for the latitude*
Z_i	*Compressibility factor evaluated at inlet conditions*
λ_{in}	*Thermal conductivity of the insulation, W/m. K*
δ_{ins}	*Thickness of the insulation, m*

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