CALCULATION METHOD FOR THE ANALYSIS AND PREVENTION OF OVERPRESSURE DURING REFILLING OF CRYOGENIC TANKS WITH RUPTURE DISK(S)

AIGA 075/20

Revision of AIGA 075/11

Asia Industrial Gases Association

N0 2 Venture Drive, #22-28 Vision Exchange, Singapore 608526
Tel: +65 67055642 Fax: +65 68633379
Internet: http://www.asiaiga.org

AIGA 075/20

CALCULATION METHOD FOR THE ANALYSIS AND PREVENTION OF OVERPRESSURE DURING REFILLING OF CRYOGENIC TANKS WITH RUPTURE DISK(S)

As part of a programme of harmonization of industry standards, the Asia Industrial Gases Association (AIGA) has issued the publication AIGA 075, *"Calculation Method for the Analysis and prevention of Overpressure During Refilling of Cryogenic Tanks With Rupture Disk(s)".* This has been jointly produced by members of the International Harmonization Council and originally published as CGA P-40 by Compressed Gases Association Inc (CGA) as *"Calculation Method for the Analysis and prevention of Overpressure During Refilling of Cryogenic Tanks With Rupture Disk(s)"*.

This publication is intended as an international harmonized publication for the worldwide use and application by all members of Asia Industrial Gases Association (AIGA), Compressed Gas Association (CGA), EIGA, and Japan Industrial and Medical Gases Association (JIMGA). Each association's technical content is identical, except for regional regulatory requirements and minor changes in formatting and spelling.

ASIA INDUSTRIAL GASES ASSOCIATION
No-2 Venture Drive,# 22-28 Vision Exchange, Singapore 608526
Tel: +65 67055642 Fax: +65 68633307
Internet: http://www.asiaiga.org

Table of Contents

NOTE—Technical changes from the previous edition are underlined.

NOTE—Appendix A (Normative) is a requirement.

NOTE—Appendices B, C, D, and E (Informative) are for information only.

Amendments from 075/19

Section	**Change**
	Editorial to align style with IHC associations
3	New Section - Addition of IHC definitions
General	Updating data and reference

Note: Technical changes from the prior version are underlined.

1 Introduction

Cryogenic transports often use pumping systems that discharge product at pressures exceeding the working pressure of the liquid storage tank being filled. In North America, pumping systems for transferring oxygen, nitrogen, or argon are typically capable of delivering pressures greater than 400 psi (2760 kPa).[1,2] The cryogenic storage tank being refilled usually has a maximum allowable working pressure (MAWP) that is considerably less than the pump discharge pressure. Depending on the inherent tank design safety factors and the size and flow capacity of the tank pressure relief system, the potential to overpressure the tank during operator-attended manual refill operations exists. AIGA 054, *Prevention of Overpressure During Filling of Cryogenic Vessels* was written in response to overpressure events that occurred in the compressed gas industry [2]. AIGA 054 discusses the requirements necessary to ensure that cryogenic storage tanks are not overpressurized in manual refill operations [2].

It is the responsibility of each tank owner to complete a technical evaluation of the storage tank fill and relief device piping. This technical evaluation shall be repeated any time a change is made in either the pump flow and pressure capability or the tank fill and relief system flow capacities. The storage tank owner shall ensure that pump operators are trained and certified.

2 Scope

This publication provides technical guidance and the complete equation set needed to determine if a particular vessel can or cannot be overpressurized during the refill operation. Acceptable engineering controls for the protection of cryogenic storage tanks and transport tanks with rupture disk(s) as part of the relief system are provided. The application of these engineering controls constitutes a minimum standard.

The calculations in this publication may be used to evaluate each pumping system and cryogenic tank combination in use with oxygen, nitrogen, or argon. It applies to tanks filled either by pump from a cryogenic transport or by a ground-mounted pump. This applies to cryogenic tanks greater than 265 gal (1000 L) water capacity. This does not apply to cryogenic tanks with flat bottoms. For flat bottomed cryogenic tanks, refer to AIGA 031, *Bulk Liquid Oxygen, Nitrogen, and Argon Storage Systems at Production Sites* [3].

3 Definitions

For the purpose of this publication, the following definitions apply.

3.1 Publication terminology

3.1.1 Shall

Indicates that the procedure is mandatory. It is used wherever the criterion for conformance to specific recommendations allows no deviation.

3.1.2 Should

Indicates that a procedure is recommended.

3.1.3 May

Indicates that the procedure is optional.

3.1.4 Will

Is used only to indicate the future, not a degree of requirement.

3.1.5 Can

Indicates a possibility or ability.

---

[1] kPa shall indicate gauge pressure unless otherwise noted as (kPa, abs) for absolute pressure or (kPa, differential) for differential pressure. All kPa values are rounded off per CGA P-11, *Metric Practice Guide for the Compressed Gas Industry* [1].

[2] References are shown by bracketed numbers and are listed in order of appearance in the reference section.

4 Nomenclature

Table 1 contains the definitions of the variables used in this standard.

Table 1—Definition of variables

Symbol	Definition	U.S. customary units (abbreviation)	Metric units (abbreviation)
A	Intermediate variable used in calculation of friction factor		
C	Flow coefficient for an orifice		
C_v	Flow coefficient for valves	gallons per minute per psi (gal/min/psi)	
d	Internal line diameter	inches (in)	millimeters (mm)
d_{disc}	Nominal pipe diameter of the rupture disk corresponding to the certified flow resistance as specified by the manufacturer	inches (in)	millimeters (mm)
d_{fill}	Reference internal diameter for the fill line	inches (in)	millimeters (mm)
d_{ori}	Diameter of the fill orifice	inches (in)	millimeters (mm)
d_{rel}	Reference internal diameter for the pressure relief line	inches (in)	millimeters (mm)
f_t	Friction factor (Fanning friction factor used)		
K	Flow resistance coefficient		
K_b	Flow resistance through a single bend of 90-degrees		
K_{fill}	Flow resistance of the fill line with fill valve in the full open condition. See Figure 1.		
K_{ori}	Flow resistance of the restricting fill line orifice sized so the pressure at the top of the tank during the fill operation cannot exceed the upper pressure limit *(UPL)*. See Figure 1.		
K_R	Certified flow resistance for a rupture disk		
K_{rel}	Flow resistance of the relief system piping from the liquid container up to the rupture disk. See Figure 1. If a diverter valve is present, calculations shall assume it to be in the fully diverted position		
K_{truck}	Flow resistance of the pump to the tee that branches to the fill valves except for the fill orifice. See Figure 1.		
L	Length	feet (ft)	meters (m)
P_{atm}	Atmospheric pressure: 14.696 psia or 1.013 bar, abs	pounds per square inch, absolute (psia)	bar, absolute (bar, abs)
UPL	Tank UPL. This is the maximum pressure that is permissible at the top of the tank under the conditions discussed in CGA P-59 [2].	pounds per square inch, gauge (psi)	bar, gauge (bar)
P_{mawp}	Tank MAWP per *ASME Boiler & Pressure Vessel Code* (ASME Code) or local code equivalent [4].	pounds per square inch, gauge (psi)	bar, gauge (bar)
P_{sup}	Pressure at the inlet of the pump. (Approximately equal to the supply tank pressure).	pounds per square inch, gauge (psi)	bar, gauge (bar)
P_{test}	Test pressure as prescribed by the ASME Code and as recorded on form U1, U1-A, or R-2 or local code equivalent [4].	pounds per square inch, gauge (psi)	bar, gauge (bar)
Q	Flow rate	gallons per minute (gal/min)	liters per minute (L/min)
Q_{rel_max}	The flow through the relief system so the pressure loss is ΔP_{rel_max}	gallons per minute (gal/min)	liters per minute (L/min)
r	Radius of a pipe bend	inches (in)	millimeters (mm)

Symbol	Definition	U.S. customary units (abbreviation)	Metric units (abbreviation)
Re	Reynolds number		
V_{liq}	Vertical distance from the bottom of the liquid container to the normal fill level for the tank. See Figure 1.	feet (ft)	meters (m)
V_{pmp}	Vertical distance from the pump to the top of the storage tank liquid container. See Figure 1.	feet (ft)	meters (m)
V_{rel}	Vertical distance from the relief device to the top of the storage tank liquid container. See Figure 1.	feet (ft)	meters (m)
V_{tank}	Vertical distance from grade to the top of the storage tank outer container	feet (ft)	meters (m)
ΔP	Pressure loss through pipe and piping components	pounds per square inch, differential (psid)	bar, differential (bar, dif)
ΔP_{disc}	Pressure loss through a rupture disk	pounds per square inch, differential (psid)	bar, differential (bar, dif)
ΔP_{fill_line}	Frictional pressure loss through the fill line	pounds per square inch, differential (psid)	bar, differential (bar, dif)
ΔP_{ori}	Pressure loss through the fill line orifice	pounds per square inch, differential (psid)	bar, differential (bar, dif)
ΔP_{pmp}	Pump discharge curve for the highest capacity pump expected to fill the tank	pounds per square inch, differential (psid)	bar, differential (bar, dif)
ΔP_{rel_max}	The maximum frictional pressure loss through the relief system so *UPL* is not exceeded at the top of the tank	pounds per square inch, differential (psid)	bar, differential (bar, dif)
α	Proportionality constant for pipe and tube fitting flow resistance used in Appendix A equation (2b)		
β	Diameter ratio (smaller/larger)		
ε	Absolute roughness	inches (in)	millimeters (mm)
μ	Absolute viscosity	centipoise (cp)	Pascal seconds (Pa s)
ρ	Fluid density	pounds (mass) per cubic foot (lbm/ft^3)	kilograms per cubic meter (kg/m^3)
ρ_{des}	Density of the highest density lading for which the tank is designed	pounds (mass) per cubic foot (lbm/ft^3)	kilograms per cubic meter (kg/m^3)
θ	Angle of a bend	degrees	degrees

5 Preventing overpressurization

5.1 Methods

AIGA 054 outlines a number of methods that protect storage tanks from overpressure during refill [2]. One method describes increasing the size of the relief system rupture disk or other component external to the tank if these are found to be restrictive. In some cases due to the internal piping, modifying external components has limited value. When this is the case, installing an external protection device that closes at a prescribed pressure or installing a permanent resistance in the fill piping are possible ways to prevent overpressurization. The solution used shall be inherently reliable, not exclusively dependent upon the driver or operator to take action and shall not introduce other hazards. The use of a liquid relief valve on the tank fill line sized to relieve the full flow capacity of the pump is not recommended because it introduces other hazards associated with large releases of cryogenic fluids to the atmosphere.

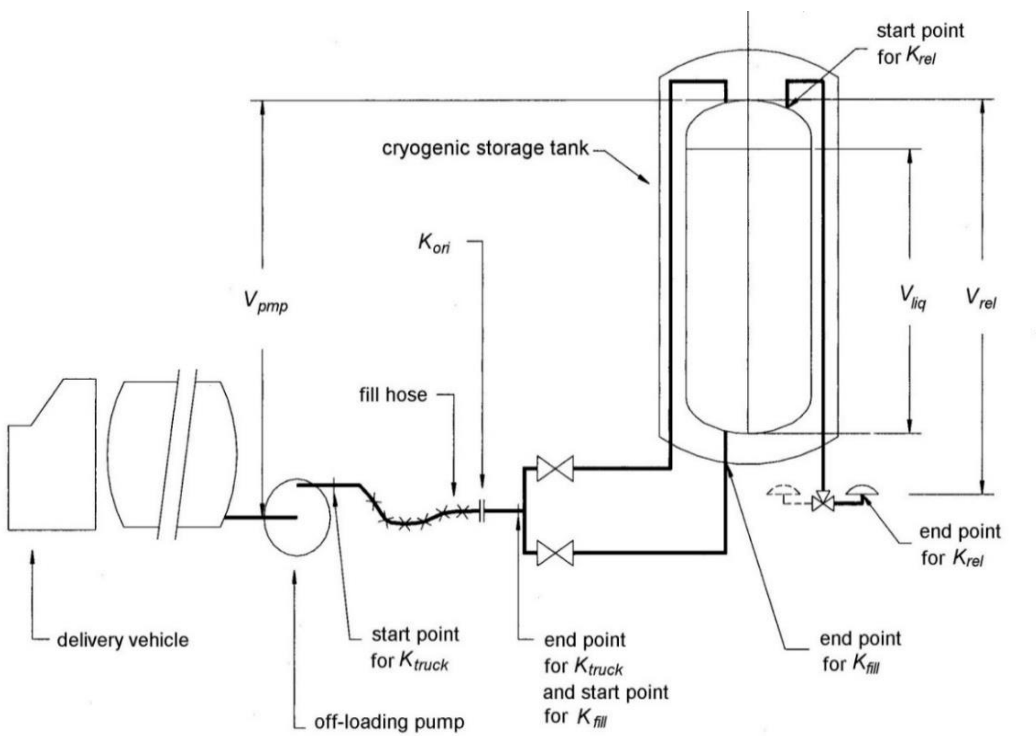
5.2 External protection device

A number of external protection devices have been developed specifically to address the issues of overpressure protection during operator-attended refilling. These include control valves installed in the fill line that are actuated by a pressure signal from the vapor space of the storage tank. Closure of the external protection device is accomplished by a pilot system that includes a pressure relief valve or a rupture disk that functions at a setpoint below the upper pressure limit (UPL). The large flow capacity of these valves avoids the operating penalty of the restrictive orifice solution.

5.3 Tank fill and relief system

As illustrated in Figure 1, the tank filling system consists of the cryogenic transport pump and piping; the product transfer hose and connections; and the storage tank, fill piping, and fill line components. The tank relief system consists of the piping from the vapor space of the storage tank, the diverter valve if used, and the tank rupture disk.

Many cryogenic storage tanks use relief device lines and components equal to or smaller than the fill lines. Normally a diverter valve, pressure relief valve, and rupture disk are used in a dual relief device assembly to facilitate maintenance. Pressure relief valves and rupture disks are sized for normal operation as well as for exposure of the tank to a fire. Normal operation is often limited to loss of vacuum or uncontrolled pressure building operation. The relief devices might not be sized for the maximum capacity of the refill system. Many older style, lower MAWP storage tanks have a relief capacity between 80 gal/min to 90 gal/min (300 L/min to 340 L/min). Following the calculation methods outlined in Section 6, orifice sizes will typically range from 0.35 in to 0.50 in (10 mm to 13 mm) diameter, effectively reducing the fill rate from a nominal 200 gal/min to as low as 80 gal/min (760 L/min to as low as 300 L/min). Since this clearly is not workable from an operating standpoint, especially with large storage tanks, alternative solutions such as an external protection device should be considered. It is left to the analyst to determine the optimum solution for a particular situation.



NOTES

1 K_{truck} and K_{fill} exclude K_{ori}.

2 If a diverter valve exists in the relief line, assume it is in the fully diverted position.

Figure 1—System configuration

6 Calculations

The steps described in 6.1 to 6.9 are used to determine if the relief system incorporated into the cryogenic tank will relieve product at a rate that is greater than the rate at which it can be pumped from the cryogenic source. In this analysis, the tank pressure is allowed to rise above MAWP as prescribed in 6.2. For the purpose of these calculations, the flow capacity of any pressure relief valve is ignored. The cryogenic tank test pressure can be found in the tank pressure vessel documentation (for ASME Code, test pressure can be found on the pressure vessel U-1, U-1A, or R-2 forms) [4].

The information, equations, and assumptions in 6.1 to 6.9 are used in the equation sets, example worksheets, and blank worksheets in the appendices. Figure 1 depicts the equipment and piping for a typical tank filling operation. References for flow resistances and distances are indicated. Appendix A contains the calculation equation sets. Appendix B presents an example when an orifice is necessary to prevent overpressure during refilling and includes a sketch of the sample relief line and liquid fill line for this example. Appendix C presents an example when additional flow restriction in the fill line is not required and includes a sketch of the sample relief line and liquid fill line for this example. Appendix D contains blank worksheets that may be used to complete the analysis described in 6.1 to 6.9. Appendix E contains useful reference data for cryogenic fluids, tanks, pipes, tubes, pumps, and flow orifices that can be helpful when completing an analysis using the blank worksheets in Appendix D.

NOTE—These calculations are based on liquid flow with sufficient subcooling available to prevent two phase flow from occurring in the piping. Two phase flow is not addressed in these calculations.

6.1 Step 1: Input tank and piping data

Collect input data specific for the tank being analyzed including the following:

- tank owner's name;
- tank capacity and configuration;
- manufacturer's serial number;
- National Board Inspection Code (NBIC) number;
- product service;
- whether or not the tank is suitable for argon, nitrogen, and oxygen;
- tank MAWP and test pressure; and
- overall height of the tank.

NOTE—Much of the previously mentioned input data information is found on the tank dataplate or the manufacturer's documentation such as ASME U-1, U-1A, or R-2 forms.

Inspect the tank relief line from where it exits the tank casing to the discharge of the rupture disk. Enter the different pipe and tube sizes found on the relief line into worksheet D1.

Inspect the tank liquid phase fill line from the fill connection to the point where it enters the casing. Enter the different pipe and tube sizes into worksheet D1.

6.2 Step 2: Determine tank upper pressure limit, *UPL*

Step 2 and worksheet D2 are based on the assumption that the tank design includes a vacuum jacket.

If the tank test pressure is known, then, the UPL is the lesser of:

$UPL = P_{mawp} \bullet 1.5$; or

$UPL = P_{test} - P_{atm}$

If the test pressure is unknown, the tank UPL can be estimated from the following:

U.S. customary units:

$$UPL = 1.1\left(P_{mawp} + (\rho_{des} - \rho) \bullet \frac{V_{liq}}{144} + P_{atm}\right) - P_{atm}$$

Metric units:

$$UPL = 1.1\left(P_{mawp} + \frac{(\rho_{des} - \rho) \bullet V_{liq} \bullet 9.81}{100000} + 1\right) - 1$$

For calculation purposes assume that $V_{liq} = V_{tank} -$ 3 ft ($V_{liq} = V_{tank} -$ 0.91 m). See Figure 1.

6.3 Step 3: Determine maximum frictional pressure loss through the relief system, ΔP_{rel_max}

The maximum pressure loss allowed through the relief system is equal to the UPL at the top of the tank plus the liquid head pressure as measured from the top of the tank to the rupture disk inlet.

U.S. customary units:

$$\Delta P_{rel\_\max} = UPL + \frac{V_{rel} \bullet \rho}{144}$$

Metric units:

$$\Delta P_{rel\_\max} = UPL + \frac{V_{rel} \bullet \rho \bullet 9.81}{100000}$$

For calculation purposes assume that $V_{rel} = V_{tank}$ – 2 ft ($V_{rel} = V_{tank}$ − 0.61 m). See Figure 1.

Use worksheet D3.

6.4 Step 4: Determine flow resistance of the pressure relief system, K_{rel}

Analyze the relief line from where it exits the tank casing to the discharge of the rupture disk. Note the different pipe and tube sizes and fittings along the entire length of line. Use actual component sizes and C_vs. Calculate the resistance of each segment using equations (2a) to (2i) in Appendix A or worksheet D4. If a diverter valve exists, assume it is in the fully diverted position. Convert the resistance of each segment to a common diameter using equation (3) in Appendix A. Total all resistances to determine K_{rel}. See Figure 1.

Step 4 and worksheet D4 are based on the following engineering assumptions:

- The calculation reference diameter is 1.481 in (37.6 mm). All tabulated resistances are converted to this diameter;
- The line friction factor, f_t, is equal to 0.0125;
- The inlet nozzle resistance is based upon a sharp-edged entrance, a 6 in (150 mm) nozzle length, and pipe schedule 40S;
- The internal line bend resistance corresponds to a 90-degree, 8 in (200 mm) radius bend; two 45-degree, 12 in (300 mm) radius bends; and a 1.185 in (30.1 mm) ID line;
- The internal relief line is pipe schedule 5S and is equal in length to the overall height of the tank;
- If the rupture disk certified flow resistance is unknown or cannot be obtained from the manufacturer, use K_R = 2.4; and
- The flow capacity of any safety relief valve is neglected.

6.5 Step 5: Calculate maximum flow rate through the relief system, Q_{rel_max}

Since the flow resistance and the maximum permissible pressure drop across the relief system is known, use the equation below or worksheet D5 to calculate the maximum flow through the relief system. A factor of 0.9 is used to modify the basic equation (1b) in Appendix A for the calculation of relieving capacity to allow for uncertainties inherent in this method. This is in accordance with the ASME Code, Section VIII, Division 1, paragraph UG-127(b) [4].

U.S. customary units:

$$Q_{rel\_max} = 0.9 \bullet \sqrt{\frac{\Delta P_{rel\_max} \bullet d_{rel}^{4}}{0.00001799 \bullet K_{rel} \bullet \rho}}$$

Metric units:

$$Q_{rel\_max} = 0.9 \bullet 21.07 \sqrt{\frac{\Delta P_{rel\_max} \bullet d_{rel}^{4}}{K_{rel} \bullet \rho}}$$

6.6 Step 6: Determine flow resistance of the truck and tank fill system, K_{truck} and K_{fill}

Analyze the fill line from the cryogenic transport pump discharge, through the fill connection, to the point where the line enters the casing. Note the different pipe and tube sizes and fittings along the entire length of line. Use actual component sizes and C_Vs and worksheet D6. Convert the resistance of each component to a common diameter using equation (3) in Appendix A and worksheet D6. Determine a flow resistance for the standard truck components, K_{truck}, and a separate resistance for the tank liquid phase components, K_{fill}. See Figure 1.

Step 6 and worksheet D6 are based on the following engineering assumptions:

- The calculation reference diameter is 1.481 in (37.6 mm). All tabulated resistances are converted to this diameter;
- The liquid fill line friction factor, f_t, is equal to 0.0138 for an assumed 50% of flow total through the liquid phase fill line. It is assumed that the liquid phase fill valve is fully opened;
- The resistance of standard fill system truck components is equal to 11.519 at a 1.481 in (37.6 mm) reference diameter. These include truck-mounted components, transfer hose, and fill connection indicated in Figure 1;
- The internal liquid line is assumed to be 3 ft (0.91 m) in length and schedule 5S. Internal line bend resistance corresponds to two 90-degree, 10 in (254 mm) radius bends and a 1.770 in (45 mm) ID line; and
- The internal nozzle resistance is based on a sharp-edged exit, a 6 in (152 mm) nozzle length, and pipe schedule 40S.

6.7 Step 7: Determine pressure loss through the fill system, ΔP_{fill_line}

Calculate the pressure drop across the fill line without an orifice at the flow capacity of the relief system. Use the basic equation (1a) in Appendix A to calculate a separate value for the fill system truck components and the tank liquid phase components. Assume that 50% of the total flow is through the tank liquid phase fill line.

U.S. customary units:

$$\Delta P_{fill\_line} = \frac{0.00001799 \bullet K_{truck} \bullet \rho \bullet Q_{rel\_max}^{2}}{d_{fill}^{4}} + \frac{0.00001799 \bullet K_{fill} \bullet \rho \bullet (Q_{rel\_max}/2)^{2}}{d_{fill}^{4}}$$

Metric units:

$$\Delta P_{fill\_line} = \frac{K_{truck} \bullet \rho \bullet Q_{rel\_max}^{2}}{21.07^{2} d_{fill}^{4}} + \frac{K_{fill} \bullet \rho \bullet (Q_{rel\_max}/2)^{2}}{21.07^{2} d_{fill}^{4}}$$

Use worksheet D7.

6.8 Step 8: Determine fill line orifice pressure drop, ΔP_{ori}

Subtract the fill line pressure drop, the liquid head from the top of the tank to the pump inlet, and the UPL at the top of the tank from the sum of the supply pressure and pump pressure rise as shown in the equation below. The pressure rise across the pump, ΔP_{pmp}, is determined by interpolation of the pump curve for the actual lading at the relief system flow capacity. A positive value for ΔP_{ori} indicates that a restricting orifice is needed to match the fill rate to the capacity of the relief system.

U.S. customary units:

$$\Delta P_{ori} = \Delta P_{pmp}(Q_{rel\_max}, \rho) + P_{sup} - \Delta P_{fill\_line} - V_{pmp}\frac{\rho}{144} - UPL$$

Metric units:

$$\Delta P_{ori} = \Delta P_{pmp}(Q_{rel\_max}, \rho) + P_{sup} - \Delta P_{fill\_line} - \frac{(V_{pmp} \bullet \rho \bullet 9.81)}{100000} - UPL$$

Step 8 and worksheet D8 are based upon the following engineering assumptions:

- For calculation purposes assume that $V_{pmp} = V_{tank}$ – 6 ft ($V_{pmp} = V_{tank}$ – 1.83 m). See Figure 1;
- The pump performance curve used in the worksheets is an example of a pump's capacity attainable with some cryogenic transport off-loading systems; and
- P_{sup} = 30 psi (2.1 bar).

It is essential that the analyst use the pump curve for the actual pump and components used in a delivery system. Anytime the delivery pump or system characteristics change, this analysis shall be redone to check fill line orifice sizing. This is a major disadvantage of the fill line orifice solution.

6.9 Step 9: Determine required fill orifice flow resistance, K_{ori} and size, d_{ori}

Using the value for ΔP_{ori} computed previously and equation (1c) in Appendix A, compute the flow resistance coefficient required.

Use worksheet D9.

U.S. customary units:

$$K_{ori} = \frac{\Delta P_{ori} \bullet d_{fill}^{\ 4}}{0.00001799 \bullet \rho \bullet Q_{rel\_max}^{\ 2}}$$

Metric units:

$$K_{ori} = \frac{21.07^2 \Delta P_{ori} \bullet d_{fill}^{\ 4}}{\rho \bullet Q_{rel\_max}^{\ 2}}$$

Where:

$$K_{ori} = \frac{1-\beta^2}{C \bullet \beta^4} \quad \text{and} \quad \beta = \frac{d_{ori}}{d_{fill}}$$

Compute the orifice size by varying d_{ori} until the required resistance is obtained. Alternatively, use worksheet D9 to select an orifice from a list of typical sizes. Select the standard orifice size that has a resistance just greater than K_{ori}.

7 References

Unless otherwise specified, the latest edition shall apply.

[1] CGA P-11, *Metric Practice Guide for the Compressed Gas Industry,* Compressed Gas Association, Inc. www.cganet.com

[2] AIGA 054, *Prevention of Overpressure During Filling of Cryogenic Vessels*, Asia Industrial Gases Association, Inc. www.asiaiga.org

NOTE—This publication is part of an international harmonization program for industry standards. The technical content of each regional document is identical, except for regional regulatory requirements. See the referenced document preface for a list of harmonized regional references.

[3] AIGA 031, *Bulk Liquid Oxygen, Nitrogen, and Argon Storage Systems at Production Sites*, Asia Industrial Gases Association, Inc. www.asiaiga.org.com

NOTE—This publication is part of an international harmonization program for industry standards. The technical content of each regional document is identical, except for regional regulatory requirements. See the referenced document preface for a list of harmonized regional references.

[4] *ASME Boiler & Pressure Vessel Code*, ASME International. www.asme.org

[5] Coker, A.K., "Understanding Two-Phase Flow in Process Piping", *Chemical Engineering Progress*, November 1990, page 60, American Institute of Chemical Engineers. www.aiche.org

[6] Crane Technical Paper No. 410, 1976, *Flow of Fluids through Valves, Fittings, and Pipes*, Crane Valve Group. www.craneco.com

Appendix A—Equation sets for the analysis and prevention of overpressure during refilling of cryogenic storage tanks (Normative)

Equations 1e and 1f in Equation set 1 come from Coker, A. K., "Understanding Two-Phase Flow in Process Piping" [5]. The remaining equations in Equation set 1 and the equations in Equation sets 2 and 3 come from Crane Technical Paper No. 410, *Flow of Fluids through Valves, Fittings, and Pipes* [6].

Equation set 1: Frictional pressure loss through pipe and pipe components

U.S. customary units	Metric units	Equation
$\Delta P = \Delta P(Q,K,d,\rho) = \dfrac{0.00001799 \bullet K \bullet \rho \bullet Q^2}{d^4}$	$\Delta P = \Delta P(Q,K,d,\rho) = \dfrac{K \bullet \rho \bullet Q^2}{21.07^2 d^4}$	(1a)
$Q = Q(\Delta P,K,d,\rho) = \sqrt{\dfrac{\Delta P \bullet d^4}{0.00001799 \bullet K \bullet \rho}}$	$Q = Q(\Delta P,K,d,\rho) = 21.07\sqrt{\dfrac{\Delta P \bullet d^4}{K \bullet \rho}}$	(1b)
$K = K(\Delta P,Q,d,\rho) = \dfrac{\Delta P \bullet d^4}{0.00001799 \bullet \rho \bullet Q^2}$	$K = K(\Delta P,Q,d,\rho) = \dfrac{21.07^2 \Delta P \bullet d^4}{\rho \bullet Q^2}$	(1c)
$K = f_t \bullet \dfrac{12 \bullet L}{d}$	$K = f_t \bullet \dfrac{10^3 \bullet L}{d}$	(1d)

$$f_t = \frac{1}{4 \bullet \log^2\left(\dfrac{\varepsilon}{3.7065 \bullet d} - \dfrac{5.0452 \bullet \log(A)}{Re}\right)} \qquad \text{(1e) [5]}$$

$$A = \frac{\left(\dfrac{\varepsilon}{d}\right)^{1.1098}}{2.8257} + \left(\frac{7.149}{Re}\right)^{.8981} \qquad \text{(1f) [5]}$$

U.S. customary units	Metric units	Equation
$Re = 50.6 \bullet \dfrac{Q \bullet \rho}{d \bullet \mu}$	$Re = 0.02122 \bullet \dfrac{Q \bullet \rho}{d \bullet \mu}$	(1g)

Equation set 2: Flow resistance of various components [6]

Bends: $K = \frac{\theta}{90} \bullet K_b$ Where: $\theta \leq 90^\circ$

$$K = \left(\frac{\theta}{90} - 1\right) \bullet \left(.25 \bullet \pi \bullet f_t \bullet \frac{r}{d} + 0.5 \bullet K_b\right) + K_b \qquad \text{Where: } \theta > 90^\circ \qquad (2a)$$

Is interpolated from:

$\frac{r}{d}$	1	1.5	2	3	4	6	8	10	12	14	16	20
$\frac{K_b}{f_t}$	20	14	12	12	14	17	24	30	34	38	42	50

Fittings: $K = \alpha \bullet f_t$ (2b)

Fitting type	α
90-degree elbow	30
45-degree elbow	16
Short radius elbow	40
Tee through run	20
Tee through branch	60
Swing check valve	100

Orifice: $K_{ori} = \frac{1 - \beta^2}{C^2 \bullet \beta^4}$ (2c)

C may be interpolated from the following table:

β	*C*
0.2	.5975
0.3	.6004
0.4	.6057
0.45	.6111
0.5	.6214
0.55	.6335
0.6	.6510
0.65	.6715
0.7	.7007
0.725	.7182
0.75	.7386

Pipe:

U.S. customary units	Metric units	Equation
$K = f_t \bullet \frac{12 \bullet L}{d}$	$K = f_t \bullet \frac{10^6 \bullet L}{d}$	(2d)

Sharp contraction: $K = \frac{(1-\beta^2)}{2 \bullet \beta^4}$ (for larger diameter) (2e)

Sharp-edged entrance: $K = 0.5$ (2f)

Pipe exit: $K = 1.0$ (2g)

Sharp expansion: $K = (1-\beta^2)^2$ (for smaller diameter) (2h)

Valve:

U.S. customary units	Metric units	
$K = \frac{891 \bullet d^4}{C_v{}^2}$	$K = \frac{0.002141 \bullet d^4}{C_v{}^2}$	(2i)

Equation set 3: Converting to an alternative line size [6]

$$K_1 = K_2 \bullet \left(\frac{d_1}{d_2}\right)^4 \quad (3)$$

Equation set 4: Pump discharge characteristics

$$\Delta P_{pmp} = \Delta P_{pmp}(\rho, Q) \quad (4)$$

Appendix B—Sample calculation 1—orifice is required (Informative)

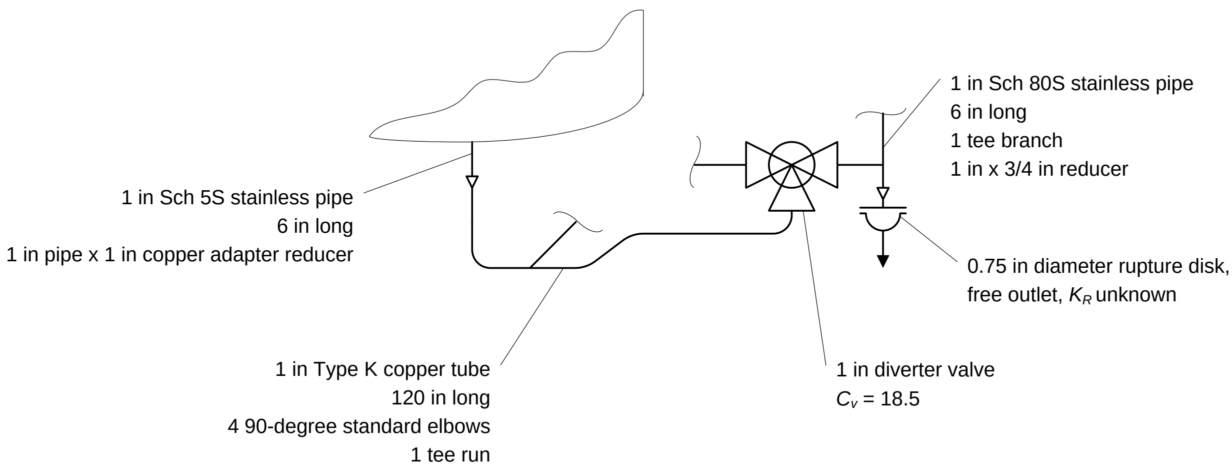


Figure B-1—Sample calculation 1—relief line sketch

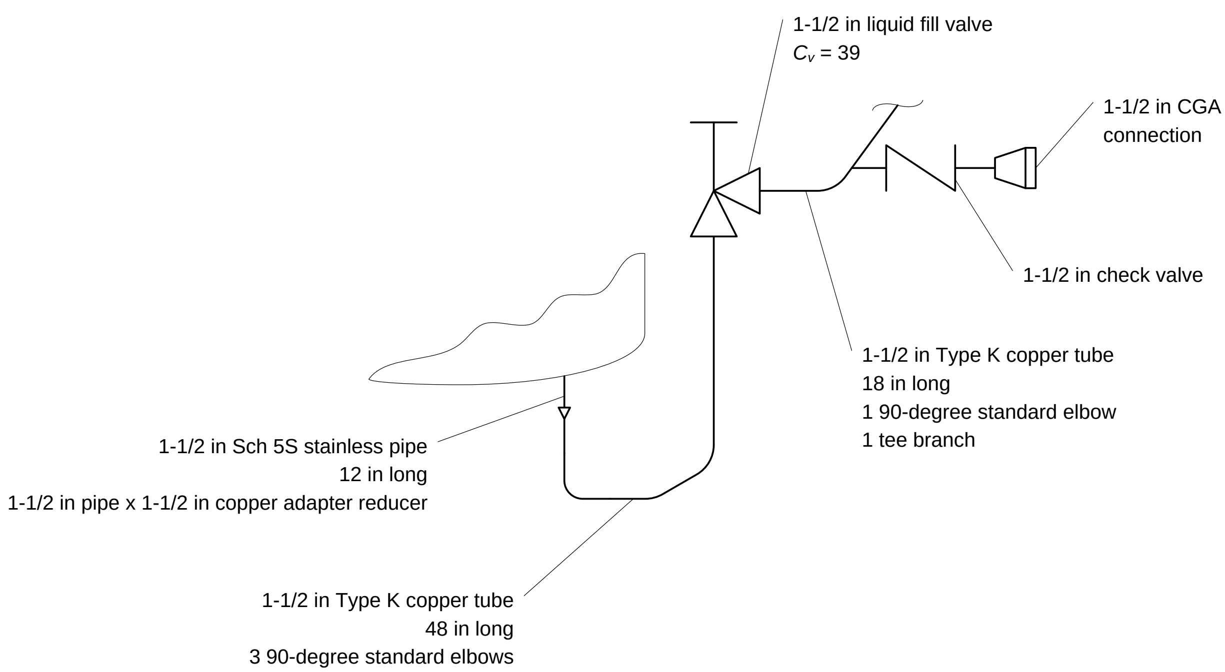


Figure B-2—Sample calculation 1—fill line sketch

Worksheet B1: Input tank and piping data

	General installation information					
A1	Enter the tank owner's name.					
B1	Enter the tank capacity and configuration.	3 000 gal, vertical (11 356 L)				
C1	Enter the manufacturer's serial number from the dataplate.					
D1	Enter the NBIC number from the dataplate.					
E1	Select the product service.	Oxygen				
F1	Is this tank designed for argon, nitrogen, and oxygen?	Yes				
G1	Enter tank MAWP from the dataplate or the manufacturer's U-1A form.	83 psi (5.72 bar)				
H1	Enter the tank test pressure from the manufacturer's U-1A form.	160 psi (11 bar)				
I1	Enter the overall height of the tank if known or measured.	16 ft (4.9 m)				
	Pressure relief line					
Instructions: Inspect the relief line from where it exits the tank casing to the discharge of the rupture disk. Make a note of the different pipe and tube sizes along the entire length of the line.						
		Size 1	**Size 2**	**Size 3**	**Size 4**	**Size 5**
J1	Enter all external relief line pipe and tube sizes. Start at the tank and finish at the rupture disk exit.	1 in (DN25)	1 in (DN25)	1 in (DN25)	3/4 in (DN20)	
K1	Enter the pipe schedule or tube type. Assume the line entering the tank is Sch 5S.	Sch 5S	Type K	Sch 80S	Sch 80S	
L1	Enter the total external relief line straight length for each diameter.	6 in (152.4 mm)	120 in (3048 mm)	6 in (152.4 mm)		
M1	Enter the number of 90-degree standard elbows for each diameter.		4			
N1	Enter the number of short radius 90-degree elbows (90s) for each diameter.					
O1	Enter the number of 45-degree elbows for each diameter.					
P1	Enter the number of tee runs for each diameter.		1			
Q1	Enter the number of tee branches for each diameter.			1		
R1	Enter the diverter valve nominal size.	1 in (DN25)				
S1	Enter the rupture disk diameter.	0.750 in (19.1 mm)				
	Liquid phase fill line					
Instructions: Inspect the tank liquid phase fill line from the fill connection to the point where it enters the casing. Make a note of the different pipe and tube sizes along the entire length of the line.						
		Size 1	**Size 2**	**Size 3**	**Size 4**	**Size 5**
T1	Enter all external liquid phase fill line pipe and tube sizes. Start at the fill connection and finish at the tank casing.	1-1/2 in (DN40)	1-1/2 in (DN40)			
U1	Enter the pipe schedule or tube type. Assume the line entering the tank is Sch 5S.	Type K	Sch 5S			
V1	Enter the total liquid phase fill line straight length for each diameter.	66 in (1676 mm)	12 in (305 mm)			
W1	Enter the number of 90-degree standard elbows for each diameter.	4				
X1	Enter the number of short radius 90s for each diameter.					
Y1	Enter the number of 45-degree elbows for each diameter.					
Z1	Enter the number of tee runs for each diameter.					
AA1	Enter the number of tee branches for each diameter.	1				
AB1	Enter the liquid phase fill valve nominal size.	1-1/2 in (DN40)				
AC1	Enter other liquid phase fill line valve nominal size if applicable.	None				
AD1	Enter the check valve nominal diameter.	1-1/2 in (DN40)				

Worksheet B2: Calculate tank <u>UPL</u>

A2	Enter the maximum design lading liquid density for the tank from Appendix E Table E-1. Assume argon unless otherwise indicated in F1 Worksheet B1, the manufacturer's dataplate, or U-1A Form.	84.99 lb/ft^3 (1361 kg/m^3)
B2	Enter the liquid density from Appendix E Table E-1 for the product in E1 of Worksheet B1.	69.57 lb/ft^3 (1114 kg/m^3)
C2	Subtract line B2 from line A2. C2 = A2–B2	15.42 lb/ft^3 (247 kg/m^3)
D2	Enter the overall height of the tank from Worksheet B1 or Appendix E Table E-2. D2 = I1	16.00 ft (4.88 m)
E2	Determine the vertical distance from the bottom of the liquid container to the normal fill level of the tank in feet. E2 = D2 – 3 ft (Metric units: E2 = D2 – 1 m)	13.00 ft (4.0 m)
F2	Determine available liquid head pressure. F2 = C2 • E2 / 144 (Metric units: F2 = (C2 • E2 • 9.81) / 100000)	1.39 psi (0.1 bar)
Instructions: If the tank test pressure is known, calculate *<u>UPL</u>* using the preferred method as follows:		
G2	Enter H1 (tank test pressure) from Worksheet B1. G2 = H1	160.0 psi (11 bar)
H2	Calculate tank <u>UPL</u> in psi. H2 = G2 – 14.696 (Metric units: H2 = G2 – 1.013)	145.3 psi (10 bar)
Instructions: If the tank test pressure is not known, calculate *<u>UPL</u>* using the optional method as follows:		
I2	Enter G1 (tank MAWP) from Worksheet B1. I2 = G1	83.00 psi (5.7 bar)
J2	Add lines F2, I2, and atmospheric pressure. J2 = F2 + I2 + 14.696 (Metric units: J2 = F2 + I2 + 1.013)	99.09 psi (6.8 bar)
K2	Calculate tank <u>UPL</u>. K2 = J2 • 1.5 – 14.696 (Metric units: K2 = J2 • 1.5 – 1.013)	133.94 psi (9.2 bar)

Worksheet B3: Calculate the maximum frictional pressure loss through the relief system, ΔP_{rel_max}

A3	Enter B2 <u>(liquid density)</u> from Worksheet B2. A2 = B1	69.57 lb/ft^3 (1114 kg/m^3)
B3	Enter D2 <u>(overall tank height)</u> from Worksheet B2. B3 = D2	16.00 ft (4.88 m)
C3	Enter H2 <u>(UPL, if tank test pressure is known)</u> from Worksheet B2, otherwise enter K2 <u>(UPL, if tank pressure is not known)</u> from Worksheet B2. C3 = H2 or K2	145.3 psi (10 bar)
D3	Determine the vertical distance from the relief device to the top of the storage tank liquid container. D3 = B3 – 2 ft (Metric units: D3 = B3 – 0.6 m)	14.00 ft (4.27 m)
E3	Determine the liquid head in the relief device line. E3 = A3 • D3 / 144 (Metric units: E3 = (A3 • D3 • 9.81) / 100000)	6.76 psi (0.47 bar)
F3	Calculate maximum pressure loss through relief system, ΔP_{rel_max}. F3 = C3 + E3	152.07 psi (10.49 bar)

Worksheet B4: Calculate the flow resistance of the pressure relief system, K_{rel}

Instructions: Inspect the relief line from where it exits the tank casing to the discharge of the rupture disk. Make a note of the different pipe and tube sizes along the entire length of the line.		
A4	Calculation reference diameter.	1.481 in (37.6 mm)
	Relief line internal nozzle	
B4	Enter the relief line schedule 40 inside diameter (ID) for the line just as it exits the casing. B4 = Relief line Sch 40 ID	1.049 in (26.6 mm)
C4	Enter pipe entrance flow resistance coefficient.	0.500
D4	Determine the flow resistance for the nozzle straight length. D4 = 0.075 / B4 (Metric units: D4 = 1.905/B4)	0.071
E4	Determine the total flow resistance for the internal nozzle. E4 = C4 + D4	0.571
F4	Determine the flow resistance conversion factor from size B4 to size A4. F4 = $(A4 / B4)^4$	3.973

G4	Convert E4 to size A4 equivalent flow resistance. G4 = E4 • F4	2.269
	Relief line internal pipe	
H4	Enter the relief line schedule 5 ID for the line just as it exits the casing. H4 = Relief line Sch 5 ID	1.185 in (30.1 mm)
I4	Determine the flow resistance for the internal relief line straight length. I4 = 0.15 • D2 / H4 (Metric units: I4 = 12.5 • D2/H4)	2.025
J4	Determine the flow resistance conversion factor from size H4 to size A4. J4 = (A4 / H4)^4	2.440
K4	Convert I4 to size A4 equivalent flow resistance. K4 = I4 • J4	4.941
	Internal line bends	
L4	Enter the flow resistance for the first bend in the internal relief line. L4 = 0.245	0.245
M4	Convert L4 to size A4 equivalent flow resistance. M4 = L4 • J4	0.598
N4	Enter the flow resistance for the second bend in the internal relief line. N4 = 0.189	0.189
O4	Convert N4 to size A4 equivalent flow resistance. O4 = N4 • J4	0.461
P4	Enter the flow resistance for the third bend in the internal relief line. P4 = 0.189	0.189
Q4	Convert P4 to size A4 equivalent resistance. Q4 = P4 • J4	0.461
R4	Determine the total flow resistance for all bends in the internal relief line. R4 = M4 + O4 + Q4	1.520

		Size 1	Size 2	Size 3	Size 4	Size 5
	External relief line inside diameters					
S4	Enter all external relief line IDs. Start at the tank and finish at the rupture disk. Select IDs from Appendix E Table E-3. S4 = All external relief line IDs	1.185 in (30.1 mm)	0.995 in (25.3 mm)	0.957 in (24.3 mm)	0.742 in (18.8 mm)	
T4	Determine the flow resistance conversion factor to size A4 for each line size. T4 = (A4 / S4)^4	2.440	4.908	5.736	15.871	
		Size 1	**Size 2**	**Size 3**	**Size 4**	**Size 5**
	Straight pipe					
U4	Enter L1 (total external relief line straight length for each diameter) from Worksheet B1. U4 = L1	6 in (152.4 mm)	120 in (3048 mm)	6 in (152.4 mm)		
V4	Determine the flow resistance for each external relief line straight length. V4 = 0.0125 • U4 / S4	0.063	1.508	0.078		
W4	Convert each V4 to size A4 equivalent. W4 = V4 • T4	0.154	7.399	0.449		
X4	Determine the total flow resistance of all straight pipe. X4 = Sum of W4 for all diameters	8.003				
	90-degree standard elbows					
Y4	Enter M1 (number of 90-degree standard elbows for each diameter) from Worksheet B1. Y4 = M1		4			
Z4	Determine each 90-degree elbow flow resistance. Z4 = Y4 • 0.375		1.500			
AA4	Convert each Z4 to size A4 equivalent. AA4 = Z4 • T4		7.362			
AB4	Determine the total flow resistance of all 90-degree standard elbows. AB4 = Sum of AA4 for all diameters	7.362				
	Short radius 90s					
AC4	Enter N1 (number of short radius elbows for each diameter) from Worksheet B1. AC4 = N1					

AD4	Determine each short radius elbow flow resistance. AD4 = AC4 • 0.500					
AE4	Convert each AD4 to size A4 equivalent. AE4 = AD4 • T4					
AF4	Determine the total flow resistance of all short radius 90s. AF4 = Sum of AE4 for all diameters	0.000				
	45-degree standard elbows					
AG4	Enter O1 (number of 45-degree elbows for each diameter) from Worksheet B1. AG4 = O1					
AH4	Determine each 45-degree elbow flow resistance. AH4 = AG4 • 0.200					
AI4	Convert each AH4 to size A4 equivalent. AI4 = AH4 • T4					
AJ4	Determine the total flow resistance of all 45-degree standard elbows. AJ4 = Sum of AI4 for all diameters	0.000				
	Tee runs					
AK4	Enter P1 (number of tee runs for each diameter) from Worksheet B1. AK4 = P1		1			
AL4	Determine each tee run flow resistance. AL4 = AK4 • 0.250		0.250			
AM4	Convert each AL4 to size A4 equivalent. AM4 = AL4 • T4		1.227			
AN4	Determine the total flow resistance of all tee runs. AN4 = Sum of AM4 for all diameters	1.227				
		Size 1	**Size 2**	**Size 3**	**Size 4**	**Size 5**
	Tee branches					
AO4	Enter Q1 (number of tee branches for each diameter) from Worksheet B1. AO4 = Q1			1		
AP4	Determine each tee branch flow resistance. AP4 = AO4 • 0.750			0.750		
AQ4	Convert each AP4 to size A4 equivalent. AQ4 = AP4 • T4			4.302		
AR4	Determine the total flow resistance of all tee branches. AR4 = Sum of AQ4 for all diameters	4.302				
	Pipe size expansions					
AS4	Enter the smaller IDs for all expansions. AS4 = Expander smaller ID					
AT4	Enter the larger IDs for all expansions. AT4 = Expander larger ID					
AU4	Determine the square of the small to large diameter ratio for each expansion. $AU4 = (AS4 / AT4)^2$					
AV4	Determine the resistance coefficient for each expansion. $AV4 = (1 – AU4)^2$					
AW4	Convert each AV4 to size A4 equivalent. AW4 = AV4 • T4					
AX4	Determine the total flow resistance of all pipe size expansions. AX4 = Sum of AW4 for all diameters	0.000				
	Pipe size reducers					
AZ4	Enter the smaller IDs for all reducers. AZ4 = Reducer smaller ID	0.995 in (25.3 mm)	0.957 in (24.3 mm)	0.742 in (18.8 mm)		
BA4	Determine the small to large diameter ratio for each reducer. BA4 = AZ4 / AY4	0.840	0.962	0.775		
BB4	Determine the resistance coefficient for each reducer. $BB4 = (1 – BA4^2) / (2 • BA4^4)$	0.297	0.044	0.552		

BC4	Convert each BB4 to size A4 equivalent. BC4 = BB4 • T4	0.724	0.215	3.165		
BD4	Determine the total flow resistance of all pipe size reducers. BD4 = Sum of BC4 for all diameters	4.104				
	Diverter valve					
BE4	Enter <u>R1</u> (diverter valve size) from Worksheet B1. BE4 = ID of R1	1.00 in (25.4 mm)				
BF4	Enter the diverter valve *Cv*. BF4 = Diverter valve *Cv*	18.5				
BG4	Determine the diverter valve resistance coefficient. $BG4 = 891 \cdot BE4^4 / BF4^2$ (Metric: $0.002141 \cdot BE4^4 / BF4^2$)	2.603				
BH4	Determine the flow resistance conversion factor to size A4 for the diverter valve. $BH4 = (A4 / BE4)^4$	4.811				
BI4	Convert BG4 to size A4 equivalent. BI4 = BG4 • BH4	12.524				
	Rupture disk					
BJ4	Enter <u>S1</u> (rupture disk diameter) from Worksheet B1. BJ4 = S1	0.750 in (19.1 mm)				
BK4	Enter the rupture disk flow resistance coefficient specified by the manufacturer. If unknown, use 2.4. BK4 = 2.4 (if unknown)	2.400				
BL4	Determine the flow resistance conversion factor to size A4 for the rupture disk. $BL4 = (A4 / BJ4)^4$	15.205				
BM4	Determine the flow resistance of the rupture disk. BM4 = BK4 • BL4	36.491				
	Pipe exit					
BN4	Enter the pipe exit flow resistance coefficient. BN4 = 1.0				1.0	
BO4	Convert the pipe exit resistance coefficient to size A4 equivalent. BO4 = BN4 • T4				15.871	
	Total relief line flow resistance, K_{rel}					
BP4	Determine the flow resistance total for the entire relief line referenced to size A4, K_{rel}. BP4 = G4 + K4 +R4 + X4 + AB4 + AF4 + AJ4 + AN4 + AR4 + AX4 + BD4 + BI4 + BM4 + BO4	98.617				

Worksheet B5: Calculate the maximum flow through the relief system, Q_{rel_max}

A5	Enter B2 <u>(liquid density)</u> from Worksheet B2. A5 = B2	69.57 lb/ft^3 (1114 kg/m^3)
B5	Enter F3 <u>(maximum pressure loss through relief system)</u> from Worksheet B3. B5 = F3	152.07 psi (10.49 bar)
C5	Enter A4 <u>(reference diameter)</u> from Worksheet B4. C5 = A4	1.481 in (37.6 mm)
D5	Enter BP4 <u>(total relief line flow resistance)</u> from Worksheet B4. D5 = BP4	98.617
E5	Determine C5 to the fourth power. $E5 = C5^4$	4.811 in^4 (2002421 mm^4)
F5	Multiply B5 by E5. F5 = B5 • E5	731.572 (21005385)
G5	Multiply A5 by D5 and 0.000018 (not required for metric). G5 = A5 • D5 • 0.000018 (Metric units: G5 = A5 • D5)	0.123 (109860)
H5	Divide F5 by G5. H5 = F5 / G5	5923.944 (191)
I5	Multiply the square root of H5 by 0.9, Q_{rel_max}. $I5 = 0.9 \cdot H5^{1/2}$ (Metric units: $I5 = 0.9 \cdot 21.07 \cdot H5^{1/2}$)	69.27 gal/min (262 L/min)

Worksheet B6: Calculate the Flow Resistance of the Tank Fill System, K_{fill}

Instructions: Inspect the tank liquid phase fill line from the fill connection to the point where it enters the casing. Make a note of the different pipe and tube sizes along the entire length of the line.						
	Fill system standard components					
A6	Enter the truck, hose, and fill connection ID. A6 = Fill system base ID	1.481 in (37.6 mm)				
B6	Enter the truck, hose, and fill connection flow resistance coefficient. B6 = 11.519	11.519				
		Size 1	**Size 2**	**Size 3**	**Size 4**	**Size 5**
	Liquid phase fill line inside diameters					
C6	Enter all external liquid phase fill line IDs. Start after the fill connection and finish at the tank casing. Select IDs from Appendix E Table E-3. C6 = All external fill line IDs	1.481 in (37.6 mm)	1.770 in (45.0 mm)			
D6	Determine the flow resistance conversion factor to size A6 for each line size. D6 = $(A6 / C6)^4$	1.000	0.490			
	Straight pipe					
E6	Enter <u>V1</u> (total liquid phase fill line straight length for each diameter) from Worksheet B1. E6 = V1	66 in (1676 mm)	12 in (305 mm)			
F6	Determine the flow resistance for each external fill line straight length. F6 = 0.0138 • E6 / C6	0.615	0.094			
G6	Convert each F6 to size A6 equivalent. G6 = F6 • D6	0.615	0.046			
H6	Determine the total flow resistance of all straight pipe. H6 = Sum of G6 for all diameters	0.661				
	Liquid fill valve(s)	**Liquid fill valve**	**Liquid line valve**			
I6	Enter <u>AB1 and AC1</u> (liquid phase valve[s] diameter[s] based upon nominal size[s]) from Worksheet B1. I6 = AB1 and AC1	1.50 in (38.1 mm)	None			
J6	Enter the C_v for each liquid phase fill valve. J6 = Fill valve C_v	39.0				
K6	Determine the liquid fill valve resistance coefficient. K6 = $(891 \cdot I6^4) / J6^2$ (Metric units: $0.002141 \cdot I6^4) / J6^2$)	2.966				
L6	Determine the flow resistance conversion factor to size A6 for each valve. L6 = $(A6 / I6)^4$	0.950				
M6	Convert K6 to size A6 equivalent. M6 = K6 • L6	2.818				
N6	Determine the flow resistance of the liquid fill valve(s). N6 = Sum of M6 for all diameters	2.818				
	Check valve(s)					
O6	Enter <u>AD1</u> (check valve nominal diameter) from Worksheet B1. O6 = AD1	1.50 in (38.1 mm)				
P6	Enter the check valve flow resistance coefficient. P6 = 1.380	1.380				
Q6	Determine the flow resistance conversion factor to size A6. Q6 = $(A6 / O6)^4$	0.950				
R6	Convert the check valve resistance coefficient to size A6 equivalent. R6 = P6 • Q6	1.311				
		Size 1	**Size 2**	**Size 3**	**Size 4**	**Size 5**
	90-degree standard elbows					
S6	Enter <u>W1</u> (number of 90-degree standard elbows for each diameter) from Worksheet B1. S6 = W1	4				
T6	Determine each 90-degree elbow flow resistance. T6 = S6 • 0.414	1.656				

U6	Convert each T6 to size A6 equivalent. U6 = T6 • D6	1.656				
V6	Determine the total flow resistance of all 90-degree standard elbows. V6 = Sum of U6 for all diameters	1.656				
	Short radius 90s					
W6	Enter X1 (number of short radius elbows for each diameter) from Worksheet B1. W6 = X1					
X6	Determine each short radius elbow flow resistance. X6 = W6 • 0.552					
Y6	Convert each W6 to size A6 equivalent. Y6 = X6 • D6					
Z6	Determine the total flow resistance of all short radius 90s. Z6 = Sum of Y6 for all diameters	0.000				
	45-degree standard elbows					
AA6	Enter Y1 (number of 45-degree elbows for each diameter) from Worksheet B1. AA6 = Y1					
AB6	Determine each 45-degree elbow flow resistance. AB6 = AA6 • 0.221					
AC6	Convert each AA6 to size A6 equivalent. AC6 = AB6 • D6					
AD6	Determine the total flow resistance of all 45-degree standard elbows. AD6 = Sum of AC6 for all diameters	0.000				
	Tee runs					
AE6	Enter Z1 (number of tee runs for each diameter) from Worksheet B1. AE6 = Z1					
AF6	Determine each tee run flow resistance. AF6 = AE6 • 0.276					
AG6	Convert each AF6 to size A6 equivalent. AG6 = AF6 • D6					
AH6	Determine the total flow resistance of all tee runs. AH6 = Sum of AG6 for all diameters	0.000				
	Tee branches					
AI6	Enter AA1 (number of tee branches for each diameter) from Worksheet B1. AI6 = AA1	1				
AJ6	Determine each tee branch flow resistance. AJ6 = AI6 • 0.828	0.828				
AK6	Convert each AJ6 to size A6 equivalent. AK6 = AJ6 • D6	0.828				
AL6	Determine the total flow resistance of all tee branches. AL6 = Sum of AK6 for all diameters	0.828				
		Size 1	**Size 2**	**Size 3**	**Size 4**	**Size 5**
	Pipe size expansions					
AM6	Enter the smaller IDs for all expansions. AM6 = Expander smaller ID	1.481 in (37.6 mm)				
AN6	Enter the larger IDs for all expansions. AN6 = Expander larger ID	1.770 in (45.0 mm)				
AO6	Determine the square of the small to large diameter ratio for each expansion. AO6 = $(AM6 / AN6)^2$	0.700				
AP6	Determine the resistance coefficient for each expansion. AP6 = $(1 – AO6)^2$	0.090				
AQ6	Convert each AP6 to size A6 equivalent. AQ6 = AP6 • D6	0.090				
AR6	Determine the total flow resistance of all pipe size expansions. AR6 = Sum of AQ6 for all diameters	0.090				

	Pipe size reducers					
AS6	Enter the larger IDs for all reducers. AS6 = Reducer larger ID					
AT6	Enter the smaller IDs for all reducers. AT6 = Reducer smaller ID					
AU6	Determine the small to large diameter ratio for each reducer. AU6 = AT6 / AS6					
AV6	Determine the resistance coefficient for each reducer. AV6 = (1 – AU6^2) / (2 • AU6^4)					
AW6	Convert each AV6 to size A6 equivalent. AW6 = AV6 • D6					
AX6	Determine the total flow resistance of all pipe size reducers. AX6 = Sum of AW6 for all diameters	0.000				
	Fill line internal pipe					
AY6	Enter the liquid phase fill line Sch 5 ID for the line just as it enters the casing. Select ID from Appendix E, Table E-3. AY6 = Fill line Sch 5 ID	1.770 in (45 mm)				
AZ6	Enter the length of the tank internal liquid phase fill line. AZ6 = 36 in (Metric units: AZ6 = 914.4 mm)	36 in (914.4 mm)				
BA6	Determine the flow resistance for the internal fill line straight length. BA6 = 0.0138 • AZ6 / AY6	0.281				
BB6	Determine the flow resistance conversion factor from size AY6 to size A6. BA6 = (A6 / AY6)^4	0.490				
BC6	Convert BA6 to size A6 equivalent flow resistance. BC6 = BA6 • BB6	0.138				
	Internal line bends					
BD6	Enter the flow resistance for the first bend in the internal fill line. BD6 = 0.228	0.228				
BE6	Convert BD6 to size A6 equivalent flow resistance. BE6 = BD6 • BB6	0.112				
BF6	Enter the flow resistance for the second bend in the internal fill line. BF6 = 0.228	0.228				
BG6	Convert BF6 to size A6 equivalent flow resistance. BG6 = BF6 • BB6	0.112				
BH6	Determine the total flow resistance for all bends in the internal fill line. BH6 = BE6 + BG6	0.224				
	Fill line internal nozzle					
BI6	Enter the fill line schedule 40 ID for the line just as it enters the casing. BI6 = Fill line Sch 40 ID	1.610 in (40.9 mm)				
BJ6	Enter pipe exit flow resistance coefficient. BJ6 = 1.0	1.000				
BK6	Determine the flow resistance for the nozzle straight length. BK6 = 0.0828 / BI6 (Metric units: BK6 = 2.1163 / BI6)	0.051				
BL6	Determine the total flow resistance for the internal nozzle. BL6 = BJ6 + BK6	1.051				
BM6	Determine the flow resistance conversion factor from size BI6 to size A6. BM6 = (A6 / BI6)^4	0.716				
BN6	Convert the internal nozzle resistance coefficient to size A6 equivalent. BN6 = BL6 • BM6	0.753				
	Total fill line flow resistance, K_{fill}					
BO6	Determine the flow resistance total for the entire fill line referenced to size A6, K_{fill}. BO6 = H6 +N6 + R6 + V6 + Z6 + AD6 + AH6 + AL6 + AR6 + AX6 + BC6 + BH6 + BN6	8.478				

Worksheet B7: Calculate the pressure loss through the fill system, ΔP_{fill_line}

	Fill system standard components	
A7	Enter B2 (liquid density) from Worksheet B2. A7 = B2	69.57 lb/ft^3 (1114 kg/m^3)
B7	Enter I5 (calculation result) from Worksheet B5. B7 = I5	69.270 gal/min (262 L/min)
C7	Enter A6 (truck, hose, and fill connection ID) from Worksheet B6. C7 = A6	1.481 in (37.6 mm)
D7	Enter B6 (truck, hose, and fill connection flow resistance) from Worksheet B6. D7 = B6	11.519
E7	Enter C7 to the fourth power. E7 = C7^4	4.811 in^4 (2002420 mm^4)
F7	Calculate the square of B7. F7 = B7^2	4798.393 gal/min^2 (68644 L/min^2)
G7	Multiply F7 by A7 and 0.000018 (not required for metric). G7 = F7 • A7 • 0.000018 (Metric units: G7 = F7 • A7)	6.009 (76469416)
H7	Multiply D7 by G7. H7 = D7 • G7	69.215 (880851203)
I7	Determine the pressure drop through the standard components. I7 = H7 / E7 (Metric units: I7 = H7 / (E7 • 21.07^2)	14.39 psi (0.99 bar)
	Fill system variable components	
J7	Enter BO6 (total fill line flow resistance) from Worksheet B6. J7 = BO6	8.478
K7	Divide F7 by 4. K7 = F7 / 4	1 199.60 gal/min^2 (17 166 L/min^2)
L7	Multiply K7 by A7 and 0.000018 (not required for metric). L7 = K7 • A7 • 0.000018 (Metric units: L7 = K7 • A7)	1.502 (19122924)
M7	Multiply J7 by L7. M7 = J7 • L7	12.736 (162124149)
N7	Determine the pressure drop through the variable components. N7 = M7 / E7 (Metric units: N7 = M7 / (E7 • 21.07^2)	2.65 psi (0.18 bar)
	Fill system total pressure drop ΔP_{fill_line}	
O7	Determine the fill system total pressure drop, ΔP_{fill_line}. O7 = I7 + N7	17.03 psi (1.17 bar)

Worksheet B8: Calculate the fill line orifice pressure drop, ΔP_{ori}

	Pump discharge pressure	
A8	Enter I5 (calculation result) from Worksheet B5. A8 = I5	69.270 gal/min (262 L/min)
B8	Enter the product. B8 = E1	Oxygen
C8	For the product in B8, select the value from Appendix E Table E-4 that is just less than the flow in A8. See Table E-4 note.	60 gal/min (230 L/min)
D8	Select the value from Appendix E Table E-4 for the flow in C8 and the product in B8.	429.60 psi (29.6 bar)
E8	For the product in B8, select the value from Appendix E Table E-4 that is just greater than the flow in A8.	70 gal/min (265 L/min)
F8	Select the value from Appendix E Table E-4 for the flow in E8 and the product in B8. See Table E-4 note.	427.79 psi 29.5 bar
G8	Subtract C8 from A8. G8 = A8 – C8	9.27 gal/min (32 L/min)
H8	Subtract C8 from E8. H8 = E8 – C8	10.00 gal/min (35 L/min)
I8	Subtract D8 from F8. I8 = F8 – D8	–1.81 psi (–0.1 bar)
J8	Multiply I8 by G8 and divide by H8. J8 = I8 • G8 / H8	–1.68 psi (–0.09 bar)

K8	Determine the pump pressure rise. K8 = D8 + J8	427.92 psi (29.5 bar)
L8	Determine the pump discharge pressure. L8 = K8 + 30 psi (Metric units: L8 = K8 + 2.1 bar)	457.92 psi (31.5 bar)
	Fill line orifice pressure drop, ΔP_{ori}	
M8	Enter D2 (overall height of the tank) from Worksheet B2. M8 = D2	16.00 ft (4.88 m)
N8	Determine the vertical distance from the pump to the top of the storage tank inner container. N8 = M8 – 6 ft (Metric units: N8 = M8 – 1.8 m)	10.00 ft (3.05 m)
O8	Enter B2 (liquid density) from Worksheet B2. O8 = B2	69.57 lb/ft^3 (1114 kg/m^3)
P8	Determine liquid head pressure based on N8. P8 = N8 • O8 / 144 (Metric units: P8 = (N8 • O8 • 9.81) / 100000)	4.83 psi (0.33 bar)
Q8	Enter H2 (UPL, if tank test pressure is known), or K2 (UPL, if tank test pressure is not known) from Worksheet B2. Q8 = H2 or K2	99.09 psi (6.8 bar)
R8	Enter O7 (fill system total pressure drop) from Worksheet B7. R8 = O7	17.03 psi (1.17 bar)
S8	Determine the fill line orifice pressure drop, ΔP_{ori}. S8 = L8 – R8 – P8 – Q8	336.97 psi (23.2 bar)

Worksheet B9: Determine the required fill line orifice size, d_{ori}

	Orifice flow coefficient, K_{ori}	
A9	Enter E7 (calculation result) from Worksheet B7. A9 = E7	4.811 in^4 (2002420 mm^4)
B9	Enter S8 (fill line orifice pressure drop) from Worksheet B8. B9 = S8	336.97 psi (23.2 bar)
C9	Enter G7 (calculation result) from Worksheet B7. C9 = G7	6.009 (76469416)
D9	Multiply A9 by B9. D9 = A9 • B9 (Metric units: D9 = 21.07^2 • A9 • B9)	1621.15 (20623968202)
E9	Determine the required flow coefficient for the fill line orifice, K_{ori}. E9 = D9 / C9	269.78
	Fill line orifice diameter	
F9	Select the flow coefficient from Appendix E Table E-5 that is just greater than E9.	295.21
G9	Select the orifice diameter from Appendix E Table E-5 that is in the same row as the flow coefficient in F9.	0.450 in 11.4 mm

Appendix C—Sample calculation 2—orifice is not required (Informative)

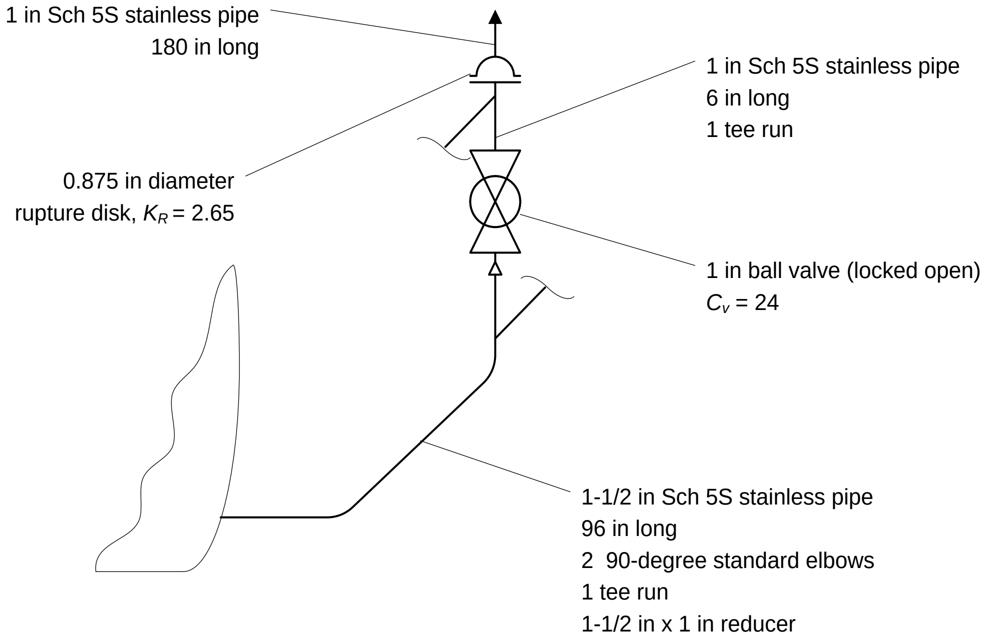
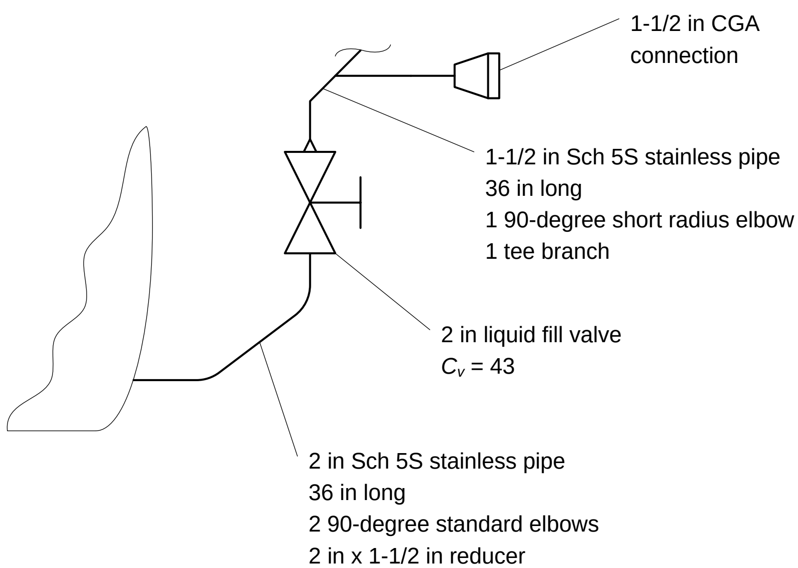


Figure C-1—Sample calculation 2—relief line sketch



-

Figure C-2—Sample calculation 2—fill line sketch

Worksheet C1: Input tank and piping data

	General installation information					
A1	Enter the tank owner's name.					
B1	Enter the tank capacity and configuration.	25 000 gal, horizontal (94 600 L)				
C1	Enter the manufacturer's serial number from the dataplate.					
D1	Enter the NBIC number from the dataplate.					
E1	Select the product service.	Nitrogen				
F1	Is this tank designed for argon, nitrogen, and oxygen?	Yes				
G1	Enter tank MAWP from the dataplate or the manufacturer's U-1A form.	175 psi (12.1 bar)				
H1	Enter the tank test pressure from the manufacturer's U-1A form.	Unknown				
I1	Enter the overall height of the tank if known or measured.	15.5 ft (4.72 m)				
	Pressure relief line					
Instructions: Inspect the relief line from where it exits the tank casing to the discharge of the rupture disk. Make a note of the different pipe and tube sizes along the entire length of the line.						
		Size 1	**Size 2**	**Size 3**	**Size 4**	**Size 5**
J1	Enter all external relief line pipe and tube size. Start at the tank and finish at the rupture disk exit.	1-1/2 in (DN40)	1 in (DN25)			
K1	Enter the pipe schedule or tube type. Assume the line entering the tank is Sch 5S.	Sch 5S	Sch 5S			
L1	Enter the total external relief line straight length for each diameter.	96 in (2438 mm)	186 in (4724 mm)			
M1	Enter the number of 90-degree standard elbows for each diameter.	2				
N1	Enter the number of short radius 90-degree elbows (90s) for each diameter.					
O1	Enter the number of 45-degree elbows for each diameter.					
P1	Enter the number of tee runs for each diameter.	1	1			
Q1	Enter the number of tee branches for each diameter.					
R1	Enter the diverter valve nominal size.	1 in (DN25)				
S1	Enter the rupture disk diameter.	0.875 in (22.2 mm)				
	Liquid phase fill line					
Instructions: Inspect the tank liquid phase fill line from the fill connection to the point where it enters the casing. Make a note of the different pipe and tube sizes along the entire length of the line.						
		Size 1	**Size 2**	**Size 3**	**Size 4**	**Size 5**
T1	Enter all external liquid phase fill line pipe and tube sizes. Start at the fill connection and finish at the tank casing.	1-1/2 in (DN40)	2 in (DN50)			
U1	Enter the pipe schedule or tube type. Assume the line entering the tank is Sch 5S.	Sch 5S	Sch 5S			
V1	Enter the total liquid phase fill line straight length for each diameter.	36 in (914 mm)	36 in (914 mm)			
W1	Enter the number of 90-degree standard elbows for each diameter.		2			
X1	Enter the number of short radius elbows for each diameter.	1				
Y1	Enter the number of 45-degree elbows for each diameter.					
Z1	Enter the number of tee runs for each diameter.					
AA1	Enter the number of tee branches for each diameter.	1				
AB1	Enter the liquid phase fill valve nominal size.	2 in (DN50)				
AC1	Enter other liquid phase fill line valve nominal size, if applicable.	None				
AD1	Enter the check valve nominal diameter.	None				

Worksheet C2: Calculate tank UPL

A2	Enter the maximum design lading liquid density for the tank from Appendix E Table E-1. Assume argon unless otherwise indicated in F1 Worksheet C1, the manufacturer's dataplate, or U-1A Form.	84.99 lb/ft^3 (1361.4 kg/m^3)
B2	Enter the liquid density in from Appendix E Table E-1 for the product in E1 of Worksheet C1.	49.09 lb/ft^3 (786.3 kg/m^3)
C2	Subtract line B2 from line A2. C2 = A2 – B2	35.90 (575.1 kg/m^3)
D2	Enter the overall height of the tank from Worksheet C1 or Appendix E Table E-2. D2 = I1	15.50 ft (4.72 m)
E2	Determine the vertical distance from the bottom of the liquid container to the normal fill level of the tank. E2 = D2 – 3 ft (Metric units: E2 = D2 – 1 m)	12.50 ft (2.81 m)
F2	Determine available liquid head pressure. F2 = C2 • E2 / 144 (Metric units: F2 = (C2 • E2 • 9.81) / 100000)	3.12 psi (0.215 bar)
Instructions: If the tank test pressure is known, calculate *UPL* using the preferred method as follows:		
G2	Enter H1 (tank test pressure) from Worksheet C1. G2 = H1	Unknown
H2	Calculate the tank UPL. H2 = G2 – 14.696 psi (Metric units: H2 = G2 – 1 bar)	
Instructions: If the tank test pressure is not known, calculate *UPL* using the optional method as follows:		
I2	Enter G1 (tank MAWP) from Worksheet C1. I2 = G1	175.00 psi (12.06 bar)
J2	Add lines F2, I2, and atmospheric pressure. J2 = F2 + I2 + 14.696 psi (Metric units: J2 = F2 + I2 + 1.013 bar)	192.81 psi (13.29 bar)
K2	Calculate tank UPL. K2 = J2 • 1.5 – 14.696 (Metric units: J2 • 1.5 – 1.013)	274.52 psi (18.83 bar)

Worksheet C3: Calculate the maximum frictional pressure loss through the relief system, ΔP_{rel_max}

A3	Enter B2 (liquid density) from Worksheet C2. A3 = B2	49.09 lb/ft^3 (786.3 kg/m^3)
B3	Enter D2 (overall tank height) from Worksheet C2. B3 = D2	15.50 ft (4.72 m)
C3	Enter H2 (UPL, if tank test pressure is known) from Worksheet C2 if tank test pressure is known, otherwise enter K2 (UPL, if tank test pressure is not known) from Worksheet C2. C3 = H2 or K2	274.52 psi (18.83 bar)
D3	Determine the vertical distance from the relief device to the top of the storage tank liquid container. D3 = B3 – 2 ft (Metric units: D3 = B3 – 0.61 m)	13.50 ft (4.11 m)
E3	Determine the liquid head in the relief device line. E3 = A3 • D3 / 144 (Metric units: E3 = (A3 • D3 • 9.81) / 100000)	4.60 psi (0.317 bar)
F3	Calculate maximum pressure loss through relief system, ΔP_{rel_max}. F3 = C3 + E3	279.12 psi (19.16 bar)

Worksheet C4: Calculate the flow resistance of the pressure relief system, K_{rel}

Instructions: Inspect the relief line from where it exits the tank casing to the discharge of the rupture disk. Make a note of the different pipe and tube sizes along the entire length of the line.		
	Calculation reference diameter	
A4	Calculation reference diameter.	1.481 in (37.6 mm)
	Relief line internal nozzle	
B4	Enter the relief line schedule 40 ID for the line just as it exits the casing. B4 = Relief line Sch 40 ID	1.610 in (40.9 mm)
C4	Enter pipe entrance flow resistance coefficient.	0.500
D4	Determine the flow resistance for the nozzle straight length. D4 = 0.075 / B4 (Metric units: D4 = 1.905 / B4)	0.047

E4	Determine the total flow resistance for the internal nozzle. E4 = C4 + D4	0.547
F4	Determine the flow resistance conversion factor from size B4 to size A4. F4 = (A4 / B4)^4	0.716
G4	Convert E4 to size A4 equivalent flow resistance. G4 = E4 • F4	0.391
	Relief line internal pipe	
H4	Enter the relief line schedule 5 ID for the line just as it exits the casing. H4 = Relief line Sch 5 ID	1.770 in (45.0 mm)
I4	Determine the flow resistance for the internal relief line straight length. I4 = 0.15 • D2 / H4 (Metric units: I4 = 12.5 • D2 / H4)	1.314
J4	Determine the flow resistance conversion factor from size H4 to size A4. J4 = (A4 / H4)^4	0.490
K4	Convert I4 to size A4 equivalent flow resistance. K4 = I4 • J4	0.644
	Internal line bends	
L4	Enter the flow resistance for the first bend in the internal relief line. L4 = 0.245	0.245
M4	Convert L4 to size A4 equivalent flow resistance. M4 = L4 • J4	0.120
N4	Enter the flow resistance for the second bend in the internal relief line. N4 = 0.189	0.189
O4	Convert N4 to size A4 equivalent flow resistance. O4 = N4 • J4	0.093
P4	Enter the flow resistance for the third bend in the internal relief line. P4 = 0.189	0.189
Q4	Convert P4 to size A4 equivalent resistance. Q4 = P4 • J4	0.093
R4	Determine the total flow resistance for all bends in the internal relief line. R4 = M4 + O4 + Q4	0.305

		Size 1	Size 2	Size 3	Size 4	Size 5
	External relief line inside diameters					
S4	Enter all external relief line IDs. Start at the tank and finish at the rupture disk. Select IDs from Appendix E Table E-3. S4 = All external relief line IDs	1.770 in (45.0 mm)	1.185 in (30.1 mm)			
T4	Determine the flow resistance conversion factor to size A4 for each line size. T4 = (A4 / S4)^4	0.490	2.440			
	Straight pipe					
U4	Enter L1 (total external relief line straight length for each diameter) from Worksheet C1. U4 = L1	96 in (2438 mm)	186 in (4724 mm)			
V4	Determine the flow resistance for each external relief line straight length. V4 = 0.0125 • U4 / S4	0.678	1.962			
W4	Convert each V4 to size A4 equivalent. W4 = V4 • T4	0.332	4.787			
X4	Determine the total flow resistance of all straight pipe. X4 = Sum of W4 for all diameters	5.119				
	90-degree standard elbows					
Y4	Enter M1 (number of 90-degree standard elbows for each diameter) from Worksheet C1. Y4 = M1	2				
Z4	Determine each 90-degree elbow flow resistance. Z4 = Y4 • 0.375	0.750				
AA4	Convert each Z4 to size A4 equivalent. AA4 = Z4 • T4	0.368				
AB4	Determine the total flow resistance of all 90-degree standard elbows. AB4 = Sum of AA4 for all diameters	0.368				

	Short radius 90s					
AC4	Enter N1 (number of short radius elbows for each diameter) from Worksheet C1. AC4 = N1					
AD4	Determine each short radius elbow flow resistance. AD4 = AC4 • 0.500					
AE4	Convert each AD4 to size A4 equivalent. AE4 = AD4 • T4					
AF4	Determine the total flow resistance of all short radius 90s. AF4 = Sum of AE4 for all diameters	0.000				
	45-degree standard elbows					
AG4	Enter O1 (number of 45-degree elbows for each diameter) from Worksheet C1. AG4 = O1					
AH4	Determine each 45-degree elbow flow resistance. AH4 = AG4 • 0.200					
AI4	Convert each AH4 to size A4 equivalent. AI4 = AH4 • T4					
AJ4	Determine the total flow resistance of all 45-degree standard elbows. AJ4 = Sum of AI4 for all diameters	0.000				
		Size 1	**Size 2**	**Size 3**	**Size 4**	**Size 5**
	Tee runs					
AK4	Enter P1 (number of tee runs for each diameter) from Worksheet C1. AK4 = P1	1	1			
AL4	Determine each tee run flow resistance. AL4 = AK4 • 0.250	0.250	0.250			
AM4	Convert each AL4 to size A4 equivalent. AM4 = AL4 • T4	0.123	0.610			
AN4	Determine the total flow resistance of all tee runs. AN4 = Sum of AM4 for all diameters	0.732				
	Tee branches					
AO4	Enter Q1 (number of tee branches for each diameter) from Worksheet C1. AO4 = Q1					
AP4	Determine each tee branch flow resistance. AP4 = AO4 • 0.750					
AQ4	Convert each AP4 to size A4 equivalent. AQ4 = AP4 • T4					
AR4	Determine the total flow resistance of all tee branches. AR4 = Sum of AQ4 for all diameters	0.000				
	Pipe size expansions					
AS4	Enter the smaller IDs for all expansions. AS4 = Expander smaller ID					
AT4	Enter the larger IDs for all expansions. AT4 = Expander larger ID					
AU4	Determine the square of the small to large diameter ratio for each expansion. AU4 = $(AS4 / AT4)^2$					
AV4	Determine the resistance coefficient for each expansion. AV4 = $(1 – AU4)^2$					
AW4	Convert each AV4 to size A4 equivalent. AW4 = AV4 • T4					
AX4	Determine the total flow resistance of all pipe size expansions. AX4 = Sum of AW4 for all diameters	0.000				
	Pipe size reducers					
AY4	Enter the larger IDs for all reducers. AY4 = Reducer larger ID	1.770 in (45.0 mm)				

AZ4	Enter the smaller IDs for all reducers. AZ4 = Reducer smaller ID	1.185 in (30.1 mm)				
BA4	Determine the small to large diameter ratio for each reducer. BA4 = AZ4 / AY4	0.669				
BB4	Determine the resistance coefficient for each reducer. $BB4 = (1 – BA4^2) / (2 \cdot BA4^4)$	1.379				
BC4	Convert each BB4 to size A4 equivalent. BC4 = BB4 • T4	0.676				
BD4	Determine the total flow resistance of all pipe size reducers. BD4 = Sum of BC4 for all diameters	0.676				
	Diverter valve					
BE4	Enter R1 (diverter valve size) from Worksheet C1. BE4 = ID of R1	1.00 in (25.4 mm)				
BF4	Enter the diverter valve Cv. BF4 = Diverter valve Cv	24.0				
BG4	Determine the diverter valve resistance coefficient. $BG4 = 891 \cdot BE4^4 / BF4^2$ (Metric: $BG4 = 0.002141 \cdot BE4^4 / BF4^2$)	1.55				
		Size 1	**Size 2**	**Size 3**	**Size 4**	**Size 5**
BH4	Determine the flow resistance conversion factor to size A4 for the diverter valve. $BH4 = (A4 / BE4)^4$	4.81				
BI4	Convert BG4 to size A4 equivalent. BI4 = BG4 • BH4	7.442				
	Rupture disk					
BJ4	Enter S1 (rupture disk diameter) from Worksheet C1. BJ4 = S1	0.875 in (22.2 mm)				
BK4	Enter the rupture disk flow resistance coefficient specified by the manufacturer. If unknown, use 2.4. BK4 = 2.4 (if unknown)	2.650				
BL4	Determine the flow resistance conversion factor to size A4 for the rupture disk. $BL4 = (A4 / BJ4)^4$	8.207				
BM4	Determine the flow resistance of the rupture disk. BM4 = BK4 • BL4	21.749				
	Pipe exit					
BN4	Enter the pipe exit flow resistance coefficient. BN4 = 1.0		1.0			
BO4	Convert the pipe exit resistance coefficient to size A4 equivalent. BO4 = BN4 • T4		2.440			
	Total relief line flow resistance, K_{rel}					
BP4	Determine the flow resistance total for the entire relief line referenced to size A4, K_{rel}. BP4 = G4 + K4 +R4 + X4 + AB4 + AF4 + AJ4 + AN4 + AR4 + AX4 + BD4 + BI4 + BM4 + BO4	39.867				

Worksheet C5: Calculate the maximum flow through the relief system, Q_{rel_max}

A5	Enter B2 (liquid density) from Worksheet C2. A5 = B2	49.09 lb/ft^3 (786 kg/m^3)
B5	Enter F3 (maximum pressure loss through relief systems) from Worksheet C3. B5 = F3	279.12 psi (19.16 bar)
C5	Enter A4 (reference diameter) from Worksheet C4. C5 = A4	1.481 in (37.6 mm)
D5	Enter BP4 (total relief line flow resistance) from Worksheet C4. D5 = BP4	39.867
E5	Determine C5 to the fourth power. $E5 = C5^4$	4.811 in^4 (2002420 mm^4)
F5	Multiply B5 by E5. F5 = B5 • E5	1342.822 (38366367)

G5	Multiply A5 by D5 and 0.000018 (not required for metric). G5 = A5 • D5 • 0.000018 (Metric units: G5 = A5 • D5)	0.035 (31332)
H5	Divide F5 by G5. H5 = F5 / G5	38122.359 (1224.5)
I5	Multiply the square root of H5 by 0.9, Q_{rel_max} (and 21.07 for metric). I5 = 0.9 • H5$^{1/2}$ (Metric units: I5 = 0.9 • 21.07 • H5$^{1/2}$)	175.725 gal/min (663.57 L/min)

Worksheet C6: Calculate the flow resistance of the tank fill system, K_{fill}

Instructions: Inspect the tank liquid phase fill line from the fill connection to the point where it enters the casing. Make a note of the different pipe and tube sizes along the entire length of the line.						
	Fill system standard components					
A6	Enter the truck, hose, and fill connection ID. A6 = Fill system base ID			1.481 in (37.6 mm)		
B6	Enter the truck, hose, and fill connection flow resistance coefficient. B6 = 11.519			11.519		
		Size 1	**Size 2**	**Size 3**	**Size 4**	**Size 5**
	Liquid phase fill line inside diameters					
C6	Enter all external liquid phase fill line IDs. Start after the fill connection and finish at the tank casing. Select IDs from Appendix E Table E-3. C6 = All external fill line IDs	1.770 in (45.0 mm)	2.245 in (57.0 mm)			
D6	Determine the flow resistance conversion factor to size A6 for each line size. D6 = (A6 / C6)^4	0.490	0.189			
	Straight pipe					
E6	Enter V1 (total liquid phase fill line straight length for each diameter) from Worksheet C1. E6 = V1	36 in (914 mm)	36 in (914 mm)			
F6	Determine the flow resistance for each external fill line straight length. F6 = 0.0138 • E6 / C6	0.281	0.221			
G6	Convert each F6 to size A6 equivalent. G6 = F6 • D6	0.138	0.042			
H6	Determine the total flow resistance of all straight pipe. H6 = Sum of G6 for all diameters	0.180				
	Liquid fill valve(s)	**Liquid fill valve**	**Liquid line valve**			
I6	Enter AB1 and AC1 (liquid phase valve[s] diameter[s] based upon nominal size[s]) from Worksheet C1. I6 = AB1 and AC1	2.00 in (50.8 mm)	None			
J6	Enter the C_v for each liquid phase fill valve. J6 = Fill valve C_v	43.0				
K6	Determine the liquid fill valve resistance coefficient. K6 = 891 • I6^4 / J6^2 (Metric units: K6 = 0.002141 • I6^4 / J6^2)	7.710				
L6	Determine the flow resistance conversion factor to size A6 for each valve. L6 = (A6 / I6)^4	0.300				
M6	Convert K6 to size A6 equivalent. M6 = K6 • L6	2.313				
N6	Determine the flow resistance of the liquid fill valve(s). N6 = Sum of M6 for all diameters	2.313				
	Check valve(s)					
O6	Enter AD1 (check valve nominal diameter) from Worksheet C1. O6 = AD1	None				
P6	Enter the check valve flow resistance coefficient. P6 = 1.380					
Q6	Determine the flow resistance conversion factor to size A6. Q6 = (A6 / O6)^4					
R6	Convert the check valve resistance coefficient to size A6 equivalent. R6 = P6 • Q6	0.000				

		Size 1	Size 2	Size 3	Size 4	Size 5
	90-degree standard elbows					
S6	Enter W1 (number of 90-degree standard elbows for each diameter) from Worksheet C1. S6 = W1		2			
T6	Determine each 90-degree elbow flow resistance. T6 = S6 • 0.414		0.828			
U6	Convert each T6 to size A6 equivalent. U6 = T6 • D6		0.157			
V6	Determine the total flow resistance of all 90-degree standard elbows. V6 = Sum of U6 for all diameters	0.157				
	Short radius 90s					
W6	Enter X1 (number of short radius elbows for each diameter) from Worksheet C1. W6 = X1	1				
X6	Determine each short radius elbow flow resistance. X6 = W6 • 0.552	0.552				
Y6	Convert each W6 to size A6 equivalent. Y6 = X6 • D6	0.271				
Z6	Determine the total flow resistance of all short radius 90s. Z6 = Sum of Y6 for all diameters	0.271				
	45-degree elbows					
AA6	Enter Y1 (number of 45-degree elbows for each diameter) from Worksheet C1. AA6 = Y1					
AB6	Determine each 45-degree elbow flow resistance. AB6 = AA6 • 0.221					
AC6	Convert each AA6 to size A6 equivalent. AC6 = AB6 • D6					
AD6	Determine the total flow resistance of all 45-degree standard elbows. AD6 = Sum of AC6 for all diameters	0.000				
	Tee runs					
AE6	Enter Z1 (number of tee runs for each diameter) from Worksheet C1. AE6 = Z1					
AF6	Determine each tee run flow resistance. AF6 = AE6 • 0.276					
AG6	Convert each AF6 to size A6 equivalent. AG6 = AF6 • D6					
AH6	Determine the total flow resistance of all tee runs. AH6 = Sum of AG6 for all diameters	0.000				
	Tee branches					
AI6	Enter AA1 (number of tee branches for each diameter) from Worksheet C1. AI6 = AA1	1				
AJ6	Determine each tee branch flow resistance. AJ6 = AI6 • 0.828	0.828				
AK6	Convert each AJ6 to size A6 equivalent. AK6 = AJ6 • D6	0.406				
AL6	Determine the total flow resistance of all tee branches. AL6 = Sum of AK6 for all diameters	0.406				
		Size 1	**Size 2**	**Size 3**	**Size 4**	**Size 5**
	Pipe size expansions					
AM6	Enter the smaller IDs for all expansions. AM6 = Expander smaller ID	1.770 in (45.0 mm)				
AN6	Enter the larger IDs for all expansions. AN6 = Expander larger ID	2.245 in (57.0 mm)				
AO6	Determine the square of the small to large diameter ratio for each expansion. AO6 = $(AM6 / AN6)^2$	0.622				

AP6	Determine the resistance coefficient for each expansion. AP6 = (1 – AO6)^2	0.143				
AQ6	Convert each AP6 to size A6 equivalent. AQ6 = AP6 • D6	0.070				
AR6	Determine the total flow resistance of all pipe size expansions. AR6 = Sum of AQ6 for all diameters	0.070				
	Pipe size reducers					
AS6	Enter the larger IDs for all reducers. AS6 = Reducer larger ID					
AT6	Enter the smaller IDs for all reducers. AT6 = Reducer smaller ID					
AU6	Determine the small to large diameter ratio for each reducer. AU6 = AT6 / AS6					
AV6	Determine the resistance coefficient for each reducer. AV6 = (1 – AU6^2) / (2 • AU6^4)					
AW6	Convert each AV6 to size A6 equivalent. AW6 = AV6 • D6					
AX6	Determine the total flow resistance of all pipe size reducers. AX6 = Sum of AW6 for all diameters	0.000				
	Fill line internal pipe					
AY6	Enter the liquid phase fill line Sch 5 ID for the line just as it enters the casing. Select ID from Appendix E Table E-3. AY6 = Fill line Sch 5 ID	2.245 in (57.0 mm)				
AZ6	Enter the length of the tank internal liquid phase fill line. AZ6 = 36 in (Metric units: AZ6 = 914.4 mm)	36.0 in (914.4 mm)				
BA6	Determine the flow resistance for the internal fill line straight length. BA6 = 0.0138 • AZ6 / AY6	0.221				
BB6	Determine the flow resistance conversion factor from size AY6 to size A6. BA6 = (A6 / AY6)^4	0.189				
BC6	Convert BA6 to size A6 equivalent flow resistance. BC6 = BA6 • BB6	0.042				
	Internal line bends					
BD6	Enter the flow resistance for the first bend in the internal fill line. BD6 = 0.228	0.228				
BE6	Convert BD6 to size A6 equivalent flow resistance. BE6 = BD6 • BB6	0.043				
BF6	Enter the flow resistance for the second bend in the internal fill line. BF6 = 0.228	0.228				
BG6	Convert BF6 to size A6 equivalent flow resistance. BG6 = BF6 • BB6	0.043				
BH6	Determine the total flow resistance for all bends in the internal fill line. BH6 = BE6 + BG6	0.086				
	Fill line internal nozzle					
BI6	Enter the fill line schedule 40 ID for the line just as it enters the casing. BI6 = Fill line Sch 40 ID	2.067 in (52.5 mm)				
BJ6	Enter pipe exit flow resistance coefficient. BJ6 = 1.0	1.000				
BK6	Determine the flow resistance for the nozzle straight length. BK6 = 0.0828 / BI6 (Metric units: BK6 = 2.1163 / BI6)	0.040				
BL6	Determine the total flow resistance for the internal nozzle. BL6 = BJ6 + BK6	1.040				
BM6	Determine the flow resistance conversion factor from size BI6 to size A6. BM6 = (A6 / BI6)^4	0.263				
BN6	Convert the internal nozzle resistance coefficient to size A6 equivalent. BN6 = BL6 • BM6	0.274				

	Total fill line flow resistance, K_{fill}		
BO6	Determine the flow resistance total for the entire fill line referenced to size A6, K_{fill}. BO6 = H6 +N6 + R6 + V6 + Z6 + AD6 + AH6 + AL6 + AR6 + AX6 + BC6 + BH6 + BN6	3.799	

Worksheet C7: Calculate the pressure loss through the fill system, ΔP_{fill_line}

	Fill system standard components	
A7	Enter B2 (liquid density) from Worksheet C2. A7 = B2	49.09 lb/ft^3 (786 kg/m^3)
B7	Enter I5 (calculation result) from Worksheet C5. B7 = I5	175.725 gal/min (663.57 L/min)
C7	Enter A6 (truck, hose, and fill connection ID) from Worksheet C6. C7 = A6	1.481 (37.6 mm)
D7	Enter B6 (truck, hose, and fill connection flow resistance) from Worksheet C6. D7 = B6	11.519
E7	Enter C7 to the fourth power. E7 = C7^4	4.811 in^4 (2002420 mm^4)
F7	Calculate the square of B7. F7 = B7^2	30879.111 gal/min^2 (440325 (L/min^2)
G7	Multiply F7 by A7 and 0.000018 (not required for metric). G7 = F7 • A7 • 0.000018 (Metric units: G7 = F7 • A7)	27.285 (346095564)
H7	Multiply D7 by G7. H7 = D7 • G7	314.301 (3986674800)
I7	Determine the pressure drop through the standard components. I7 = H7 / E7 (Metric units: I7 = H7 / (21.07^2 • E7)	65.33 psi (4.48 bar)
	Fill system variable components	
J7	Enter BO6 (total fill line flow resistance) from Worksheet C6. J7 = BO6	3.799
K7	Divide F7 by 4. K7 = F7 / 4	7719.78 gal/min^2 (110224 L/min^2)
L7	Multiply K7 by A7 and 0.000018 (not required for metric). L7 = K7 • A7 • 0.000018 (Metric units: L7 = K7 • A7)	6.821 (86636064)
M7	Multiply J7 by L7. M7 = J7 • L7	25.91 (329476951)
N7	Determine the pressure drop through the variable components. N7 = M7 / E7 (Metric units: N7 = M7 / (E7 • 21.07^2)	5.39 psi (0.37 bar)
	Fill system total pressure drop ΔP_{fill_line}	
O7	Determine the fill system total pressure drop, ΔP_{fill_line}. O7 = I7 + N7	70.73 psi (4.86 bar)

Worksheet C8: Calculate the fill line orifice pressure drop, ΔP_{ori}

	Pump discharge pressure	
A8	Enter I5 (calculation result) from Worksheet C5. A8 = I5	175.725 gal/min (663.57 L/min)
B8	Enter the product. B8 = E1	Nitrogen
C8	For the product in B8, select the value from Appendix E Table E-4 that is just less than the flow in A8. See note in Table E-4.	170 gal/min (644 L/min)
D8	Select the value from Appendix E Table E-4 for the flow in C8 and the product in B8.	233.68 psi (16.11 bar)
E8	For the product in B8, select the value from Appendix E Table E-4 that is just greater than the flow in A8. See note in Table E-4.	180 gal/min (681 L/min)
F8	Select the value from Appendix E Table E-4 for the flow in E8 and the product in B8. See Table E-4 note.	218.66 psi (15.08 bar)

G8	Subtract C8 from A8. G8 = A8 – C8	5.73 gal/min (19.57 L/min)
H8	Subtract C8 from E8. H8 = E8 – C8	10.00 gal/min (37.00 L/min)
I8	Subtract D8 from F8. I8 = F8 – D8	–15.02 psi (–1.03 bar)
J8	Multiply I8 by G8 and divide by H8. J8 = I8 • G8 / H8	–8.60 psi (–0.55 bar)
K8	Determine the pump pressure rise. K8 = D8 + J8	225.08 psi (15.56 bar)
L8	Determine the pump discharge pressure. L8 = K8 + 30 psi (Metric units: L8 = K8 + 2.1 bar)	255.08 psi (17.66 bar)
	Fill line orifice pressure drop, ΔP_{ori}	
M8	Enter D2 (overall height of the tank) from Worksheet C2. M8 = D2	15.50 ft (4.72 m)
N8	Determine the vertical distance from the pump to the top of the storage tank inner container. N8 = M8 – 6 ft (Metric units: N8 = M8 – 1.8 m)	9.50 ft (2.92 m)
O8	Enter B2 (liquid density) from Worksheet C2. O8 = B2	49.09 lb/ft^3 (786.3 kg/m^3)
P8	Determine liquid head pressure based on N8. P8 = N8 • O8 / 144 (Metric units: P8 = (N8 • O8 • 9.81) / 100000)	3.24 psi (0.23 bar)
Q8	Enter H2 (UPL, if tank test pressure is known), or K2 (UPL, if tank test pressure is not known) from Worksheet C2. Q8 = H2 or K2	192.81 psi (13.29 bar)
R8	Enter O7 (fill system total pressure drop) from Worksheet C7. R8 = O7	70.73 psi (4.86 bar)
S8	Determine the fill line orifice pressure drop, ΔP_{ori}. S8 = L8 – R8 – P8 – Q8	–11.70 psi (–0.72 bar)

Worksheet C9: Determine the required fill line orifice size, d_{ori}

	Orifice flow coefficient, K_{ori}	
A9	Enter E7 (calculation result) from Worksheet C7. A9 = E7	4.811 in^4 (2002420 mm^4)
B9	Enter S8 (fill line orifice pressure drop) from Worksheet C8. B9 = S8	–11.70 psi (–0.72 bar)
C9	Enter G7 (calculation result) from Worksheet C7. C9 = G7	27.285 (346095564)
D9	Multiply A9 by B9. D9 = A9 • B9	–56.29 (–1441742.4)
E9	Determine the required flow coefficient for the fill line orifice, K_{ori}. E9 = D9 / C9 (Metric units: E9 = (21.07^2 • D9) / C9)	–2
	Fill line orifice diameter	
F9	Select the flow coefficient from Appendix E Table E-5 that is just greater than E9.	N/A
G9	Select the orifice diameter from Appendix E Table E-5 that is in the same row as the flow coefficient in F9.	None

Appendix D—Blank calculation forms for the analysis and prevention of overpressure during refilling of cryogenic storage tanks (Informative)

Worksheet D1: Input tank and piping data

	General installation information	
A1	Enter the tank owner's name.	
B1	Enter the tank capacity and configuration.	
C1	Enter the manufacturer's serial number from the dataplate.	
D1	Enter the NBIC number from the dataplate.	
E1	Select the product service.	
F1	Is this tank designed for argon, nitrogen, and oxygen?	
G1	Enter tank MAWP from the dataplate or the manufacturer's U-1A form.	
H1	Enter the tank test pressure from the manufacturer's U-1A form.	
I1	Enter the overall height of the tank if known or measured.	

	Pressure relief line					
Instructions: Inspect the relief line from where it exits the tank casing to the discharge of the rupture disk. Make a note of the different pipe and tube sizes along the entire length of the line.						
		Size 1	**Size 2**	**Size 3**	**Size 4**	**Size 5**
J1	Enter all external relief line pipe and tube size. Start at the tank and finish at the rupture disk exit.					
K1	Enter the pipe schedule or tube type. Assume the line entering the tank is Sch 5S.					
L1	Enter the total external relief line straight length for each diameter.					
M1	Enter the number of 90-degree standard elbows for each diameter.					
N1	Enter the number of short radius 90-degree elbows (90s) for each diameter.					
O1	Enter the number of 45-degree elbows for each diameter.					
P1	Enter the number of tee runs for each diameter.					
Q1	Enter the number of tee branches for each diameter.					
R1	Enter the diverter valve nominal size.					
S1	Enter the rupture disk diameter.					

	Liquid phase fill line					
Instructions: Inspect the tank liquid phase fill line from the fill connection to the point where it enters the casing. Make a note of the different pipe and tube sizes along the entire length of the line.						
		Size 1	**Size 2**	**Size 3**	**Size 4**	**Size 5**
T1	Enter all external liquid phase fill line pipe and tube sizes. Start at the fill connection and finish at the tank casing.					
U1	Enter the pipe schedule or tube type. Assume the line entering the tank is Sch 5S.					
V1	Enter the total liquid phase fill line straight length for each diameter.					
W1	Enter the number of 90-degree standard elbows for each diameter.					
X1	Enter the number of short radius elbows for each diameter.					
Y1	Enter the number of 45-degree elbows for each diameter.					
Z1	Enter the number of tee runs for each diameter.					
AA1	Enter the number of tee branches for each diameter.					
AB1	Enter the liquid phase fill valve nominal size.					
AC1	Enter other liquid phase fill line valve nominal size if applicable.					
AD1	Enter the check valve nominal diameter.					

Worksheet D2: Calculate tank UPL

A2	Enter the maximum design lading liquid density for the tank from Appendix E Table E-1. Assume argon unless otherwise indicated in F1 Worksheet C1, the manufacturer's dataplate, or U-1A Form.	
B2	Enter the liquid density in from Appendix E Table E-1 for the product in E1 Worksheet C1.	
C2	Subtract line B2 from line A2. C2 = A2 – B2	
D2	Enter the overall height of the tank from Worksheet C1 or Appendix E Table E-2. D2 = I1	
E2	Determine the vertical distance from the bottom of the liquid container to the normal fill level of the tank. E2 = D2 – 3 ft (Metric units: E2 = D2 – 1 m)	
F2	Determine available liquid head pressure. F2 = C2 • E2 / 144 (Metric F2 = (C2 • E2 • 9.81) / 100000)	
Instructions: If the tank test pressure is known, calculate *UPL* using the preferred method as follows:		
G2	Enter H1 (tank test pressure) from Worksheet C1. G2 = H1	
H2	Calculate the tank UPL. H2 = G2 – 14.696 psi (Metric units: H2 = G2 – 1.013 bar)	
Instructions: If the tank test pressure is not known, calculate *UPL* using the optional method as follows:		
I2	Enter G1 (tank MAWP) from Worksheet C1. I2 = G1	
J2	Add lines F2, I2, and atmospheric pressure. J2 = F2 + I2 + 14.696 psi (Metric units: J2 = F2 + I2 + 1.013 bar)	
K2	Calculate tank UPL. K2 = J2 • 1.5 – 14.696 (Metric units: K2 = J2 • 1.5 – 1.013)	

Worksheet D3: Calculate the maximum frictional pressure loss through the relief system, ΔP_{rel_max}

A3	Enter B2 (liquid density) from Worksheet D2. A3 = B2	
B3	Enter D2 (overall tank height) from Worksheet D2. B3 = D2	
C3	Enter H2 (UPL, if tank test pressure is known) from Worksheet D2 if tank test pressure is known, otherwise enter K2 (UPL, if tank test pressure is not known) from Worksheet D2. C3 = H2 or K2	
D3	Determine the vertical distance from the relief device to the top of the storage tank liquid container. D3 = B3 – 2 ft (Metric units: D3 = B3 – 0.61 m)	
E3	Determine the liquid head in the relief device line. E3 = A3 • D3 / 144 (Metric units: E3 = (A3 • D3 • 9.81) / 100000)	
F3	Calculate maximum pressure loss through relief system, ΔP_{rel_max}. F3 = C3 + E3	

Worksheet D4: Calculate the flow resistance of the pressure relief system, K_{rel}

Instructions: Inspect the relief line from where it exits the tank casing to the discharge of the rupture disk. Make a note of the different pipe and tube sizes along the entire length of the line.		
	Calculation reference diameter	
A4	Calculation reference diameter.	
	Relief line internal nozzle	
B4	Enter the relief line schedule 40 ID for the line just as it exits the casing. B4 = Relief line Sch 40 ID	
C4	Enter pipe entrance flow resistance coefficient.	
D4	Determine the flow resistance for the nozzle straight length. D4 = 0.075 / B4 (Metric units: D4 = 1.905 / B4)	
E4	Determine the total flow resistance for the internal nozzle. E4 = C4 + D4	

F4	Determine the flow resistance conversion factor from size B4 to size A4. $F4 = (A4 / B4)^{4}$					
G4	Convert E4 to size A4 equivalent flow resistance. G4 = E4 • F4					
	Relief line internal pipe					
H4	Enter the relief line schedule 5 ID for the line just as it exits the casing. H4 = Relief line Sch 5 ID					
I4	Determine the flow resistance for the internal relief line straight length. I4 = 0.15 • D2 / H4 (Metric units: I4 = 12.5 • D2 / H4)					
J4	Determine the flow resistance conversion factor from size H4 to size A4. $J4 = (A4 / H4)^{4}$					
K4	Convert I4 to size A4 equivalent flow resistance. K4 = I4 • J4					
	Internal line bends					
L4	Enter the flow resistance for the first bend in the internal relief line. L4 = 0.245					
M4	Convert L4 to size A4 equivalent flow resistance. M4 = L4 • J4					
N4	Enter the flow resistance for the second bend in the internal relief line. N4 = 0.189					
O4	Convert N4 to size A4 equivalent flow resistance. O4 = N4 • J4					
P4	Enter the flow resistance for the third bend in the internal relief line. P4 = 0.189					
Q4	Convert P4 to size A4 equivalent resistance. Q4 = P4 • J4					
R4	Determine the total flow resistance for all bends in the internal relief line. R4 = M4 + O4 + Q4					
		Size 1	**Size 2**	**Size 3**	**Size 4**	**Size 5**
	External relief line inside diameters					
S4	Enter all external relief line IDs. Start at the tank and finish at the rupture disk. Select IDs from Appendix E Table E-3. S4 = All external relief line IDs					
T4	Determine the flow resistance conversion factor to size A4 for each line size. $T4 = (A4 / S4)^{4}$					
		Size 1	**Size 2**	**Size 3**	**Size 4**	**Size 5**
	Straight pipe					
U4	Enter L1 (total external relief line straight length for each diameter) from Worksheet D1. U4 = L1					
V4	Determine the flow resistance for each external relief line straight length. V4 = 0.0125 • U4 / S4					
W4	Convert each V4 to size A4 equivalent. W4 = V4 • T4					
X4	Determine the total flow resistance of all straight pipe. X4 = Sum of W4 for all diameters					
	90-degree standard elbows					
Y4	Enter M1 (number of 90-degree standard elbows for each diameter) from Worksheet D1. Y4 = M1					
Z4	Determine each 90-degree elbow flow resistance. Z4 = Y4 • 0.375					
AA4	Convert each Z4 to size A4 equivalent. AA4 = Z4 • T4					
AB4	Determine the total flow resistance of all 90-degree standard elbows. AB4 = Sum of AA4 for all diameters					

	Short radius 90s					
AC4	Enter N1 (number of short radius elbows for each diameter) from Worksheet D1. AC4 = N1					
AD4	Determine each short radius elbow flow resistance. AD4 = AC4 • 0.500					
AE4	Convert each AD4 to size A4 equivalent. AE4 = AD4 • T4					
AF4	Determine the total flow resistance of all short radius 90s. AF4 = Sum of AE4 for all diameters					
	45-degree elbows					
AG4	Enter O1 (number of 45-degree elbows for each diameter) from Worksheet D1. AG4 = O1					
AH4	Determine each 45-degree elbow flow resistance. AH4 = AG4 • 0.200					
AI4	Convert each AH4 to size A4 equivalent. AI4 = AH4 • T4					
AJ4	Determine the total flow resistance of all 45-degree standard elbows. AJ4 = Sum of AI4 for all diameters					
	Tee runs					
AK4	Enter P1 (number of tee runs for each diameter) from Worksheet D1. AK4 = P1					
AL4	Determine each tee run flow resistance. AL4 = AK4 • 0.250					
AM4	Convert each AL4 to size A4 equivalent. AM4 = AL4 • T4					
AN4	Determine the total flow resistance of all tee runs. AN4 = Sum of AM4 for all diameters					
		Size 1	**Size 2**	**Size 3**	**Size 4**	**Size 5**
	Tee branches					
AO4	Enter Q1 (number of tee branches for each diameter) from Worksheet D1. AO4 = Q1					
AP4	Determine each tee branch flow resistance. AP4 = AO4 • 0.750					
AQ4	Convert each AP4 to size A4 equivalent. AQ4 = AP4 • T4					
AR4	Determine the total flow resistance of all tee branches. AR4 = Sum of AQ4 for all diameters					
	Pipe size expansions					
AS4	Enter the smaller IDs for all expansions. AS4 = Expander smaller ID					
AT4	Enter the larger IDs for all expansions. AT4 = Expander larger ID					
AU4	Determine the square of the small to large diameter ratio for each expansion. $AU4 = (AS4 / AT4)^2$					
AV4	Determine the resistance coefficient for each expansion. $AV4 = (1 – AU4)^2$					
AW4	Convert each AV4 to size A4 equivalent. AW4 = AV4 • T4					
AX4	Determine the total flow resistance of all pipe size expansions. AX4 = Sum of AW4 for all diameters					
	Pipe size reducers					
AY4	Enter the larger IDs for all reducers. AY4 = Reducer larger ID					

AZ4	Enter the smaller IDs for all reducers. AZ4 = Reducer smaller ID					
BA4	Determine the small to large diameter ratio for each reducer. BA4 = AZ4 / AY4					
BB4	Determine the resistance coefficient for each reducer. $BB4 = (1 – BA4^2) / (2 \cdot BA4^4)$					
BC4	Convert each BB4 to size A4 equivalent. BC4 = BB4 • T4					
BD4	Determine the total flow resistance of all pipe size reducers. BD4 = Sum of BC4 for all diameters					
	Diverter valve					
BE4	Enter <u>R1</u> (diverter valve size) from Worksheet <u>D1</u>. BE4 = ID of R1					
BF4	Enter the diverter valve Cv. BF4 = Diverter valve Cv					
BG4	Determine the diverter valve resistance coefficient. $BG4 = 891 \cdot BE4^4 / BF4^2$ (Metric: $BG4 = 0.002141 \cdot BE4^4 / BF4^2$)					
BH4	Determine the flow resistance conversion factor to size A4 for the diverter valve. $BH4 = (A4 / BE4)^4$					
BI4	Convert BG4 to size A4 equivalent. BI4 = BG4 • BH4					
		Size 1	**Size 2**	**Size 3**	**Size 4**	**Size 5**
	Rupture disk					
BJ4	Enter <u>S1</u> (rupture disk diameter) from Worksheet <u>D1</u>. BJ4 = S1					
BK4	Enter the rupture disk flow resistance coefficient specified by the manufacturer. If unknown, use 2.4. BK4 = 2.4 (if unknown)					
BL4	Determine the flow resistance conversion factor to size A4 for the rupture disk. $BL4 = (A4 / BJ4)^4$					
BM4	Determine the flow resistance of the rupture disk. BM4 = BK4 • BL4					
	Pipe exit					
BN4	Enter the pipe exit flow resistance coefficient. BN4 = 1.0					
BO4	Convert the pipe exit resistance coefficient to size A4 equivalent. BO4 = BN4 • T4					
	Total relief line flow resistance, K_{rel}					
BP4	Determine the flow resistance total for the entire relief line referenced to size A4, K_{rel}. BP4 = G4 + K4 +R4 + X4 + AB4 + AF4 + AJ4 + AN4 + AR4 + AX4 + BD4 + BI4 + BM4 + BO4					

Worksheet D5: Calculate the maximum flow through the relief system, Q_{rel_max}

A5	Enter B2 <u>(liquid density)</u> from Worksheet <u>D2</u>. A5 = B2	
B5	Enter F3 <u>(maximum pressure loss through relief system)</u> from Worksheet <u>D3</u>. B5 = F3	
C5	Enter A4 <u>(reference diameter)</u> from Worksheet <u>D4.</u> C5 = A4	
D5	Enter BP4 <u>(total relief line flow resistance)</u> from Worksheet <u>D4</u>. D5 = BP4	
E5	Determine C5 to the fourth power. $E5 = C5^4$	
F5	Multiply B5 by E5. F5 = B5 • E5	

G5	Multiply A5 by D5 and 0.000018 (not required for metric). G5 = A5 • D5 • 0.000018 (Metric units: G5 = A5 • D5)	
H5	Divide F5 by G5. H5 = F5 / G5	
I5	Multiply the square root of H5 by 0.9, Q_{rel_max} (and 21.07 for metric). I5 = 0.9 • $H5^{1/2}$ (Metric units: I5 = 0.9 • 21.07 • $H5^{1/2}$)	

Worksheet D6: Calculate the flow resistance of the tank fill system, K_{fill}

Instructions: Inspect the tank liquid phase fill line from the fill connection to the point where it enters the casing. Make a note of the different pipe and tube sizes along the entire length of the line.						
	Fill system standard components					
A6	Enter the truck, hose, and fill connection ID. A6 = Fill system base ID					
B6	Enter the truck, hose, and fill connection flow resistance coefficient. B6 = 11.519					
		Size 1	**Size 2**	**Size 3**	**Size 4**	**Size 5**
	Liquid phase fill line inside diameters					
C6	Enter all external liquid phase fill line IDs. Start after the fill connection and finish at the tank casing. Select IDs from Appendix E Table E-3. C6 = All external fill line IDs					
D6	Determine the flow resistance conversion factor to size A6 for each line size. D6 = $(A6 / C6)^4$					
	Straight pipe					
E6	Enter V1 (total liquid phase fill line straight length for each diameter) from Worksheet D1. E6 = V1					
F6	Determine the flow resistance for each external fill line straight length. F6 = 0.0138 • E6 / C6					
G6	Convert each F6 to size A6 equivalent. G6 = F6 • D6					
H6	Determine the total flow resistance of all straight pipe. H6 = Sum of G6 for all diameters					
	Liquid fill valve(s)	**Liquid fill valve**	**Liquid line valve**			
I6	Enter AB1 and AC1 (liquid phase valve[s] diameter[s] based upon nominal size[s]) from Worksheet D1. I6 = AB1 and AC1					
J6	Enter the C_v for each liquid phase fill valve. J6 = Fill valve C_v					
K6	Determine the liquid fill valve resistance coefficient. K6 = 891 • $I6^4$ / $J6^2$ (Metric units: 0.002141 • $I6^4$) / $J6^2$)					
L6	Determine the flow resistance conversion factor to size A6 for each valve. L6 = $(A6 / I6)^4$					
M6	Convert K6 to size A6 equivalent. M6 = K6 • L6					
N6	Determine the flow resistance of the liquid fill valve(s). N6 = Sum of M6 for all diameters					
	Check valve(s)					
O6	Enter AD1 (check valve nominal diameter) from Worksheet D1. O6 = AD1					
P6	Enter the check valve flow resistance coefficient. P6 = 1.380					
Q6	Determine the flow resistance conversion factor to size A6. Q6 = $(A6 / O6)^4$					
R6	Convert the check valve resistance coefficient to size A6 equivalent. R6 = P6 • Q6					

		Size 1	Size 2	Size 3	Size 4	Size 5
	90-degree standard elbows					
S6	Enter W1 (number of 90-degree standard elbows for each diameter) from Worksheet D1. S6 = W1					
T6	Determine each 90-degree elbow flow resistance. T6 = S6 • 0.414					
U6	Convert each T6 to size A6 equivalent. U6 = T6 • D6					
V6	Determine the total flow resistance of all 90-degree standard elbows. V6 = Sum of U6 for all diameters					
	Short radius 90s					
W6	Enter X1 (number of short radius elbows for each diameter) from Worksheet D1. W6 = X1					
X6	Determine each short radius elbow flow resistance. X6 = W6 • 0.552					
Y6	Convert each W6 to size A6 equivalent. Y6 = X6 • D6					
Z6	Determine the total flow resistance of all short radius 90s. Z6 = Sum of Y6 for all diameters					
	45-degree elbows					
AA6	Enter Y1 (number of 45-degree elbows for each diameter) from Worksheet D1. AA6 = Y1					
AB6	Determine each 45-degree elbow flow resistance. AB6 = AA6 • 0.221					
AC6	Convert each AA6 to size A6 equivalent. AC6 = AB6 • D6					
AD6	Determine the total flow resistance of all 45-degree standard elbows. AD6 = Sum of AC6 for all diameters					
	Tee runs					
AE6	Enter Z1 (number of tee runs for each diameter) from Worksheet D1. AE6 = Z1					
AF6	Determine each tee run flow resistance. AF6 = AE6 • 0.276					
AG6	Convert each AF6 to size A6 equivalent. AG6 = AF6 • D6					
AH6	Determine the total flow resistance of all tee runs. AH6 = Sum of AG6 for all diameters					
	Tee branches					
AI6	Enter AA1 (number of tee branches for each diameter) from Worksheet D1. AI6 = AA1					
AJ6	Determine each tee branch flow resistance. AJ6 = AI6 • 0.828					
AK6	Convert each AJ6 to size A6 equivalent. AK6 = AJ6 • D6					
AL6	Determine the total flow resistance of all tee branches. AL6 = Sum of AK6 for all diameters					
		Size 1	**Size 2**	**Size 3**	**Size 4**	**Size 5**
	Pipe size expansions					
AM6	Enter the smaller IDs for all expansions. AM6 = Expander smaller ID					
AN6	Enter the larger IDs for all expansions. AN6 = Expander larger ID					
AO6	Determine the square of the small to large diameter ratio for each expansion. $AO6 = (AM6 / AN6)^2$					

AP6	Determine the resistance coefficient for each expansion. AP6 = $(1 – AO6)^2$					
AQ6	Convert each AP6 to size A6 equivalent. AQ6 = AP6 • D6					
AR6	Determine the total flow resistance of all pipe size expansions. AR6 = Sum of AQ6 for all diameters					
	Pipe size reducers					
AS6	Enter the larger IDs for all reducers. AS6 = Reducer larger ID					
AT6	Enter the smaller IDs for all reducers. AT6 = Reducer smaller ID					
AU6	Determine the small to large diameter ratio for each reducer. AU6 = AT6 / AS6					
AV6	Determine the resistance coefficient for each reducer. AV6 = $(1 – AU6^2) / (2 • AU6^4)$					
AW6	Convert each AV6 to size A6 equivalent. AW6 = AV6 • D6					
AX6	Determine the total flow resistance of all pipe size reducers. AX6 = Sum of AW6 for all diameters					
	Fill line internal pipe					
AY6	Enter the liquid phase fill line Sch 5 ID for the line just as it enters the casing. Select ID from Appendix E Table E-3. AY6 = Fill line Sch 5 ID					
AZ6	Enter the length of the tank internal liquid phase fill line. AZ6 = 36 in (Metric units: AZ6 = 914.4 mm)					
BA6	Determine the flow resistance for the internal fill line straight length. BA6 = 0.0138 • AZ6 / AY6					
BB6	Determine the flow resistance conversion factor from size AY6 to size A6. BA6 = $(A6 / AY6)^4$					
BC6	Convert BA6 to size A6 equivalent flow resistance. BC6 = BA6 • BB6					
	Internal line bends					
BD6	Enter the flow resistance for the first bend in the internal fill line. BD6 = 0.228					
BE6	Convert BD6 to size A6 equivalent flow resistance. BE6 = BD6 • BB6					
BF6	Enter the flow resistance for the second bend in the internal fill line. BF6 = 0.228					
BG6	Convert BF6 to size A6 equivalent flow resistance. BG6 = BF6 • BB6					
BH6	Determine the total flow resistance for all bends in the internal fill line. BH6 = BE6 + BG6					
	Fill line internal nozzle					
BI6	Enter the fill line schedule 40 ID for the line just as it enters the casing. BI6 = Fill line Sch 40 ID					
BJ6	Enter pipe exit flow resistance coefficient. BJ6 = 1.0					
BK6	Determine the flow resistance for the nozzle straight length. BK6 = 0.0828 / BI6 (Metric units: BK6 = 2.1163 / BI6)					
BL6	Determine the total flow resistance for the internal nozzle. BL6 = BJ6 + BK6					
BM6	Determine the flow resistance conversion factor from size BI6 to size A6. BM6 = $(A6 / BI6)^4$					
BN6	Convert the internal nozzle resistance coefficient to size A6 equivalent. BN6 = BL6 • BM6					

	Total fill line flow resistance, K_{fill}		
BO6	Determine the flow resistance total for the entire fill line referenced to size A6, K_{fill}. BO6 = H6 +N6 + R6 + V6 + Z6 + AD6 + AH6 + AL6 + AR6 + AX6 + BC6 + BH6 + BN6		

Worksheet D7: Calculate the pressure loss through the fill system, ΔP_{fill_line}

	Fill system standard components	
A7	Enter B2 (liquid density) from Worksheet D2. A7 = B2	
B7	Enter I5 (calculation result) from Worksheet D5. B7 = I5	
C7	Enter A6 (truck, hose, and fill connection ID) from Worksheet D6. C7 = A6	
D7	Enter B6 (truck, hose, and fill connection flow resistance) from Worksheet D6. D7 = B6	
E7	Enter C7 to the fourth power. $E7 = C7^4$	
F7	Calculate the square of B7. $F7 = B7^2$	
G7	Multiply F7 by A7 and 0.000018 (not required for metric). G7 = F7 • A7 • 0.000018 (Metric units: G7 = F7 • A7)	
H7	Multiply D7 by G7. H7 = D7 • G7	
I7	Determine the pressure drop through the standard components. I7 = H7 / E7 (Metric units: I7 = H7 / 21.07^2 • E7)	
	Fill system variable components	
J7	Enter BO6 (total fill line flow resistance) from Worksheet D6. J7 = BO6	
K7	Divide F7 by 4. K7 = F7 / 4	
L7	Multiply K7 by A7 and 0.000018 (not required for metric). L7 = K7 • A7 • 0.000018 (Metric units: L7 = K7 • A7)	
M7	Multiply J7 by L7. M7 = J7 • L7	
N7	Determine the pressure drop through the variable components. N7 = M7 / E7 (Metric units: N7 = M7 / (E7 • 21.07^2)	
	Fill system total pressure drop ΔP_{fill_line}	
O7	Determine the fill system total pressure drop, ΔP_{fill_line}. O7 = I7 + N7	

Worksheet D8: Calculate the fill line orifice pressure drop, ΔP_{ori}

	Pump discharge pressure	
A8	Enter I5 (calculation result) from Worksheet D5. A8 = I5	
B8	Enter the product. B8 = E1	
C8	For the product in B8, select the value from Appendix E Table E-4 that is just less than the flow in A8. See note in Table E-4.	
D8	Select the value from Appendix E Table E-4 for the flow in C8 and the product in B8.	
E8	For the product in B8, select the value from Appendix E Table E-4 that is just greater than the flow in A8. See note in Table E-4.	
F8	Select the value from Appendix E Table E-4 for the flow in E8 and the product in B8. See Table E-4 note.	
G8	Subtract C8 from A8. G8 = A8 – C8	

H8	Subtract C8 from E8. H8 = E8 – C8	
I8	Subtract D8 from F8. I8 = F8 – D8	
J8	Multiply I8 by G8 and divide by H8. J8 = I8 • G8 / H8	
K8	Determine the pump pressure rise. K8 = D8 + J8	
L8	Determine the pump discharge pressure. L8 = K8 + 30 psi (Metric units: L8 = K8 + 2.1 bar)	
	Fill line orifice pressure drop, ΔP_{ori}	
M8	Enter D2 (overall height of the tank) from Worksheet D2. M8 = D2	
N8	Determine the vertical distance from the pump to the top of the storage tank inner container. N8 = M8 – 6 ft (Metric units: N8 = M8 – 1.8 m)	
O8	Enter B2 (liquid density) from Worksheet D2. O8 = B2	
P8	Determine liquid head pressure based on N8. P8 = N8 • O8 / 144 (Metric units: P8 = (N8 • O8 • 9.81) / 100 000)	
Q8	Enter H2 (UPL, if tank test pressure is known), or K2 (UPL, if tank test pressure is not known) from Worksheet D2. Q8 = H2 or K2	
R8	Enter O7 (fill system total pressure drop) from Worksheet D7. R8 = O7	
S8	Determine the fill line orifice pressure drop, ΔP_{ori}. S8 = L8 – R8 – P8 – Q8	

Worksheet D9: Determine the required fill line orifice size, d_{ori}

	Orifice flow coefficient, K_{ori}	
A9	Enter E7 (calculation result) from Worksheet D7. A9 = E7	
B9	Enter S8 (fill line orifice pressure drop) from Worksheet D8. B9 = S8	
C9	Enter G7 (calculation result) from Worksheet D7. C9 = G7	
D9	Multiply A9 by B9. D9 = A9 • B9	
E9	Determine the required flow coefficient for the fill line orifice, K_{ori}. E9 = D9 / C9 (Metric units: E9 = (21.07^2 • D9) / C9)	
	Fill line orifice diameter	
F9	Select the flow coefficient from Appendix E Table E-5 that is just greater than E9.	
G9	Select the orifice diameter from Appendix E Table E-5 that is in the same row as the flow coefficient in F9.	

Appendix E—Reference data
(Informative)

Table E-1—Liquid density

Product name	Density	
	lb/ft³	kg/m³
Argon	84.99	1361
Nitrogen	49.09	786.4
Oxygen	69.57	1114

Table E-2—Overall height for typical tanks

Capacity		Orientation	Height	
gal	L		ft	m
500	1 893	Vertical	15.50	4.72
900	3 407	Vertical	15.75	4.80
1 500	5 678	Vertical	15.75	4.80
3 000	11 356	Vertical	16.00	4.88
6 000	22 712	Vertical	25.75	7.85
9 000	34 069	Vertical	27.83	8.48
11 000	41 639	Vertical	31.58	9.63
13 000	49 210	Vertical	36.17	11.02
1 000	3 785	Horizontal	7.58	2.31
1 500	5 678	Horizontal	8.00	2.44
2 000	7 571	Horizontal	8.00	2.44
3 000	11 356	Horizontal	8.42	2.57
6 000	22 712	Horizontal	8.67	2.64
9 000	34 069	Horizontal	10.92	3.33
11 000	41 639	Horizontal	11.67	3.56
13 000	49 210	Horizontal	11.67	3.56
15 000	56 781	Horizontal	11.67	3.56
20 000	75 708	Horizontal	11.67	3.56
25 000	94 635	Horizontal	12.17	3.71
30 000	113 562	Horizontal	12.33	3.76
35 000	132 489	Horizontal	12.33	3.76
40 000	151 416	Horizontal	12.33	3.76
50 000	189 270	Horizontal	12.33	3.76
55 000	208 197	Horizontal	13.33	4.06
65 000	246 051	Horizontal	13.33	4.06
90 000	340 686	Horizontal	13.50	4.11

Table E-3—Pipe and tube inside diameters and inside diameters to the 4th power

Size	Inside diameter			
	in	mm	in^4	mm^4
1/2 in Type K	0.527	13.4	0.077	32105
1/2 in Type L	0.545	13.8	0.088	36722
1/2 in Sch 5S	0.710	18.0	0.254	105771
1/2 in Sch 10S	0.674	17.1	0.206	85896
1/2 in Sch 40S	0.622	15.8	0.150	62301
1/2 in Sch 80S	0.546	13.9	0.089	36992
5/8 in Type K	0.652	16.6	0.181	75219
5/8 in Type L	0.666	16.9	0.197	81890
3/4 in Type K	0.745	18.9	0.308	128221
3/4 in Type L	0.785	19.9	0.380	158057
3/4 in Sch 5S	0.920	23.4	0.716	298185
3/4 in Sch 10S	0.884	22.5	0.611	254181
3/4 in Sch 40S	0.824	20.9	0.461	191886
3/4 in Sch 80S	0.742	18.8	0.303	126168
1 in Type K	0.995	25.3	0.980	407969
1 in Type L	1.025	26.0	1.104	459442
1 in Sch 5S	1.185	30.1	1.972	820745
1 in Sch 10S	1.097	27.9	1.448	602784
1 in Sch 40S	1.049	26.6	1.211	504007
1 in Sch 80S	0.957	24.3	0.839	349126
1-1/4 in Type K	1.245	31.6	2.403	1000028
1-1/4 in Type L	1.265	32.1	2.561	1065852
1-1/2 in Type K	1.481	37.6	4.811	2002420
1-1/2 in Type L	1.505	38.2	5.130	2135408
1-1/2 in Sch 5S	1.770	45.0	9.815	4085337
1-1/2 in Sch 10S	1.682	42.7	8.004	3331492
1-1/2 in Sch 40S	1.610	40.9	6.719	2796652
1-1/2 in Sch 80S	1.500	38.1	5.063	2107172
2 in Type K	1.959	49.8	14.728	6130171
2 in Type L	1.985	50.4	15.525	6462148
2 in Sch 5S	2.245	57.0	25.402	10573049
2 in Sch 10S	2.157	54.8	21.647	9010221
2 in Sch 40S	2.067	52.5	18.254	7597956
2 in Sch 80S	1.939	49.3	14.136	5883640
2-1/2 in Type K	2.435	61.8	35.156	14632911
2-1/2 in Type L	2.465	62.6	36.921	15367477
2-1/2 in Sch 5S	2.709	68.8	53.856	22416659
2-1/2 in Sch 10S	2.635	66.9	48.208	20065840
2-1/2 in Sch 40S	2.469	62.7	37.161	15467468
2-1/2 in Sch 80S	2.323	59.0	29.120	12120812
3 in Type K	2.907	73.8	71.413	29724530
3 in Type L	2.945	74.8	75.221	31309495
3 in Sch 5S	3.334	84.7	123.556	51427717
3 in Sch 10S	3.260	82.8	112.946	47011625
3 in Sch 40S	3.068	77.9	88.597	36877060
3 in Sch 80S	2.900	73.7	70.728	29439258

Table E-4—Typical hydraulic truck pump performance

Flow		Pressure rise across pump					
		Argon		Nitrogen		Oxygen	
gal/min	L/min	psi	bar	psi	bar	psi	bar
50	189	426.02	29.37	368.00	25.37	431.68	29.76
60	227	423.86	29.22	367.76	25.36	429.60	29.62
70	265	422.04	29.10	366.14	25.24	427.79	29.50
80	303	420.11	28.97	364.86	25.16	426.13	29.38
90	341	409.68	28.25	363.58	25.07	423.49	29.20
100	379	399.25	27.53	358.37	24.71	414.01	28.54
110	416	386.63	26.66	340.62	23.48	404.52	27.89
120	454	372.79	25.70	322.88	22.26	393.52	27.13
130	492	357.14	24.62	302.88	20.88	380.93	26.26
140	530	337.66	23.28	282.18	19.46	368.34	25.40
150	568	318.17	21.94	264.40	18.23	350.36	24.16
160	606	298.15	20.56	249.04	17.17	331.86	22.88
170	644	276.49	19.06	233.68	16.11	313.36	21.61
180	681			218.66	15.08	294.19	20.28
190	719			204.63	14.11	274.45	18.92
NOTE—The analyst is responsible for verifying pump performance for the actual operation being analyzed.							

Table E-5—Fill line orifice sizes and flow resistance coefficient referenced to 1.481 in (37.6 mm) internal diameter

Orifice size	Flow resistance, K_{ori}	Fill orifice diameter, d_{ori}	
		in	mm
Size A	1.32	1.200	30.5
Size B	2.76	1.100	27.9
Size C	5.56	1.000	25.4
Size D	10.81	0.900	22.9
Size E	20.88	0.800	20.3
Size F	29.13	0.750	19.1
Size G	41.04	0.700	17.8
Size H	58.50	0.650	16.5
Size I	84.42	0.600	15.2
Size J	124.16	0.550	14.0
Size K	187.94	0.500	12.7
Size L	295.21	0.450	11.4
Size M	484.68	0.400	10.2
Size N	844.86	0.350	8.9