INDUSTRY GUIDELINES FOR DETERMINING THE MAXIMUM LIQUID TRANSFER RATE FOR A TANK VESSEL TRANSFERRING A FLAMMABLE OR COMBUSTIBLE CARGO USING A VAPOR CONTROL SYSTEM

This document provides guidance from the Coast Guard Marine Safety Center for determining the maximum liquid transfer rate for a tank vessel using a vapor control system (VCS) while transferring a flammable or combustible liquid cargo. An example showing how these guidelines may be applied is provided which compares how the calculations differ from the requirements for benzene, crude oil, and gasoline in 46 Code of Federal Regulations Part 39.

The VCS requirements in 46 Code of Federal Regulations (CFR) Part 39 for benzene, crude oil and gasoline remain unchanged.

Background

Title 46 CFR Part 39 limits the maximum liquid transfer rate for a tank vessel transferring a flammable or combustible cargo using a VCS by the following factors:

- The capacity of the cargo tank venting system (46 CFR 39.20-11);
- The relieving capacity of the cargo tank spill valves or rupture disks (46 CFR 39.20-9);
- The setpoint of the overfill alarm (46 CFR 39.20-7, 39.20-9); and
- The internal pressure of the tank relative to the pressure at the facility vapor connection and the pressure drop in the VCS piping (46 CFR 39.30-1(d)(3)).

In determining the maximum liquid transfer rate for a vessel's VCS, each of these factors must be addressed.

If the cargo tank is inerted, the calculations must use the physical properties of nitrogen. Since these guidelines use the English system of units, equations will have to be changed to reflect the use of a different system of units.

Condition of the Vapor Space Inside the Cargo Tank

A temperature of 115 ºF and a pressure equal to the pressure setting of the cargo tank P/V valve should be used in the calculations to determine the factor that limits the transfer rate. A temperature of 115 ºF was chosen because it is the reference temperature for the design pressure of cargo tanks as specified in 46 CFR 151.15-3, and the IMO Chemical Codes (BCH (4.11) and IBC (15.14)). If the cargo tank P/V valves are adequately sized, the maximum pressure inside the cargo space should be only slightly higher than the pressure setting of the P/V valves. The temperature and pressure used is important because the vapor-air mixture weight density and vapor growth rate are affected by the temperature and pressure of the vapor space in the cargo tank.

Determining the Vapor-Air Mixture Weight Density

Cargoes with a Saturated Vapor Pressure of 14.7 psia or less at 115°F (VCS Categories 1 through 4)

Ideal gas laws may be used to estimate the density of the vapor-air mixture in the vapor space of the cargo tank. Equations (1) through (5) are derived from the ideal gas law. Equation (1) defines the relationship between partial pressures and partial volumes and equation (2) defines the maximum total pressure of the vapor space inside the cargo tank. Equation (3) may be used to calculate the vapor-air mixture weight density. If the cargo tank is not inerted, the air weight density in equation (3) may be substituted with equation (4), leading to equation (5).

$$V_{v,115} = \frac{P_{v,115}}{P_{t,115}} \qquad V_{a,115} = \frac{P_{t,115} - P_{v,115}}{P_{t,115}} \tag{1}$$

$$P_{t,115} = P_{p/v} \tag{2}$$

$$r_{v-a,115} = \left[(S.G._{v})(V_{v,115}) + V_{a,115}\right] r_{a,115} \tag{3}$$

$$r_{a,115} = 0.0047 P_{p/v} \tag{4}$$

$$r_{v-a,115} = \left[(S.G._{v})(V_{v,115}) + V_{a,115}\right] 0.0047(P_{p/v}) \tag{5}$$

$r_{v\text{-}a,115}$ -	vapor-air weight density (lbm/ft^3) at 115 ºF and the pressure setting of the cargo tank P/V valves
$S.G._v$ -	specific gravity of cargo vapor
$V_{v,115}$ -	partial volume of vapor at 115 ºF
$V_{a,115}$ -	partial volume of air at 115 ºF
$r_{a,115}$ -	air weight density (lbm/ft^3) at 115 ºF and the pressure setting of the cargo tank of the cargo tank P/V valves in lbm/ft^3
$P_{v,115}$ -	saturated vapor pressure at 115 ºF in psia
$P_{p/v}$ -	cargo tank P/V valve setting in psia
$P_{t,115}$ -	total vapor-air pressure at 115 ºF in psia

For benzene, crude oil and gasoline as required by 46 CFR 39.30-1(b)(2) the cargo vapor density must be calculated using a 50/50 mixture. The MSC does accept using partial pressures in equation (3) for gasoline for it yields a more conservative vapor density when using the physical properties in the *Coast Guard's Chemical Data Guide for Bulk Shipment by Water (CIM 16616.6A).*

Saturated vapor pressures at 115 ºF ($P_{v,115}$) and cargo vapor specific gravities ($S.G._v$) may be obtained from various sources including the *Coast Guard's Chemical Data Guide for Bulk Shipment by Water (CIM 16616.6A)* and *CHRIS Hazardous Chemical Data Manual (COMDTINST M16465.12B).* Both of these references can be purchased from the

Superintendent of Documents, Government Printing Office, Washington, DC 20402 (telephone 202-783-3238).

Cargoes with a Saturated Vapor Pressure Greater Than 14.7 psia at 115°F (VCS Categories 5 through 7)

Saturated vapor weight density at 115ºF from the CHRIS Manual or estimates as determined by equation (6) may be used:

$$r_{v-a,115} = \frac{(S.G._v)(P_{v,115})}{14.7}(0.0047 P_{p/v}) \qquad (6)$$

Determining the Vapor Growth Rate

During cargo loading, some of the cargo will change from the liquid phase to the vapor phase (evaporate) until the pressure in the cargo tank vapor space reaches the saturation pressure of the cargo. If vapors are being removed from the cargo tank through a VCS, the saturation pressure is never reached and the evaporation of the cargo continues throughout the loading operation. As a result, the volume of the vapors emitted from the cargo tank (Q_{v-a}) is equal to the volume that is displaced by the incoming cargo (q_{disp}) plus the volume of the cargo vapors that have evaporated (q_{vg}). The rate of evaporation is cargo dependent and is called the cargo's vapor growth rate.

$$Q_{v-a} = q_{disp} + q_{vg}$$

Q_{v-a} = volume of vapors (vapor-air mixture) emitted from cargo tank
q_{disp} = vapor flow due to cargo displacement
q_{vg} = vapor flow from cargo evaporation (vapor growth)

The rate of evaporation is influenced by the following factors:

- The area of the exposed surface of the liquid;
- The temperature of the liquid and the air above it;
- The movement of the air above the surface of the liquid; and
- The amount of cargo in vapor phase relative to amount at saturation.

To simplify calculations, a vapor growth rate factor (VGR) is used to quickly obtain the vapor-air flow rate from the liquid transfer rate.

$$Q_{v-a} = (Q_l)(VGR)$$

The vapor growth rate factor is the ratio of volumetric liquid transfer rate (Q_l) to the volumetric vapor-air flow rate (Q_{v-a}).

$$VGR = 1 + \left(\frac{q_{vg}}{Q_l} \right)$$

The regulations in 46 CFR Part 39 require the venting system to be able to discharge 1.25 times the maximum transfer rate. This allows for additional flow due to cargo evaporation (or vapor growth) of 25% of the cargo transfer rate. Therefore the assumed vapor growth rate factor (VGR) for crude oil, gasoline blends and benzene is 1.25.

Cargoes with a Saturated Vapor Pressure of 12.5 psia or less at 115°F (VCS Categories 1 through 4)

Using gasoline as a baseline cargo with an assumed vapor growth rate of 25% of the cargo transfer rate, equation (7) may be used to estimate the vapor growth rate factors of other cargoes.

$$VGR = 1 + 0.25 \frac{P_{v,115}}{12.5 \text{ (vapor pressure of gasoline)}} \qquad (7)$$

Note that you must use a VGR of 1.25 for benzene, crude oil and gasoline. This will ensure you satisfy 39.20-11(a)(1), which requires the cargo tank venting system be capable of relieving at 125% the maximum transfer rate without exceeding any cargo tank maximum design working pressure.

Cargoes with a Saturated Vapor Pressure Greater Than 12.5 psia at 115°F (VCS Categories 5 through 7)

A VGR of 1.25 may be used if the saturated vapor weight density using equation (6) is used. It has been determined that using these two values in the pressure drop calculation gives a worst case loading scenario. Use of the saturated vapor density for the cargo vapor density requires using the equation (7).

Maximum Liquid Transfer Rate Imposed by the Capacity of the Cargo Tank Venting System

The capacity of the venting system is best measured by determining the pressure drop through the venting system. This includes the venting piping and the P/V valve. The pressure drop between the cargo tank and the point of vapor discharge cannot exceed the cargo tank maximum design working pressure.

Darcy's Equation, equation (8), is an acceptable method to estimate the pressure drop of the vapor-air mixture through the vent piping.

$$\Delta P = \frac{r\, f\, L v^2}{144 D 2 g_c} \qquad (8)$$

ΔP - pressure drop (psig)
ρ - weight density of fluid (lbm/ft^3)
f - Darcy friction factor
L - equivalent length of pipe (ft)
υ - mean velocity of flow (ft/s)
D - internal diameter of pipe (ft)
g_c - acceleration constant (32.2 $ft.lbm/s^2.lbf$)

Darcy's Equation provides a reasonable approximation of the pressure drop for compressible fluids, provided the calculated pressure drop is no more than 10% of the initial **absolute** pressure. Section II.B. already addresses how the weight density (ρ) of the vapor-air mixture is calculated. Since the Reynolds numbers (Re) for the maximum liquid transfer rates are generally in the complete turbulent region (i.e., 10^4-10^7), the friction factor (f) may be determined from a technical reference such as Crane's *Flow of Fluids Through Valves, Fittings, and Pipe (Technical Paper No. 410).* The equivalent length of the system (L) may be obtained by summing the length of straight pipe and the equivalent lengths of various fittings in the system. Again, *Crane's* may also be used for this determination. The mean velocity of the vapor-air mixture (v) can be determined using the following equation:

$$v = \frac{(Q_l)(VGR)}{3600(D/2)^2 p} \qquad (9)$$

P/V valves can have an important effect on the overall pressure drop in the venting system. They must be adequately sized to keep the pressure in the vapor space of the cargo tank below the cargo tank's maximum design working pressure. The pressure relieving capacity and the vacuum relieving capacity may be different for a P/V valve; therefore, they must be evaluated separately.

For the pressure relieving capacity, the required vapor-air mixture volumetric flow rate through a P/V valve is equal to the liquid loading rate multiplied by the vapor-air mixture growth rate (equation (10)). If the data supplied by the manufacturer on the P/V valve's venting capacity is for air, a vapor density correction must be made (equation (11)). Once the required air-equivalent volumetric flow rate is known, the pressure drop across the P/V valve can be determined from data supplied by the manufacturer. Please note that the manufacturer's pressure drop versus flow rate data for each part of the valve must be submitted to the MSC. See Instructions.

$$Q_{v-a} = (Q_1)\,(VGR) \qquad (10)$$

Q_{v-a} - vapor-air mixture volumetric flow rate (bbl/hr)
Q_l - liquid transfer rate (bbl/hr)

VGR – vapor growth rate factor for vapor-air mixture

$$Q_a = Q_{v-a}\sqrt{\frac{\rho_{v-a,115}}{\rho_{a,115}}} \qquad (11)$$

Q_{v-a} - vapor-air mixture volumetric flow rate (bbl/hr)
Q_a - required air equivalent volumetric flow rate (bbl/hr)
$\rho_{v-a,\,115}$ - vapor –air weight density (lbm/ft^3) at 115^{0}F and the pressure setting of the cargo tank P/V valves
$\rho_{a,\,115}$ - air weight density (lbm/ft^3) at 115^{0}F and the pressure setting of the cargo tank P/V valves

For the vacuum relieving capacity, **no vapor growth rate or vapor density correction is necessary**. The P/V valve vacuum relieving capacity must be equal to or greater than the maximum liquid discharge rate. When a maximum discharge rate is not included in your submittal, the MSC will use the maximum cargo transfer rate to determine if the VCS satisfies 46 CFR 39.20-11(a)(3). Again, once the required vacuum relieving capacity of the P/V valve is known, the pressure drop across the P/V can be determined from the data supplied by the manufacturer.

Maximum Liquid Transfer Rate Imposed by the Relieving Capacity of the Cargo Tank Spill Valves or Rupture Disks

Paragraph 46 CFR 39.20-9(c)(3) requires that the maximum pressure at the cargo tank top during liquid overfill at the maximum loading rate for the tank not exceed the tank maximum design working pressure. Where spill valves or rupture disks are used to limit the tank pressure in a liquid overfill scenario, their liquid relieving capacity (Q_l) must be corrected for density if the data supplied by the manufacturer is for water. Equation (12) may be used for this correction.

$$Q_l = \frac{Q_w}{\sqrt{S.G._l}} \qquad (12)$$

Q_w – relieving capacity of spill valve based on the density of water
$S.G._1$ – specific gravity of the liquid cargo
Q_l – relieving capacity of spill valve based on liquid cargo

When making the density correction to determine the pressure drop across the spill valve, use the maximum density cargo authorized for carriage in the cargo tanks. For subchapter D barges the maximum value is generally a specific gravity of 1.05. For O/D barges, the maximum density is listed on the COI or on the first page of the barge’s 46 CFR Part 151 Cargo List, which is created by the Marine Safety Center.

Maximum Liquid Transfer Rate Imposed by the Set Point of the Overfill Alarm

Paragraphs 46 CFR 39.20-7(d)(4) and 39.20-9(b)(2) require the maximum liquid transfer rate to be such that, after the sounding of the overfill alarm, there is sufficient time to stop the transfer operation before the tank overflows. The maximum liquid transfer rate will be reduced if the operator fails to demonstrate to the cognizant Officer in Charge, Marine Inspection (OCMI) that the system meets this requirement. The calculations submitted to the MSC for barges installing an intrinsically safe overfill control system must demonstrate the overfill control system shutdowns cargo transfer operation at least 60 seconds prior to tank becoming 100% full at the maximum requested transfer rate.

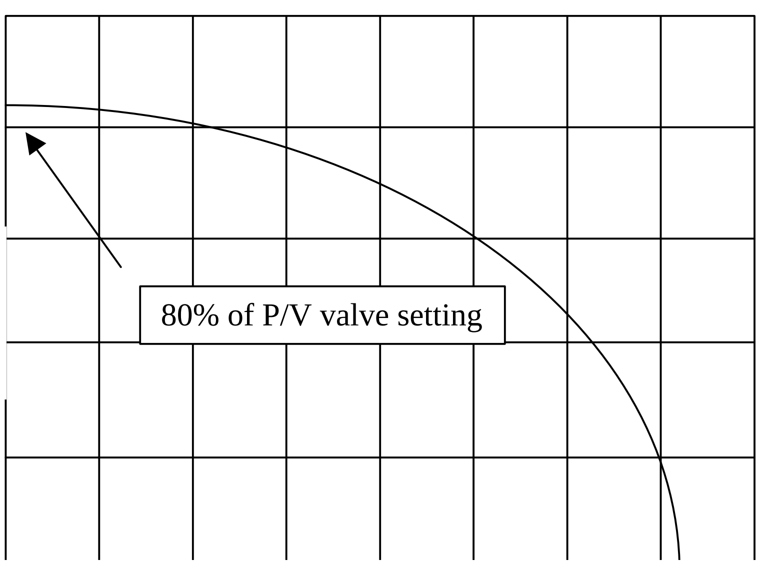
The Maximum Liquid Transfer Rate as Imposed by 46 CFR 39.30-1(d)(3)

Paragraph 46 CFR 39.30-1(d)(3) requires the sum of the pressure drop in the VCS piping and the pressure at the facility vapor connection not to exceed 80 percent of the setting of any pressure relief valve in the cargo tank venting system.

There are several ways the person in charge of cargo transfer can determine whether the pressure at the facility vapor connection would lower the vessel's designed maximum liquid transfer rate as described above. The MSC requires the VCS pressure drop calculations to contain either a table or graph vessel operators can use to determine the maximum allowable transfer rate as a function of the pressure at the facility vapor connection. Figure 1 on the following page is an example of an acceptable graph. To obtain this graph, simply subtract the pressure drop through the vapor control system piping from 80% of the P/V valve setting and plot that versus the cargo transfer rate. Use the graph required by paragraph 10 of The "Marine Safety Center Form for Tank Vessels Installing a Vapor Control System." for the pressure drop through the VCS piping as a function of flow rate.

Figure 1 shows the relationship between the pressure at the facility vapor connection and the maximum liquid transfer rate. With the pressure at the facility vapor connection known, the person in charge of cargo transfer can use the graph to get the maximum liquid transfer rate.

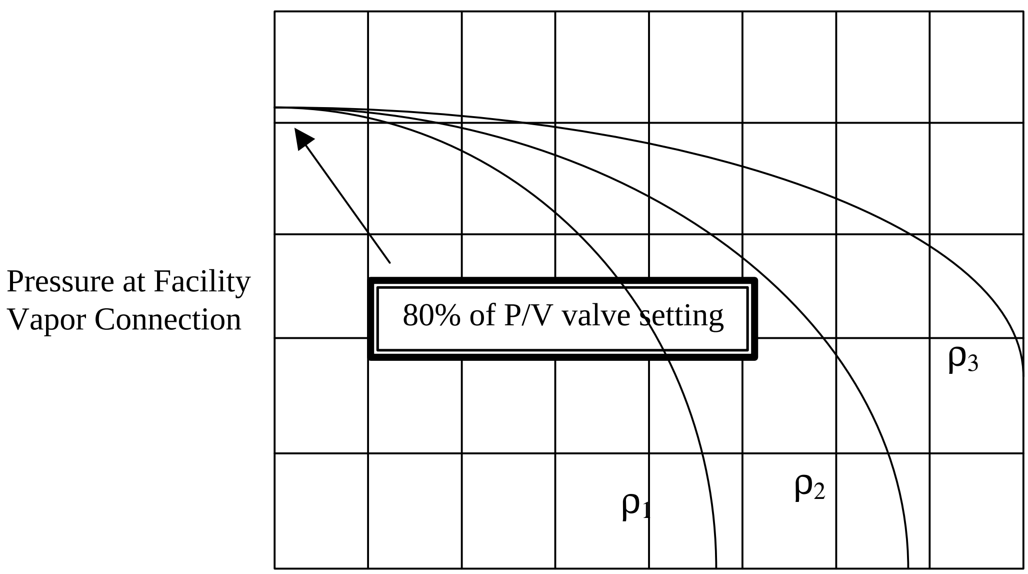
Pressure at Facility
Vapor Connection



Maximum Cargo Transfer Rate

Figure 1

To accommodate a higher rate for a cargo with a vapor-air mixture weight density less than that of the maximum, information may be presented as in Figures 2. For extrapolation, the curves should be labeled with values of at least the heaviest, lowest and intermediate vapor-air mixture weight densities. For these graphs to be of any use, vapor density of the vapor being transferred must be available at the time of transfer.



Maximum Cargo Transfer Rate

Figure 2

ρ_1 – Highest vapor-air mixture density

ρ_2 – Intermediate vapor-air mixture density

ρ_3 – Lowest vapor-air mixture density

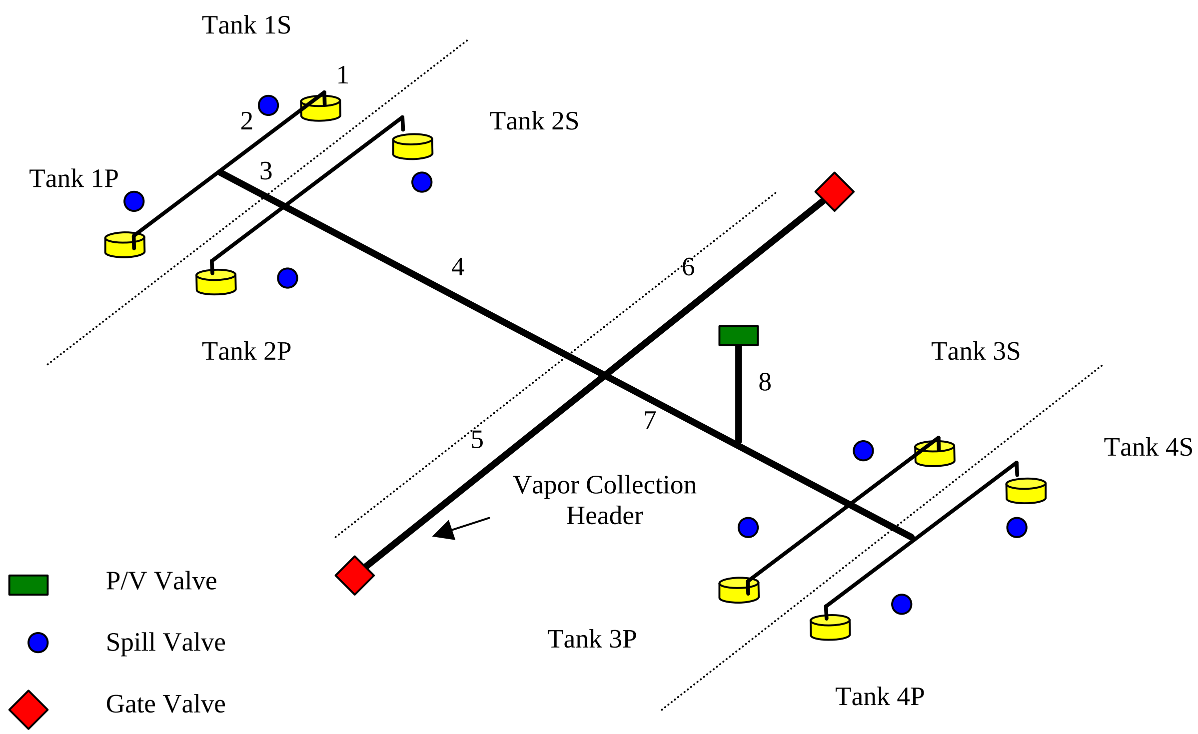
VCS SAMPLE PROBLEM

1. General Description of Vessel

A. **Vessel Particulars**: USCG Barge MSC, O.N. 000000, DOT Hull 01
B. **Dimension**: 297.5' x 54' x 12.5'
C. **Service:** Tank Barge (O/D)
D. **Max. Design Working Pressure**: 3.0 psig

2. Complete VCS Piping Plan and List of Materials. The piping plan must include all of the information required Section I. of the "Guidelines."

3. Vapor Control System Configuration



Pipe Diameter: 6 and 8 inches
Pipe Lengths:

1- 2.5'	2 – 15'	3 – 10'	4 – 60'
5- 25'	6- 27'	7 – 25'	8 – 10.5'

P/V Valve: MSC 8" High Velocity Type Bravo
(2) Set at 1.5 psig
(3) Vacuum Set at –0.5 psig below atmospheric pressure
Spill Valve: MSC 12" Type Delta, Set at 2.75 psig (Only means of tank overfill protection)

Requested Maximum Transfer Rate: 7500 bbl/hr

1. Cargo Authority: A barge must have carriage authority for a cargo prior to requesting the MSC add its VCS List of Cargoes. For instance, this barge's VCS can safely handle Benzene vapors, but it does not have carriage authority for cargo.

2. Vapor Control Categories: This submittal only includes calculations for 5 flammable and combustible cargoes. All of these cargoes are Category 1 cargoes, therefore, the MSC will not include any High Vapor Growth Rate Cargoes (VCS Categories 5 through 7) in the VCS List of Cargoes it creates. In addition, barges with spill valves or rupture disks as their primary means of tank overfill protection will not be able to use their VCS to capture VCS toxic cargoes (VCS Categories 3, 4 & 6). Click here for an explanation of VCS Categories.

Requested Cargoes
Dodecylbenzene
Methyl tert-Butyl Ether (MTBE)
Styrene
Gasoline
1,1 Dichoroethane

Verify your requested cargoes are approved by the Coast Guard for collection by a vapor control system. Coast Guard's Hazardous Materials and Standards Divisions (add link to website and phone number) reviews cargoes for use with vapor control systems and assigns it VCS Category. If there is any doubt whether the cargoes have been approved by the Coast Guard, contact the MSC's Cargo Authority branch at 202 366-6441.

Cargo	VCS Cat.	Liquid Specific Gravity	Vapor Specific Gravity	Vapor Pressure 115F (psia)	Vapor Growth Rate
Dodecylbenzene	**1**	**0.86**	**8.4**	**4.7**	**1.09**
MTBE	**1**	**0.74**	**3.1**	**4.1**	**1.084**
Styrene monomer	**2**	**0.92**	**3.6**	**.4**	**1.01**
Gasoline	**1**	**0.75**	**3.4**	**12.5**	**1.25**
1,1 Dichloroethane	**1**	**1.18**	**3.41**	**9.9**	**1.2**

The Maximum Liquid Transfer Rate as Imposed by the Capacity of the Cargo Tank Venting System

Calculate the equivalent length from the most remote cargo tank to the facility vapor connection and the P/V valve. In this case, 1 Starboard is the most remote cargo tank. Click Here to see an example of the equivalent length calculation. The equivalent length for the 6" pipe is approximately 84' for both routes. The equivalent length for the 8" pipe is 209' and 190' to the PV valve and the facility vapor connection, respectively.

Use Darcy's Equation, equation (8), and the friction factor obtained from Crane's Technical Pub. 410 to determine the pressure drop at the maximum requested transfer rate through the VCS piping from the most remote cargo tank to both the P/V valve and Facility Vapor Connection. Note that the ideal gas law was used to calculate Gasoline: Polymer's vapor density. This is acceptable because a more conservative value is derived than the 50/50 mixture required by 46 CFR 39.30-1(b)(2). Next, determine the required venting capacity for the pressure side of the P/V valve using equations (10) and (11). Then determine required spill valve relieving capacity using equation (12). With these values you can verify that cargo tank's maximum design working is not exceed when using the vapor control system or its relieving devices.

Cargo	Vapor Density (lbm/ft^3)	ΔP to P/V Valve (psi)	ΔP to Facility Connect. (psi).	Required P/V Vent. Capacity (bbl/hr) air	Required Spill Valve Capacity (bbl/hr) Water
Dodecylbenzene	0.2396	0.5940	0.5705	14555	6955
MTBE	0.1166	0.2838	0.2726	10061	6452
Styrene monomer	0.0810	0.1705	0.1638	7799	7194
Gasoline: Polymer	0.2171	0.7027	0.6750	15832	6495
1,1 Dichloroethane	0.1883	0.5597	0.5376	14129	8147

The MSC 8" High Velocity Bravo P/V valve when set at 1.5 psig has pressure drop of .875 psi across the valve at 15832 bbl/hr of air. 15832 bbl/hr is the highest required venting capacity calculated for the 5 cargoes requested. The back pressure in the most remote cargo tank when venting through the P/V for Gasoline: Polymer at the maximum transfer rate requested is only 1.57 psig, which doe not exceed the cargo tank maximum design working pressure (3.0 psig).

The vacuum side of the valve must be adequately sized for the barge's maximum discharge rate. In many cases submitters opt not differentiate between the maximum transfer rate and the discharge rate. In these cases the MSC will size the vacuum valve according to the requested maximum transfer rate.

3. **The Maximum Liquid Transfer Rate as Imposed by the Relieving Capacity of the Cargo Tank Spill Valves.**

The MSC 12" Type Delta, set at 2.75 psig, has a pressure drop of 2.1 psi across the valve at 8147 bbl/hr (water). This value is less than the tank maximum design working pressure; therefore, the spill valve is adequately sized for the cargoes requested. Use the maximum density authorized for carriage on the barge to make the density correction for the spill valve. Without making the correction for the maximum density cargo authorize, the VCS List of Cargoes created by the MSC may not include a large number of cargoes that would otherwise appear on the list.

3. Create table of graph required by 46 CFR 39.30-1(b)(3)

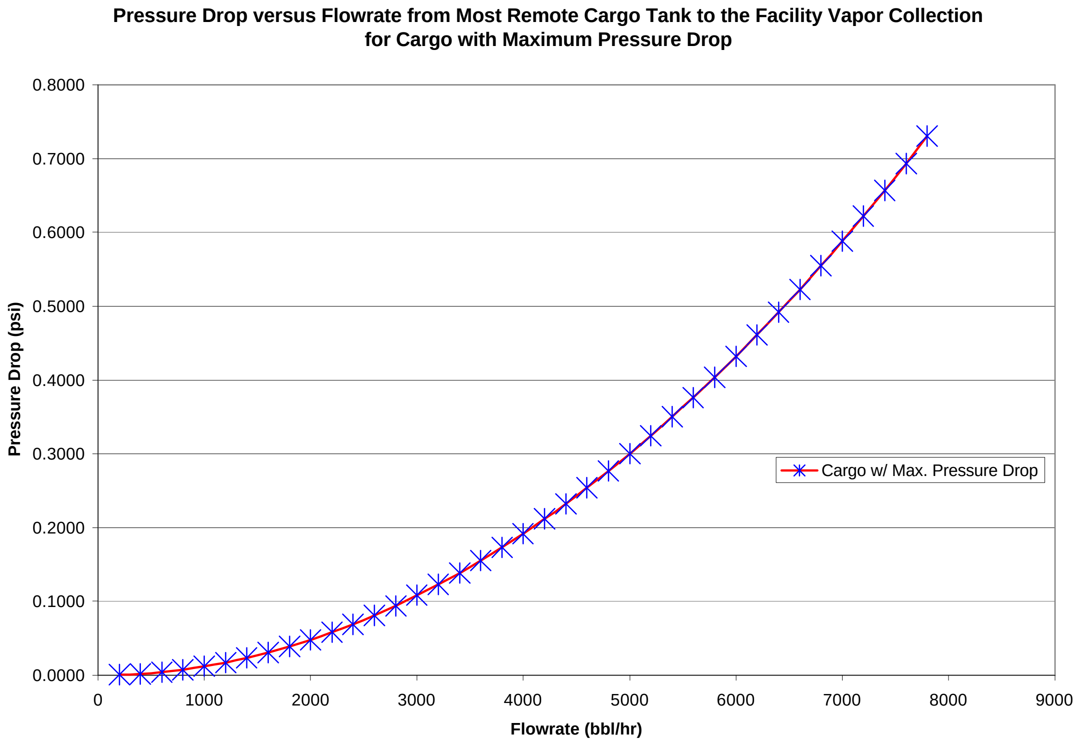
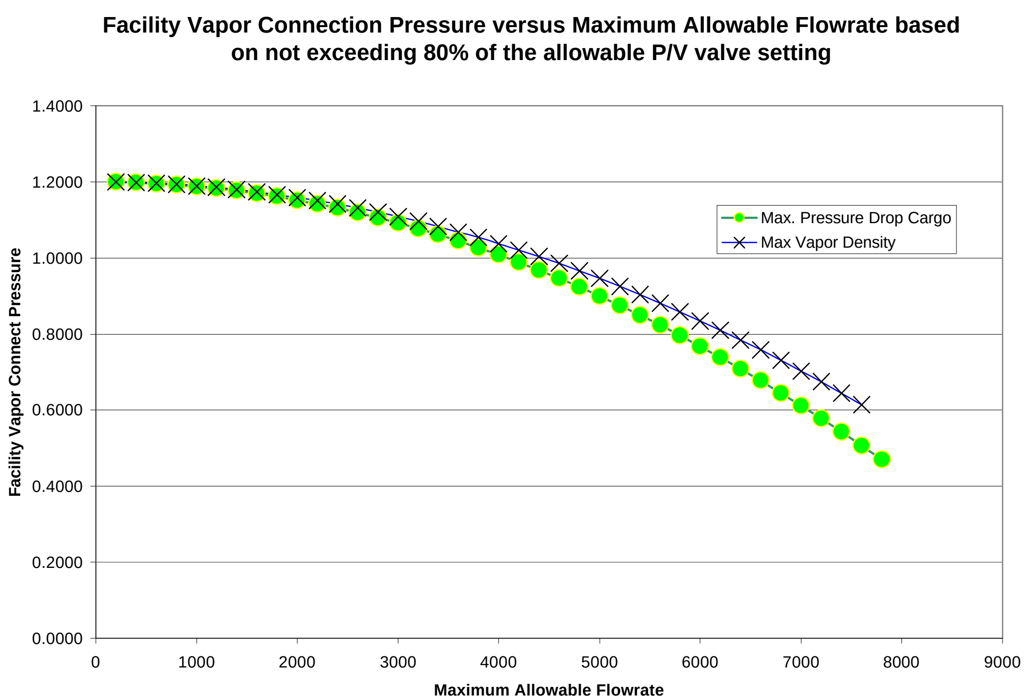


Table or Graph as Imposed by 46 CFR 39.30-1(d)(3):



The pressure at the facility vapor connection must be kept below 0.6 psig in order to achieve the maximum transfer rate of 7500 bbl/hr when loading Gasoline: Polymer.

The following is an example of the completed Form required to be submitted when requesting vapor control system plan review.

Example MSC Form

Example of the Tank Group Characteristics for the subject barge in order to determine which subchapter O cargoes the barge may carry. The final VCS List of Cargoes will only include cargoes for which the barge has carriage authority. :

Example Tank Group Characteristic Form

The barge's 46 CFR Part 151 Cargo List, which contains all of the Subchapter O cargoes which the barge is authorized to carry. Note there are two parts.

Tank Group Characteristics
46 CFR Part 151 Cargo List

The following is an example of the approval letter for the subject barge along with the enclosures the MSC produces:

Approval Letter
VCS List of Cargoes
VCS PRIS

Required Plans and Pressure Drop Calculations for installing a Vapor Control System

The information required to be submitted under 46 CFR 39.10-13 for a **NEW** vapor control system must include the following:

- A Vapor Control System Piping Plan with the following information listed and/or designed to meet to following requirements:

  - **List of Materials:** The list must include the components used to construct the VCS piping system such as piping pieces, flanges, valves and other miscellaneous fittings. Piping components are required to satisfy the material and design specifications in 46 CFR Table 56.60-1 A&B.

  - *Note that the P/V valves and Spill valves are not required to meet these requirements. P/V valves receive a generic CG approval as per 46 CFR Part 162.017 and must satisfy 39.20-11(b). Spill valves must satisfy American Society of Testing and Materials (ASTM) standard F1271.*

  - VCS piping is permanently installed and the vessel's vapor connection is located as close as practical to the cargo loading manifold. See 46 CFR 39.20-1(a)(1).

  - A means to eliminate liquid condensate. See 46 CFR 39.20-1(a)(3).

  - The piping system is electrically bonded to hull and electrically continuous. See 46 CFR 39.20-1(a)(5).

  - An isolation valve with manual override provided at each point where the vessel's vapor control system may be attached to a VCS facility. See 46 CFR 39.20-1(a)

  - The vessel's VCS system cannot interfere with the vessel's venting system. See 46 CFR 39.20-1(b).

  - The last meter of the VCS piping before the vapor connection flange is marked as follows:

    - Painted Red/Yellow/Red (.1m/.8m/.1m)

    - Labeled with **VAPOR** in black letters 50 mm high

  - The standard vapor connection flange has a stud located as described in 46 CFR Part 39.20-1(e).

Vapor Control System Pressure Drop Calculations must include **ALL** of the information requested in the "Marine Safety Center Form for Tank Vessels Installing a Vapor Control System." (Click to go to Form). See the Instructions for filling out this form. Your calculations must embody the principles described in the following sections. Pay specific attention to the method for determining the appropriate vapor growth rate for each cargo and the cargo-air mixture vapor density.