

Venting Atmospheric and Low-pressure Storage Tanks

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Introduction

This standard has been developed from the accumulated knowledge and experience of qualified engineers of the oil, petroleum, petrochemical, chemical, and general bulk liquid storage industry.

Engineering studies of a particular tank can indicate that the appropriate venting capacity for the tank is not the venting capacity estimated in accordance with this standard. The many variables associated with tank-venting requirements make it impractical to set forth definite, simple rules that are applicable to all locations and conditions.

In this standard, where practical, U.S. customary (USC) units are included in parentheses or in separate tables, for information.

Venting Atmospheric and Low-pressure Storage Tanks

1 Scope

This standard covers the normal and emergency vapor venting requirements for aboveground liquid petroleum or petroleum products storage tanks and aboveground and underground refrigerated storage tanks designed for operation at pressures from full vacuum through 103.4 kPa (ga) (15 psig). Discussed in this standard are the causes of overpressure and vacuum; determination of venting requirements; means of venting; selection and installation of venting devices; and testing and marking of relief devices.

This standard is intended for tanks containing petroleum and petroleum products, but it can also be applied to tanks containing other liquids; however, it is necessary to use sound engineering analysis and judgment whenever this standard is applied to other liquids.

This standard does not apply to external floating-roof tanks.

2 Terms, Definitions, and Abbreviated Terms

For the purposes of this document, the following terms, definitions, and abbreviated terms apply.

2.1

accumulation

Pressure increase over the maximum allowable working pressure or design pressure of the vessel during discharge through the pressure-relief device.

NOTE Accumulation is expressed in units of pressure or as a percentage of maximum allowable working pressure or design pressure. Maximum allowable accumulations are established by pressure-design codes for emergency operating and fire contingencies.

2.2

adjusted set pressure

Inlet static pressure at which a pressure-relief valve is adjusted to open on the test stand.

See **set pressure** (2.20).

NOTE 1 Adjusted set pressure is equivalent to set pressure for direct-mounted end-of-line installations.

NOTE 2 The adjusted set pressure includes corrections for service conditions of superimposed back-pressure.

2.3

British thermal unit

Btu

Unit of heat that increases the temperature of one pound of water by one degree Fahrenheit.

2.4

bubble point

Temperature at which the first vapor bubble is produced from a liquid mixture of two or more components heated at constant pressure. For single component systems the bubble point is referred to as the boiling point.

2.5

emergency venting

Venting required for external fire or other abnormal conditions (see 3.2.5).

2.6**full open position**

Position where lift of the pallet is sufficient for the nozzle to control the flow or where the pallet or main valve seat lifts against a fixed stop.

2.7**nonrefrigerated tank**

Container that stores material in a liquid state without the aid of refrigeration, either by evaporation of the tank contents or by a circulating refrigeration system.

NOTE Generally, the storage temperature is close to, or higher than, ambient temperature.

2.8**normal cubic meters per hour**

Nm³/h

SI unit for volumetric flow rate of air or gas at a temperature of 0 °C and pressure of 101.3 kPa, expressed in cubic meters per hour.

2.9**normal venting**

Venting required because of operational requirements or atmospheric changes.

2.10**overpressure**

Pressure increase at the PV valve inlet above the set pressure, when the PV valve is relieving.

NOTE 1 Overpressure is expressed in pressure units or as a percentage of the set pressure.

NOTE 2 The value or magnitude of the overpressure is equal to the value or magnitude of the accumulation when the valve is set at the maximum allowable working pressure or design pressure and the inlet piping losses are zero.

2.11**petroleum**

Crude oil.

2.12**petroleum products**

Hydrocarbon materials or other products derived from crude oil.

2.13**PV valve**

Weight-loaded, pilot-operated, or spring-loaded pressure vacuum valve used to relieve excess pressure and/or vacuum that has developed in a tank.

2.14**rated relieving capacity**

Flow capacity of a relief device expressed in terms of air flow at standard or normal conditions at a designated pressure or vacuum.

NOTE Rated relieving capacity is expressed in SCFH or Nm³/h.

2.15**refrigerated tank**

Container that stores liquid at a temperature below atmospheric temperature with or without the aid of refrigeration, either by evaporation of the tank contents or by a circulating refrigeration system.

2.16**relief device**

Device used to relieve excess pressure and/or vacuum that has developed in a tank.

2.17**relieving pressure**

Pressure at the inlet of a relief device when the fluid is flowing at the required relieving capacity.

2.18**required flow capacity**

Flow through a relief device required to prevent excessive pressure or vacuum in a tank under the most severe operating or emergency conditions.

2.19**rollover**

Uncontrolled mass movement of stored liquid, correcting an unstable state of stratified liquids of different densities and resulting in a significant evolution of product vapor.

2.20**set pressure**

Gauge pressure at the relief device inlet at which the device is set to start opening under service conditions.

2.21**standard cubic feet per hour****SCFH**

USC unit for volumetric flow rate of air or gas (same as free air or free gas) at a temperature of 15.6 °C (60 °F) and an absolute pressure of 101.3 kPa (14.7 psi), expressed in cubic feet per hour.

2.22**thermal inbreathing**

Movement of air or blanketing gas into a tank when vapors in the tank contract or condense as a result of weather changes (e.g. a decrease in atmospheric temperature).

2.23**thermal out-breathing**

movement of vapors out of a tank when vapors in the tank expand and/or liquid in the tank vaporizes as a result of weather changes (e.g. an increase in atmospheric temperature).

2.24**vapor pressure**

The pressure exerted when a liquid is in equilibrium with its own vapor. Vapor pressure is a function of the substance and temperature.

2.25**wetted area**

Surface area of a tank exposed to liquid on the interior and heat from a fire on the exterior.

3 Nonrefrigerated Aboveground Tanks

3.1 General

Section 4 covers the causes of overpressure or vacuum; determination of venting requirements; means of venting; and selection and installation of venting devices.

3.2 Causes of Overpressure or Vacuum

3.2.1 General

When determining the possible causes of overpressure or vacuum in a tank, consider the following:

- a) liquid movement into or out of the tank;
- b) weather changes (e.g. pressure and temperature changes);
- c) fire exposure;
- d) other circumstances resulting from equipment failures and operating errors.

There can be additional circumstances that should be considered but are not included in this standard.

3.2.2 Liquid Movement into or out of a Tank

Liquid can enter or leave a tank by pumping, by gravity flow, or by process pressure.

Vacuum can result from the outflow of liquid from a tank. Overpressure can result from the inflow of liquid into a tank and from the vaporization or flashing of the feed liquid. The user is cautioned that a flashing feed stream can create an outbreathing load that is much greater than the volumetric inflow of liquid. See 3.3 for calculation methods.

3.2.3 Weather Changes

Vacuum can result from the contraction or condensation of vapors caused by a decrease in atmospheric temperature or other weather changes, such as wind changes, precipitation, etc. Overpressure can result from the expansion and vaporization that is caused by an increase in atmospheric temperature or weather changes. See 3.3 for calculation methods.

3.2.4 Fire Exposure

Overpressure can result from the expansion of the vapors and vaporization of the liquid that may occur when a tank absorbs heat from an external fire. See 3.3.3 for calculation methods.

3.2.5 Other Circumstances

3.2.5.1 General

When the possible causes of overpressure or vacuum in a tank are being determined, other circumstances resulting from equipment failures and operating errors shall be considered and evaluated. Calculation methods for these other circumstances are not provided in this standard.

3.2.5.2 Pressure Transfer Vapor Breakthrough

Liquid transfer from other vessels, tank trucks, and tank cars can be aided or accomplished entirely by pressurization of the supply vessel with a gas, but the receiving tank can encounter a flow surge at the end of the transfer due to vapor breakthrough. Depending on the preexisting pressure and free head space in the receiving tank, the additional gas volume can be sufficient to overpressure the tank. The controlling case is a transfer that fills the receiving tank to its maximum level so that little head space remains to absorb the pressure surge.

3.2.5.3 Inert Pads and Purges

Inert pads and purges are provided on tanks to protect the contents of the tanks from contamination, maintain nonflammable atmospheres in the tanks, and reduce the extent of the flammable envelope of the

vapors vented from the tanks. An inert pad and purge system normally has a supply regulator and a back-pressure regulator to maintain interior tank pressure within a narrow operating range. Failure of the supply regulator can result in unrestricted gas flow into the tank and subsequent tank overpressure, reduced gas flow, or complete loss of the gas flow. Failure closed of the back-pressure regulator can result in a blocked outlet and overpressure. If the back-pressure regulator is connected to a vapor-recovery system, its failure open can result in vacuum.

3.2.5.4 Abnormal Heat Transfer

Steam, tempered water, and hot oil are common heating media for tanks that contain materials that must be maintained at elevated temperature. Electrical heating elements are also used for the same purpose. Failure of a tank's heat medium supply control valve, temperature-sensing element, or control system can result in tank overpressure due to increased heat input and liquid vaporization.

Heated tanks that have two liquid phases present the possibility of a rapid vaporization if the lower phase is heated to the point where its density becomes lower than the density of the liquid above it. It is recommended to specify design and operating practices to avoid these conditions.

If a tank maintained at elevated temperatures is empty, excessive feed vaporization can result when the tank is filled. If the temperature control system of the tank is active with the temperature sensing element exposed to vapor, the tank's heating medium can be circulating at maximum rate with the tank wall at maximum temperature. Filling under such conditions can result in excessive feed vaporization. The excessive feed vaporization stops as soon as the walls have cooled and the fluid level covers the sensing element.

For a tank with a cooling jacket or coils, liquid vaporization as a result of the loss of coolant flow shall be considered.

3.2.5.5 Internal Failure of Heat-transfer Devices

Mechanical failure of a tank's internal heating or cooling device can release the heating or cooling medium into the tank. Chemical compatibility of the tank contents and the heat-transfer medium shall be considered. Relief of the heat-transfer medium (e.g. steam) can be necessary.

3.2.5.6 Vent Treatment Systems

If vapor from a tank is collected for treatment or disposal by a vent treatment system, the vent collection system can fail. This failure shall be evaluated. Failures affecting the safety of a tank can include back-pressure developed from problems in the piping (liquid-filled pockets and solids build-up), other equipment venting, or relieving into the header or blockage due to equipment failure. An emergency venting device that relieves to atmosphere, set at a higher pressure than the vent treatment system, may be used if appropriate.

3.2.5.7 Utility Failure

Local and plant-wide power and utility failures shall be considered as possible causes of overpressure or vacuum. Loss of electrical power directly affects any motorized valves or controllers and can also shut down the instrument air supply. Also, cooling and heating fluids can be lost during an electrical failure.

3.2.5.8 Change in Temperature of the Input Stream to a Tank

A change in the temperature of the input stream to a tank, brought about by a loss of cooling or an increase in heat input, can cause overpressure in the tank. A lower-temperature inlet stream can result in vapor condensation and contraction, which can cause vacuum.

3.2.5.9 Chemical Reactions

The contents of some tanks can be subject to chemical reactions that generate heat and/or vapors. Some examples of chemical reactions include inadvertently adding water to acid or spent acid tanks, thereby

generating steam and/or vaporizing light hydrocarbons; runaway reactions in tanks containing cumene hydroperoxide; etc. In some cases, the material can foam, causing two-phase relief.

Technology available from the Design Institute for Emergency Relief Systems (DIERS) Users Group of the American Institute of Chemical Engineers (AIChE) or from the DIERS group in Europe may be used to evaluate these cases.

3.2.5.10 Liquid Overfill

Tank venting devices should not be used for protection against liquid overfill. For information on liquid overfill protection, see API 2510, API 2350, and EN 13616.

3.2.5.11 Atmospheric Pressure Changes

A rise or drop in barometric pressure is a possible cause of vacuum or overpressure in a tank. This is usually insignificant for nonrefrigerated tanks; however, it should be considered for refrigerated tanks since the material is being stored close to its boiling point (see 4.2.1.2).

3.2.5.12 Control Valve Failure

The effect of a control valve failing open or failing closed shall be considered to determine the potential for pressure or vacuum due to mass and/or energy imbalances. For example, failure of a control valve on the liquid line to a tank can increase heat input or decrease heat removal resulting in the admission of high-temperature material into the tank. A control-valve failure can also cause the liquid level in a pressurized vessel feeding liquid to a tank to drop below the vessel outlet nozzle, allowing high-pressure vapor to enter the tank (see 3.2.5.2).

3.2.5.13 Steam Condensation

If an uninsulated tank is filled with steam (e.g. for steam-out decontamination), the condensing rate due to ambient cooling can exceed the venting rates specified in this standard. Procedures, such as the use of large vents (open manways), controlling the tank cooling rate, or adding a noncondensable gas such as air or nitrogen, are often necessary to prevent excessive internal vacuum.

3.2.5.14 Uninsulated Hot Tanks

Uninsulated tanks with exceptionally hot vapor spaces can exceed the thermal inbreathing requirements in this standard during a rainstorm. Vapor contraction and/or condensing can cause excessive vacuum. An engineering review of heated, uninsulated tanks with vapor-space temperatures above 48.9 °C (120 °F) is recommended.

3.2.5.15 Internal Explosion/Deflagration

If a tank vapor space becomes flammable and is ignited, the resulting gas expansion can exceed the capabilities of storage tank pressure relief vents. API 937 allows the use of a weak (frangible) roof-to-shell attachment to relieve internal deflagration. See API 650 for detailed requirements for the frangible roof-to-shell attachment design. See NFPA 68 and EN 13237 for alternative methods for mitigating tank internal deflagration. Internal explosions/deflagrations can be prevented by utilizing proper tank inerting. See Annex F for guidance on tank inerting.

3.2.5.16 Mixing of Products of Different Composition

Introduction of materials that are more volatile than those normally stored can be possible due to upsets in upstream processing or human error. This can result in overpressure.

3.3 Determination of Venting Requirements

3.3.1 General

Determine the applicable causes of overpressure and vacuum (refer to 3.2) and quantify the venting requirements for each one. The following guidance can assist in quantifying the venting requirements for commonly encountered conditions:

- a) normal inbreathing resulting from a maximum outflow of liquid from the tank (liquid-transfer effects),
- b) normal inbreathing resulting from contraction or condensation of vapors caused by a maximum decrease in vapor-space temperature (thermal effects),
- c) normal out-breathing resulting from a maximum inflow of liquid into the tank and maximum vaporization caused by such inflow (liquid-transfer effects),
- d) normal out-breathing resulting from expansion and vaporization that results from a maximum increase in vapor-space temperature (thermal effects),
- e) emergency venting resulting from fire exposure.

When determining the venting requirements, the largest single contingency requirement or any reasonable and probable combination of contingencies shall be considered as the design basis. At a minimum, the combination of the liquid-transfer effects and thermal effects for normal venting shall be considered when determining the total normal inbreathing or out-breathing.

With the exception of refrigerated storage tanks, common practice is to consider only the total normal inbreathing for determining the venting requirements. That is, inbreathing loads from other circumstances described in 3.2.5 are generally not considered coincident with the normal inbreathing. This is considered a reasonable approach because the thermal inbreathing is a severe and short-lived condition.

For the total out-breathing, consider the scenarios described in 3.2.5 and determine whether these should be coincident with normal out-breathing venting requirements.

3.3.2 Calculation of Required Flow Capacity for Normal Out-breathing and Inbreathing

3.3.2.1 General

The method described in 3.3.2.1 is based on engineering calculations. See Annex E for the assumptions on which this calculation method is based. For a more detailed understanding of this model, see References [21] and [22].

Alternatively, the normal out-breathing and inbreathing flow rates may be based on the method described in Annex A where the tank meets the service conditions specified in Annex A. It is the user's responsibility to determine which method is used for sizing tank vents for new or existing tanks.

The calculation method utilized shall be documented.

3.3.2.2 Required Flow Capacity Due to Filling and Discharge

3.3.2.2.1 Out-breathing

The out-breathing shall be determined as follows. In these calculations, the vapor/gas being displaced will be at the actual pressure and temperature conditions of the tank vapor space. Out-breathing flows shall be converted to an air-equivalent flow at normal or standard conditions for tanks operating above 49 °C (120 °F). Annex D.9 provides more information on performing this conversion.

- a) **Nonvolatile Liquids**—Nonvolatile liquids are products with a vapor pressure equal to or less than 5.0 kPa (0.73 psi).

The out-breathing volumetric flow rate $\dot{V}_{op}$, expressed in SI units of cubic meters per hour of vapor/gas at the actual pressure and temperature conditions of the tank vapor space, shall be as given by Equation (1):

$$\dot{V}_{op} = \dot{V}_{pf} \quad (1)$$

where $\dot{V}_{pf}$ is the maximum volumetric filling rate of nonvolatile liquids, expressed in cubic meters per hour.

The out-breathing volumetric flow rate $\dot{V}_{op}$, expressed in USC units of cubic feet per hour of-vapor/gas at the actual pressure and temperature conditions of the tank vapor space shall be as given by Equation (2):

$$\dot{V}_{op} = 8.02 \cdot \dot{V}_{pf} \quad (2)$$

where $\dot{V}_{pf}$ is the maximum volumetric filling rate of nonvolatile liquids, expressed in U.S. gallons per minute.

- b) **Volatile Liquids**—Volatile liquids are products with a vapor pressure greater than 5.0 kPa (0.73 psi). The flow of volatile liquids into a tank will result in higher out-breathing flow (compared to the same inflow with a nonvolatile liquid) due to changes in liquid-vapor equilibrium.

The out-breathing volumetric flow rate $\dot{V}_{op}$, expressed in SI units of cubic meters per hour of vapor/gas at the actual pressure and temperature conditions of the tank vapor space, shall be as given by Equation (3):

$$\dot{V}_{op} = 2.0 \cdot \dot{V}_{pf} \quad (3)$$

where $\dot{V}_{pf}$ is the maximum volumetric filling rate of volatile liquid, expressed in cubic meters per hour.

The out-breathing volumetric flow rate $\dot{V}_{op}$, expressed in USC units of cubic feet per hour of vapor/gas at the actual pressure and temperature conditions of the tank vapor space, shall be as given by Equation (4):

$$\dot{V}_{op} = 16.04 \cdot \dot{V}_{pf} \quad (4)$$

Where $\dot{V}_{pf}$ is the maximum volumetric filling rate of volatile liquid, expressed in U.S. gallons per minute.

- c) **Flashing Liquids**—Flashing liquids can cause the venting requirement to be many times greater than the volumetric in-flow of the liquid. Flashing will occur when the vapor pressure of the entering stream is greater than the operating pressure of the tank. For products that can flash due to high temperature or because of dissolved gases (e.g. oil spiked with methane), perform an equilibrium flash calculation and increase the out-breathing venting requirements accordingly.

3.3.2.2.2 Inbreathing

The inbreathing venting requirement $\dot{V}_{ip}$, expressed in SI units of normal cubic meters per hour of air, shall be the maximum specified liquid discharging capacity for the tank as given by Equation (5).

$$\dot{V}_{ip} = \dot{V}_{pe} \quad (5)$$

where $\dot{V}_{pe}$ is the maximum rate of liquid discharging, expressed in cubic meters per hour.

Calculate the inbreathing venting requirement $\dot{V}_{ip}$, expressed in USC units of standard cubic feet per hour of air, in accordance with Equation (6):

$$\dot{V}_{ip} = 8.02 \cdot \dot{V}_{pe} \quad (6)$$

where $\dot{V}_{pe}$ is the maximum rate of liquid discharging, expressed in U.S. gallons per minute.

The calculated inbreathing assumes ambient air flow through the tank vent. It is typical practice to assume the ambient air is at normal or standard conditions. If a medium other than air is used for vacuum relief, then it may be necessary to convert the rate to an air equivalent flow. See D.9.

3.3.2.3 Required Flow Capacity Due to Thermal Out-breathing and Inbreathing

3.3.2.3.1 General

Consider thermal out-breathing and inbreathing due to atmospheric heating or cooling of the external surfaces of the tank shell and roof. Calculation of the thermal in and out-breathing is a function of tank vapor volume. For vertical cylindrical tanks, use of volume based on the tank shell height is acceptable. The calculated thermal inbreathing and out-breathing are expressed in normal/standard air equivalent flow as defined in Annex D.2.

3.3.2.3.2 Thermal Out-breathing

Calculate the thermal out-breathing (i.e. the maximum thermal flow rate for heating up) $\dot{V}_{OT}$, expressed in SI units of normal cubic meters per hour of air, in accordance with Equation (7):

$$\dot{V}_{OT} = Y \cdot V_{tk}^{0.9} \cdot R_i \quad (7)$$

where

Y is a factor for the latitude (see Table 1);

V_{tk} is the tank volume, expressed in cubic meters;

R_i is the reduction factor for insulation [$R_i = 1$ if no insulation is used; $R_i = R_{inp}$ for partially insulated tanks [see Equation (12)]; $R_i = R_{in}$ for fully insulated tanks [see Equation (11)]].

Calculate the thermal out-breathing (i.e. the maximum thermal flow rate for heating up) $\dot{V}_{OT}$, expressed in USC units as standard cubic feet per hour of air, in accordance with Equation (8):

$$\dot{V}_{OT} = 1.51 \cdot Y \cdot V_{tk}^{0.9} \cdot R_i \quad (8)$$

where

Y is a factor for the latitude (see Table 1);

V_{tk} is the tank volume, expressed in cubic feet;

R_i is the reduction factor for insulation [$R_i = 1$ if no insulation is used; $R_i = R_{inp}$ for partially insulated tanks [see Equation (12)]; $R_i = R_{in}$ for fully insulated tanks [see Equation (11)]].

The Y -factor for the latitude in Equations (7) and (8) can be taken from Table 1.

Table 1— Y -factor for Various Latitudes

Latitude	Y -factor
Below 42°	0.32
Between 42° and 58°	0.25
Above 58°	0.2

3.3.2.3.3 Thermal Inbreathing

Calculate the maximum thermal flow rate during cooling down $\dot{V}_{IT}$, expressed in SI units of normal cubic meters per hour of air, in accordance with Equation (9):

$$\dot{V}_{IT} = C \cdot V_{tk}^{0.7} \cdot R_i \quad (9)$$

where

C is a factor that depends on vapor pressure, average storage temperature and latitude (see Table 2);

V_{tk} is the tank volume, expressed in cubic meters;

R_i is the same as for Equation (7).

Calculate the maximum thermal flow rate during cooling down $\dot{V}_{IT}$, expressed in USC units of standard cubic feet per hour of air, in accordance with Equation (10):

$$\dot{V}_{IT} = 3.08 \cdot C \cdot V_{tk}^{0.7} \cdot R_i \quad (10)$$

where

C is a factor that depends on vapor pressure, average storage temperature and latitude (see Table 2);

V_{tk} is the tank volume, expressed in cubic feet;

R_i is the same as for Equation (8).

The calculated inbreathing assumes ambient air flow through the tank vent. It is typical practice to assume the ambient air is at normal or standard conditions. If a medium other than air is used for vacuum relief, then it may be necessary to convert the rate to an air equivalent flow. See D.9.

Uninsulated hot tanks that could be subjected to a rapid temperature drop greater than 40 °C may have inbreathing rates higher than indicated above. These should be evaluated on a case-by-case basis. See 3.2.5.14.

Table 2—C-factors

Latitude	C-factor for various conditions			
	Vapor pressure similar to Hexane		Vapor pressure higher than hexane, or unknown	
	Average storage temperature °C			
	< 25	≥ 25	< 25	≥ 25
Below 42°	4	6.5	6.5	6.5
Between 42° and 58°	3	5	5	5
Above 58°	2.5	4	4	4

3.3.2.4 Reduction Factor for Tanks with Insulation

The thermal flow rate for heating up (thermal out-breathing) or cooling down (thermal inbreathing) is reduced by insulation and depends upon the properties and thickness of the insulation.

Calculate the reduction factor, R_{in} , for a fully insulated tank as given by Equation (11).

$$R_{in} = \frac{1}{1 + \frac{h \cdot l_{in}}{\lambda_{in}}} \quad (11)$$

where

h is the inside heat-transfer coefficient, expressed in watts per square meter-kelvin [Btu/(h·ft²·°F)];

NOTE An inside heat-transfer coefficient of 4 W/(m²·K) [0.7 Btu/(h·ft²·°F)] is commonly assumed for typical tanks.

l_{in} is the wall thickness of the insulation, expressed in meters (ft);

λ_{in} is the thermal conductivity of the insulation, expressed in watts per meter-kelvin [Btu/(h·ft·°F)].

EXAMPLE For an insulation thickness l_{in} , equal to 0.1 m, a thermal conductivity of the insulation λ_{in} , equal to 0.05 W/(m·K), and a heat-transfer coefficient h , equal to 4 W/(m²·K), the reduction factor R_{in} is equal to 0.11. Thus, the out-breathing venting requirement of the insulated tank is 0.11 times that of the uninsulated tank.

Calculate the reduction factor, R_{inp} , for a partially insulated tank as given by Equation (12):

$$R_{inp} = \frac{A_{inp}}{A_{TTS}} \cdot R_{in} + \left(1 - \frac{A_{inp}}{A_{TTS}}\right) \quad (12)$$

where

A_{TTS} is the total tank surface area (shell and roof), expressed in square meters (square feet);

A_{inp} is the insulated surface area of the tank, expressed in square meters (square feet).

3.3.2.5 Reduction Factor for Double Wall Tanks

Double wall tanks will have reduced heat transfer to the environment. The reduction factor, R_c , may be calculated using Equation (13):

$$R_c = 0.25 + 0.75 \frac{A_c}{A} \quad (13)$$

where

A is the total tank surface area (shell and roof), in square meters or square feet;

A_c is the tank surface area not inside of the containment tank, in square meters or square feet.

Use the R_c value for R_i in Equations (7), (8), (9), and (10).

3.3.3 Required Flow Capacity for External Fire Exposure (Emergency Venting)

3.3.3.1 General

When storage tanks are exposed to fire, the venting rate can exceed the rate resulting from normal out-breathing.

3.3.3.2 Tanks with Weak Roof-to-shell Attachment

On a fixed-roof tank with a weak (frangible) roof-to-shell attachment, such as that described in API 650, the roof-to-shell connection will fail prior to other tank welds, allowing relief of the excess pressure if the normal venting capacity proves inadequate. For a tank built to these specifications, it is not necessary to consider additional requirements for emergency venting; however, additional emergency vents may be used to avoid failure of the frangible joint. Care should be taken to ensure that the current requirements for a frangible roof-to-shell attachment are met, particularly for tanks smaller than 15 m (50 ft) in diameter.

3.3.3.3 Fire Relief Requirements

3.3.3.3.1 When a tank is not provided with a weak roof-to-shell attachment as described in 3.3.3.2, the procedure given in 3.3.3.3.2 through 3.3.3.3.7 shall govern in evaluating the required flow capacity for fire exposure.

3.3.3.3.2 Calculate the required flow capacity q , expressed in SI units of normal cubic meters per hour of air, for tanks subject to fire exposure as given by Equation (14):

$$q = 906.6 \cdot \frac{Q \cdot F}{L} \cdot \left(\frac{T}{M} \right)^{0.5} \quad (14)$$

where

Q is the heat input from fire exposure as given by Table 3, expressed in watts;

F is the environmental factor from Table 9 (credit may be taken for only one environmental factor);

L is the latent heat of vaporization of the stored liquid at the relieving pressure and temperature, expressed in joules per kilogram;

T is the absolute temperature of the relieving vapor, expressed in kelvins;

NOTE It is normally assumed that the temperature of the relieving vapor corresponds to the bubble point of the stored fluid at the relieving pressure.

M is the relative molecular mass of the vapor.

Table 3—Heat Input, Q
(Expressed in SI Units)

Wetted Surface Area, A_{TWS} m ²	Design Pressure kPa (gauge)	Heat Input, Q W
<18.6	≤103.4	$63,150A_{TWS}$
≥18.6 and <93	≤103.4	$224,200 \times (A_{TWS})^{0.566}$
≥93 and <260	≤103.4	$630,400 \times (A_{TWS})^{0.338}$
≥260	>7 and ≤103.4	$43,200 \times (A_{TWS})^{0.82}$
≥260	≤7	4,129,700

Calculate the required flow capacity q , expressed in USC units of standard cubic feet per hour of air, for tanks subject to fire exposure as given by Equation (15).

$$q = 3.091 \cdot \frac{Q \cdot F}{L} \cdot \left(\frac{T}{M} \right)^{0.5} \quad (15)$$

where

Q is the heat input from fire exposure as given by Table 4, expressed in British thermal units per hour;

F is the environmental factor from Table 9 (credit may be taken for only one environmental factor);

L is the latent heat of vaporization of the stored liquid at the relieving pressure and temperature, expressed in British thermal units per pound;

T is the absolute temperature of the relieving vapor, expressed in degrees Rankine;

NOTE It is normally assumed that the temperature of the relieving vapor corresponds to the bubble point of the stored fluid at the relieving conditions in the tank.

M is the relative molecular mass of the vapor.

The fire relief requirements presented are expressed as air-equivalent flow rates based on the conversion of the actual vapor generation rate into an equivalent volume of air (at either normal or standard conditions) Refer to D.9 for more information.

Table 4—Heat Input, Q
(Expressed in USC Units)

Wetted Surface Area, A_{TWS} ft ²	Design Pressure psig	Heat Input, Q Btu/h
<200	≤15	$20,000A_{TWS}$
≥200 and <1,000	≤15	$199,300 \times (A_{TWS})^{0.566}$
≥1,000 and <2,800	≤15	$963,400 \times (A_{TWS})^{0.338}$
≥2,800	>1 and ≤15	$21,000 \times (A_{TWS})^{0.82}$
≥2,800	≤1	14,090,000

3.3.3.3.3 Where the fluid properties are similar to those of hexane, the required venting capacity can be determined from Table 5 or Table 6.

Table 5—Venting Capacity
(Expressed in SI Units)

Wetted Surface Area, A_{TWS} ^a m ²	Design Pressure kPa (gauge)	Required Venting Capacity Nm ³ /h of air
<260	≤103.4	See Table 7 and 3.3.3.3.4
≥260	≤7	19,910 (see 3.3.3.3.4)
≥260	>7 and ≤103.4	Use Equation (16) ^b

^a The wetted area of a tank or storage vessel shall be calculated as follows.

- For spheres and spheroids, the wetted area is equal to 55 % of the total surface area or the surface area to a height of 9.14 m above grade, whichever is greater.
- For horizontal tanks, the wetted area is equal to 75 % of the total surface area or the surface area to a height of 9.14 m above grade, whichever is greater.
- For vertical tanks, the wetted area is equal to the total surface area of the vertical shell to a height of 9.14 m above grade. For a vertical tank setting on the ground, the area of the ground plates is not included as wetted area. For a vertical tank supported above grade, it is necessary to include a portion of the area of the bottom as additional wetted surface. The portion of the bottom area exposed to a fire depends on the diameter and elevation of the tank above grade. It is necessary to use engineering judgment in evaluating the portion of the area exposed to fire.

^b Calculate the venting requirement q , expressed in normal cubic meters per hour of air as given in Equation (16), which is based on the total heat absorbed Q , expressed in watts, equal to $43,200A_{TWS}^{0.82}$ [see Equation (B.7)]:

$$q = 208.2 F A_{TWS}^{0.82} \quad (16)$$

where

F is the environmental factor from Table 9 (credit may be taken for only one environmental factor);

A_{TWS} is the wetted surface area, expressed in square meters.

The total heat absorbed, Q , is expressed in watts for Equation (16). Table 7 and the constant 208.2 in Equation (16) are derived from Equation (14) and Figure B.1 by using the 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 results within an acceptable degree of accuracy for many fluids having similar properties (see Annex B).

Table 6—Venting Capacity
(Expressed in USC Units)

Wetted Surface Area, A_{TWS}^a ft ²	Design Pressure psig	Required Venting Capacity SCFH of air
<2,800	≤15	See Table 8 and 3.3.3.3.4
≥2,800	≤1	742,000 (see 3.3.3.3.4)
≥2,800	>1 and ≤15	Use Equation (17) ^b

^a The wetted area of a tank or storage vessel shall be calculated as follows.

- For spheres and spheroids, the wetted area is equal to 55 % of the total surface area or the surface area to a height of 30 ft above grade, whichever is greater.
- For horizontal tanks, the wetted area is equal to 75 % of the total surface area or the surface area to a height of 30 ft above grade, whichever is greater.
- For vertical tanks, the wetted area is equal to the total surface area of the vertical shell to a height of 30 ft above grade. For a vertical tank setting on the ground, the area of the ground plates is not included as wetted area. For a vertical tank supported above grade, it is necessary to include a portion of the area of the bottom as additional wetted surface. The portion of the bottom area exposed to a fire depends on the diameter and elevation of the tank above grade. It is necessary to use engineering judgment in evaluating the portion of the area exposed to fire.

^b Calculate the venting requirement q , expressed in normal cubic feet per hour of air as given in Equation (17), which is based on the total heat absorbed Q , expressed in British thermal units per hour, equal to $21,000 A_{TWS}^{0.82}$ [see Equation (B.8)]:

$$q = 1107 F \cdot A_{TWS}^{0.82} \quad (17)$$

where

F is the environmental factor from Table 9 (credit may be taken for only one environmental factor);

A_{TWS} is the wetted surface area, expressed in square feet.

The total heat absorbed, Q , is expressed in Btu per hour for Equation (17). Table 8 and the constant 1107 in Equation (17) are derived from Equation (15) and Figure B.1 by using the latent heat of vaporization of hexane, equal to 144 Btu/lb at atmospheric pressure, and the relative molecular mass of hexane (86.17) and assuming a vapor temperature of 60 °F. This method provides results within an acceptable degree of accuracy for many fluids having similar properties (see Annex B).

Table 7—Emergency Venting Required for Fire Exposure vs Wetted Surface Area
(Expressed in SI Units)

Wetted Area ^a m ²	Venting Required Nm ³ /h		Wetted Area ^a m ²	Venting Required Nm ³ /h
2	608		35	8,086
3	913		40	8,721
4	1,217		45	9,322
5	1,521		50	9,895
6	1,825		60	10,971
7	2,130		70	11,971
8	2,434		80	12,911
9	2,738		90	13,801
11	3,347		110	15,461
13	3,955		130	15,751
15	4,563		150	16,532
17	5,172		175	17,416
19	5,780		200	18,220
22	6,217		230	19,102
25	6,684		260	19,910
30	7,411		>260 ^b	—

^a The wetted area of a tank or storage vessel shall be calculated as follows.

- For spheres and spheroids, the wetted area is equal to 55 % of the total surface area or the surface area to a height of 9.14 m above grade, whichever is greater.
- For horizontal tanks, the wetted area is equal to 75 % of the total surface area or the surface area to a height of 9.14 m above grade, whichever is greater.
- For vertical tanks, the wetted area is equal to the total surface area of the vertical shell to a height of 9.14 m above grade. For a vertical tank setting on the ground, the area of the ground plates is not included as wetted area. For a vertical tank supported above grade, it is necessary to include a portion of the area of the bottom as additional wetted surface. The portion of the bottom area exposed to a fire depends on the diameter and elevation of the tank above grade. It is necessary to use engineering judgment in evaluating the portion of the area exposed to fire.

^b For wetted surfaces larger than 260 m², see Table 5.

NOTE This table and the constant 208.2 in Equation (16) are derived from Equation (14) and Figure B.1 by using the 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 results within an acceptable degree of accuracy for many fluids having similar properties (see Annex B).

Table 8—Emergency Venting Required for Fire Exposure vs Wetted Surface Area
(Expressed in USC Units)

Wetted Area ^a ft ²	Venting Required SCFH		Wetted Area ^a ft ²	Venting Required SCFH
20	21,100		350	288,000
30	31,600		400	312,000
40	42,100		500	354,000
50	52,700		600	392,000
60	63,200		700	428,000
70	73,700		800	462,000
80	84,200		900	493,000
90	94,800		1,000	524,000
100	105,000		1,200	557,000
120	126,000		1,400	587,000
140	147,000		1,600	614,000
160	168,000		1,800	639,000
180	190,000		2,000	662,000
200	211,000		2,400	704,000
250	239,000		2,800	742,000
300	265,000		>2,800 ^b	—

^a The wetted area of a tank or storage vessel shall be calculated as follows.

- For spheres and spheroids, the wetted area is equal to 55 % of the total surface area or the surface area to a height of 30 ft above grade, whichever is greater.
- For horizontal tanks, the wetted area is equal to 75 % of the total surface area or the surface area to a height of 30 ft above grade, whichever is greater.
- For vertical tanks, the wetted area is equal to the total surface area of the vertical shell to a height of 30 ft above grade. For a vertical tank setting on the ground, the area of the ground plates is not included as wetted area. For a vertical tank supported above grade, it is necessary to include a portion of the area of the bottom as additional wetted surface. The portion of the bottom area exposed to a fire depends on the diameter and elevation of the tank above grade. It is necessary to use engineering judgment in evaluating the portion of the area exposed to fire.

^b For wetted surfaces larger than 2800 ft², see Table 6.

NOTE This table, and the constant 1107 in Equation (17), were derived from Equation (15) and Figure B.1 by using the latent heat of vaporization of hexane, equal to 144 Btu/lb at atmospheric pressure, and the relative molecular mass of hexane (86.17) and assuming a vapor temperature of 60 °F. This method provides results within an acceptable degree of accuracy for many fluids having similar properties (see Annex B).

Table 9—Environmental Factors for Nonrefrigerated Aboveground Tanks
(Expressed in SI and USC Units)

Tank Design/Configuration	Insulation Conductance		Insulation Thickness		<i>F</i> -factor ^b
	W/m ² ·K	Btu/(h·ft ² ·°F)	cm	in.	
Bare metal tank	—	—	0	0	1.0
Insulated tank ^a	22.7	4.0	2.5	1	0.3 ^b
	11.4	2.0	5.1	2	0.15 ^b
	5.7	1.0	10.2	4	0.075 ^b
	3.8	0.67	15.2	6	0.05 ^b
	2.8	0.5	20.3	8	0.0375 ^b
	2.3	0.4	25.4	10	0.03 ^b
	1.9	0.33	30.5	12	0.025 ^b
Concrete tank or fireproofing	—	—	—	—	^c
Water-application facilities ^d	—	—	—	—	1.0
Depressuring and emptying facilities ^e	—	—	—	—	1.0
Underground storage	—	—	—	—	0
Earth-covered storage above grade	—	—	—	—	0.03
Impoundment away from tank ^f	—	—	—	—	0.5

^a The insulation shall resist dislodgment by fire-fighting equipment, shall be noncombustible and shall not decompose at temperatures up to 537.8 °C (1000 °F). The user is responsible for determining whether the insulation can resist dislodgment by the available fire-fighting equipment. If the insulation does not meet these criteria, no credit for insulation shall be taken. The conductance values are based on insulation with a thermal conductivity of 9 W/m²·K/cm (4 Btu/h·ft²·°F/in.) of thickness. The user is responsible for determining the actual conductance value of the insulation used. The conservative value of 9 W/m²·K/cm (4 Btu/h·ft²·°F/in.) of thickness for the thermal conductivity is used.

^b These *F*-factors are based on the thermal conductance values shown and a temperature differential of 887.9 K (1600 °F) when using a heat input value of 66,200 W/m² (21,000 Btu/h·ft²) in accordance with the conditions assumed in ISO 23251. When these conditions do not exist, engineering judgment should be used to select a different *F*-factor or to provide other means for protecting the tank from fire exposure.

NOTE For the purposes of this provision, API 521 is equivalent to ISO 23251.

^c Use the *F*-factor for an equivalent conductance value of insulation.

^d Under ideal conditions, water films covering metal surfaces can absorb most incident radiation. The reliability of water application depends on many factors. Freezing weather, high winds, clogged systems, undependable water supply, and tank surface conditions can prevent uniform water coverage. Because of these uncertainties, no reduction in environmental factors is recommended; however, as stated previously, properly applied water can be very effective.

^e Depressuring devices may be used, but no credit shall be allowed in sizing the venting device for fire exposure.

^f The following conditions shall be met.

- A slope of not less than 1 % away from the tank shall be provided for at least 15 m (50 ft) toward the impounding area.
- The impounding area shall have a capacity that is not less than the capacity of the largest tank that can drain into it.
- The drainage system routes from other tanks to their impounding areas shall not seriously expose the tank.
- The impounding area for the tank, as well as the impounding areas for the other tanks (whether remote or with dikes around the other tanks), shall be located so that when the area is filled to capacity, its liquid level is no closer than 15 m (50 ft) to the tank.

^g Local regulations may specify or allow different *F*-factors. For example, OSHA 1910.106 allows different credit for water spray and insulation.

3.3.3.3.4 The total rate of venting determined from Table 7 or Table 8 may be multiplied by an appropriate environmental factor, F , selected from Table 9; credit may be taken for only one environmental factor.

3.3.3.3.5 Credit may be taken for the venting capacity provided by the device installed for normal venting, since the normal thermal effect can be disregarded during a fire. Also, it can be assumed that there is no liquid movement into the tank during fire exposure.

3.3.3.3.6 If normal venting devices have inadequate capacity, additional emergency venting devices of the type described in 3.4.2 shall be provided so that the total venting capacity is at least equivalent to that required by Table 5 or Table 6 or by Equation (14) or Equation (15).

3.3.3.3.7 The total venting capacity shall be based on the pressure indicated in 3.6.2.

3.4 Means of Venting

3.4.1 Normal Venting

3.4.1.1 General

Normal venting for pressure and vacuum shall be accomplished by a PV valve with or without a flame-arresting device or by an open vent with or without a flame-arresting device.

Protect atmospheric storage tanks against flame transmission from outside the tank if

- the stored liquid has a low flash point, i.e. less than 60 °C (140 °F) or in accordance with the applicable regulations, whichever is higher; or
- the storage temperature can exceed the flash point; or
- the tank can otherwise contain a flammable vapor space.

See 3.5 for design considerations for tanks that have potentially flammable atmospheres. A discussion of the types and operating characteristics of venting devices can be found in Annex C.

Relief devices equipped with a weight-lever mechanism for adjusting the set pressure, and nonreclosing relief devices are not recommended for normal venting.

3.4.1.2 Pressure/Vacuum Valves

To avoid product loss, PV valves are recommended for use on atmospheric storage tanks.

3.4.1.3 Open Vents

If open vents are selected to provide venting capacity for tanks that can contain a flammable vapor space as defined in 3.4.1.1, a flame-arresting device should be used. Open vents without a flame-arresting device may be used for tanks that do not contain a flammable vapor space.

In the case of viscous oils, such as cutback and penetration-grade asphalts, where the danger of tank collapse resulting from sticking pallets or from plugging of flame arresters is greater than the possibility of flame transmission into the tank, open vents may be used as an exception to the requirements of 3.4.1.1; or heat traced vents that ensure that the vapor temperature stays above the dew point may be used.

In areas with strict fugitive emissions regulations, open vents might not be acceptable and vent-device selection should consider the maximum leakage requirements during periods of normal tank operation.

3.4.2 Emergency Venting

Emergency venting may be accomplished by the use of the following:

- a) larger or additional open vents as limited by 3.4.1.3,
- b) larger or additional PV valves,
- c) a gauge hatch that permits the cover to lift under abnormal internal pressure,
- d) a manhole cover that lifts when exposed to abnormal internal pressure,
- e) weak (frangible) roof-to-shell attachment (see 3.3.3.2),
- f) a rupture-disk device,
- g) other forms of construction that can be proven to be comparable for the purposes of pressure relief.

3.5 Considerations for Tanks with Potentially Flammable Atmospheres

3.5.1 General

Depending on the process, operating conditions, and/or relieving conditions, the vapor space in the tank can be flammable. Ignition of the vapor space while within the flammable region likely leads to tank roof damage and/or loss of containment. Ignition sources include, but are not limited to, static discharge inside the tank due to splash filling or improper level gauging, pyrophoric materials on the inside surfaces of the tank, external hot work on the tank, tank or tank fittings above the auto-ignition temperature due to external fire exposure, or flame propagation through a tank opening or vent caused by a lightning strike or external fire. Consider the potential for a flammable atmosphere inside the tank and determine whether safeguards are adequate.

If explosion/deflagration venting is necessary, see 3.2.5.15.

3.5.2 Design Options for Explosion Prevention

If the tank's vapor space can be within the flammable range, the user shall determine what safeguards are required to prevent internal deflagration. The following are typical safeguards.

- a) *Different Tank Selection*—A different type of tank design can reduce or eliminate the formation of a flammable atmosphere.

EXAMPLES Floating-roof tank or a tank rated for full vacuum.

- b) *Inert-gas Blanketing*—An effective means of reducing the likelihood of a flammable atmosphere inside a tank, when engineered and maintained properly. Note that inerting can introduce an asphyxiation risk and in sour services can promote the formation of pyrophoric deposits.
- c) *Flame Arrester*—The use of this in an open vent line or on the inlet to the pressure/vacuum valve is an effective method to reduce the risk of flame transmission. The user is cautioned that a sustained fire on the outlet of the flame arrester not designed for endurance burning or on other parts of the tank/fittings may result in temperatures high enough to ignite internal flammable vapors. The use of high temperature alarms on flame arresters can provide warning of flame contact. In addition the use of a flame arrester within the tank's relief path introduces the risk of tank damage from overpressure or vacuum due to plugging if the arrester is not maintained properly. The use of a flame arrester increases the pressure drop of the venting system. The manufacturer(s) should be consulted for assessing the magnitude of these effects. More information on flame arresters can be found in ISO 16852^[31], NFPA 69^[16], TRbF 20^[17], FM 6061^[26], and USCG 33 CFR 154^[19].

For the proper selection of a flame arrester, the piping configuration, operating pressure and temperature, oxygen concentration, compatibility of flame arrester material, and explosive gas group (IIA, IIB, etc.) should be considered. For selection of the correct flame arrester, the manufacturer should be consulted.

- d) *Pressure/Vacuum Valve*—The petroleum industry has had good experience with tanks protected by pressure and vacuum vents without flame arresters. As a result, there has been a belief that this good experience is due to the pressure vents' potentially inherent flame-arresting capabilities. Recent testing, however, disproves this hypothesis at least for the tested conditions. See 3.5.4 for more information on flame propagation through pressure vents.

3.5.3 Inert-gas-blanketed Tanks

An inert-gas system may be used to avoid drawing air into the tank during vacuum conditions. The use of inert-gas systems instead of a vacuum-relief device is beyond the scope of this standard. For tanks that use an inert-gas supply system, the likelihood of a potentially explosive atmosphere is reduced and there can be benefits related to a less severe hazardous area classification. See Annex F for a discussion of other benefits and for informative guidance for inert-gas blanketing of tanks for flashback protection. The venting devices shall be sized for the case where the inert gas is unavailable (see 3.3.1).

3.5.4 Flame Propagation Through Pressure/Vacuum Valves

Testing has demonstrated that a flame can propagate through a pressure/vacuum valve and into the vapor space of the tank. Tests have shown that ignition of a PV valve's relief stream (possibly due to a lighting strike) can result in a flashback to the PV valve with enough overpressure to lift the vacuum pallet, allowing the flame to enter the tank's vapor space. Other tests show that, under low-flow conditions, a flame can propagate through the pressure side of the PV; see Reference [23].

Flashbacks through PV valves are rare in the petroleum industry. The following are some factors that may explain this.

- The materials stored in most cone roof tanks often do not result in a flammable atmosphere in the tank.
- A lightning strike is likely to occur under conditions of cloud cover, so there is a reduced likelihood that the tank is out-breathing. However, it can still be out-breathing if liquid is entering.
- A lightning strike is almost always preceded by winds, which keeps the size of the flammable cloud near the PV valve to a minimum.

3.6 Relief-device Specification

3.6.1 Sizing Basis

The pressure- and vacuum-relief device(s), including open vents, shall be suitable to pass the venting requirements for the largest single contingency or any reasonable and probable combination of contingencies (see 3.2.5 and 3.3.1).

When evaluating the overpressure scenarios in 3.2.5, the user should determine if the relief load should be handled using normal out-breathing relief devices or emergency venting. This can be an important consideration if the emergency venting is via a frangible roof or a nonreclosing relief device (e.g. rupture-disk or blow-off hatch).

A tank inerting system as described in 3.5.3 may be specified to avoid pulling air into the tank during vacuum conditions. No credit for these inerting systems shall be taken for the purpose of sizing the vacuum-relief device.

The inlet and outlet hydraulics can affect the relief-device sizing, which can be an iterative design process.

The basis for the sizing equations is explained in Annex D.