# Cylinder Maximum Fill Density

**April 2022**

To prevent a cylinder from rupturing due to overpressure, The transportation regulations limit the amount of gas that can be put into a cylinder.

> 49CFR173.301 General requirements for shipment of compressed gases and other hazardous materials in cylinders, UN pressure receptacles and spherical pressure vessels.
>
> (a) *General qualifications for use of cylinders.* Unless otherwise stated, as used in this section, the term "cylinder" includes a UN pressure receptacle. As used in this subpart, filled or charged means an introduction or presence of a hazardous material in a cylinder. A cylinder filled with a Class 2 hazardous material (gas) and offered for transportation must meet the requirements in this section and §§ 173.301a through 173.305, as applicable.

Liquid expands with increasing temperatures as well as the vapor pressure. It could expand to completely fill the cylinder (liquid full).

Fig. 1: Overfilled Trifluoromethane Cylinder

A compressed gas above it's critical temperature cannot exceed the pressure rating of the cylinder at 55°C.

In the US, the transportation regulations estimates the maximum fill amount as follows

49 CFR 173.300 Shippers-General Requirements for Shipments and Packages

- Pressure in the cylinder at 70°F (21°C) less than or equal to the rated pressure of the cylinder . Reference 173.301.
- The cylinder not to be liquid full at any temperature up to 131°F (55°C). Ref. 173.304(b) with some exceptions.
- The pressure in the cylinder at 131°F (55°C) is less than 5/4 the cylinder's rated pressure. Ref. 173.301 (a) 8

In the US, cylinders with a plus symbol next to the hydrotest date are authorized to be filled 10% above the service pressure for certain gases (49CFR173.302) and cylinders. This is common for nitrogen, helium, argon, etc.

Internationally the cylinder fill density is lower since a higher temperature reference is used.

ADR & United Nation ST/SG/AC.10/C.3/34

- 95% of the liquid density under its own vapor pressure at (50°C (122°F) Ref.: Packing Instructions P-200
- 100% of the liquid density under its own vapor pressure at 60°C (140°F) Ref.: Packing Instructions P-200
- The density such that the pressure at 65°C (149°F) is at the cylinder's test pressure. Ref.: Packing Instructions P-200

Some gases have reduced fill densities due to other factors

Overpressure that would occur from a decomposition reaction

Acetylene

Diborane (pure is shipped in dry ice) Mixtures are limited in pressure 49CFR173.302(d)

Germane

Nitric Oxide

Stibine

Reaction Pressure

Fluorine (limited to 400 psig) 49CFR173.302(e)

Fluorine Mixtures (limit partial pressure of $F_2$ to 400 psig)

Nitrogen Trifluoride (<1450 psig, Adiabatic Compression Heat)

Tetrafluorohydrazine (limited to 100 psig)

Stress Corrosion Cracking

Carbon monoxide pure and mixtures in carbon steel cylinders are limited in pressure to 1,800 psig unless they are very dry and sulfur free . 49CFR173.302(d). The Compressed Gas Association also has guidance on how to fill these cylinders safely, CGA P-57, Avoidance Of Failure Of Carbon Monoxide And Of Carbon Monoxide/Carbon Dioxide Mixtures Cylinders.

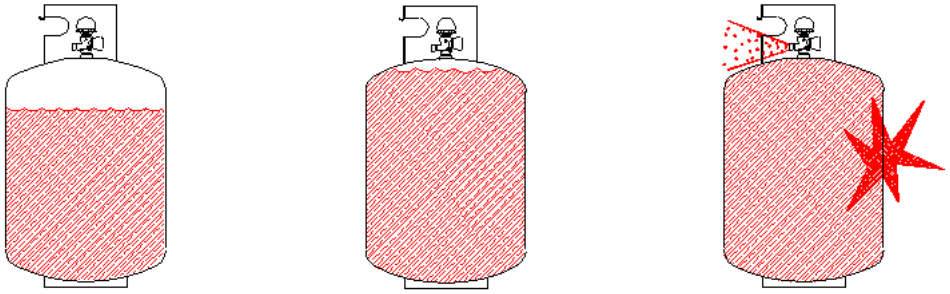
If 130°F is exceeded the cylinder while it is full. It could rupture. This condition can be reached if there is

1. Faulty heating blanket on the cylinder
2. The control thermocouple not being placed on the cylinder or in the wrong location
3. Flame impingement only on the side of the cylinder

An overfilled cylinder however could rupture before reaching this temperature

The following example is a typical consumer 20 lb propane cylinder at various temperatures and liquid expansion

Cylinder volume will vary between 47.1 - 47.8 lbs water capacity



| 70°F (21°C) | 130°F (54.4°C) | 152°F (66.7°C) |
|---|---|---|
| 83.6% Full | 94% Full | 100% Full |
| 110 psig (8.5 atm) | 258 psig (18.6 atm) | 350 psig (24.8 atm) |

Fig. 1: 20 lb propane cylinder

Never trap liquid compressed gas between two valves without a spring loaded pressure relief valve to relieve pressure due to liquid expansion.

**Cylinder DOT Fill Densities @ 130°F**

49 CFR 173.300 Shippers-General Requirements for Shipments and Packages

1. Pressure in the cylinder at 70°F (21°C) less than or equal to the rated pressure of the cylinder . Reference 173.301.
2. The cylinder not to be liquid full at any temperature up to 131°F (55°C). Ref. 173.304(b) with some exceptions.
3. The pressure in the cylinder at 131°F (55°C) is less than 5/4 the cylinder's rated pressure. Ref. 173.301 (a) 8

Ratio is kg of gas/kg of water

| Ratio | Gas/liquid | Remarks |
|---|---|---|
| 0.41 | acetylene | Requires special solid filled cylinder and solvent |
| 0.58 | ammonia | |
| | arsenic pentafluoride | (liquid filled in cylinders) |
| 1.32 | arsine | |
| 1.31 | boron trichloride | |
| 0.78 | boron trifluoride | |
| 2.63 | bromine trifluoride | (liquid filled in cylinders) |
| 1.50 | bromine chloride | |
| 2.42 | bromine pentafluoride | (liquid filled in cylinders) |
| 1.62 | bromotrifluoromethane (R13B1) | |
| 0.61 | 1,3 butadiene | Stabilized with inhibitor |
| 0.77 | carbon dioxide | |
| | carbon monoxide | Stress corrosion cracking of steel, pressure 1,800 psig |
| 0.77 | carbonyl fluoride | |

| | | |
|---|---|---|
| 1.00 | carbonyl sulphide | |
| 1.37 | chlorine | |
| 1.77 | chlorine pentafluoride | |
| 1.71 | chlorine trifluoride | |
| 1.35 | chloropentafluoroethane (R115) | |
| 1.19 | chlorodifluoromethane (R22) | |
| 1.10 | chlorotrifluoromethane (R13) | |
| 0.85 | cyanogen | Dermal toxicity |
| 1.14 | cyanogen chloride | Dermal toxicity |
| 0.29 | diborane | Pure must be shipped at dry ice temperature |
| 1.33 | dichlorodifluoromethane (R12) | |
| 1.21 | dichlorosilane | |
| 0.90 | 1,1-difluoroethane (R152a) | |
| 0.77 | 1,1-difluoroethylene | |
| 0.96 | difluoromethane (R32) | |
| 0.38 | ethane | |
| 0.35 | ethylene | |
| 0.85 | ethylene oxide | |
| 0.88 | ethyl chloride | |
| 0.71 | ethyl fluoride | |
| | fluorine | Pressure limited to 400 psig due to reactivity |
| 0.06 | germane | Can autodecompose |
| 1.42 | heptafluoropropane (R227ea) | |
| 1.38 | hexafluoroacetone | |
| 1.19 | hexafluoroethane (R116) | |
| 1.33 | hexafluoropropylene | |
| 1.71 | hydrogen bromide | |
| 0.78 | hydrogen chloride | |
| 0.64 | hydrogen cyanide | Stabilized with sulfuric or phosphoric acid |
| 0.87 | hydrogen fluoride | Slowly reacts with carbon steel to form $H_2$ |
| 2.49 | hydrogen iodide | slowly decomposes store at 34°F |
| 1.71 | hydrogen selenide | |
| 0.76 | hydrogen sulphide | |
| 3.14 | iodine pentafluoride | (liquid filled in cylinders) |
| 1.63 | methyl bromide | |
| 0.61 | methyl fluoride (R41) | |
| 0.85 | methyl mercaptan | |
| | nitric oxide | Fill limited to 500 psig, decomposition reaction |
| 1.38 | nitrogen dioxide | |
| 0.69 | nitrogen trifluoride | Fill pressure limited to 1450 psig to reduce adiabatic compression heat |

| | | |
|---|---|---|
| 0.76 | Nitrous oxide propogate | Large diameter piping can allow decomposition to |
| 1.24 | nitrosyl chloride | |
| 1.51 | octafluorobut-2-ene | |
| 1.52 | octafluorocyclobutane (RC318) | |
| 1.41 | octafluoropropane (R218) | |
| 1.25 | pentafluoroethane (R125) | |
| 1.41 | perchloryl fluoride | |
| 1.29 | perfluoromethylvinylether | |
| 1.35 | phosgene | |
| 0.52 | phosphine | |
| 1.18 | phosphorous pentafluoride | |
| 0.50 | propane | |
| 0.52 | propylene | |
| 1.09 | R404A | |
| 1.25 | R502 | |
| 1.16 | R407A | |
| 1.16 | R500 | |
| 1.15 | R407C | |
| 2.09 | selenium hexafluoride | |
| 0.34 | silane | |
| 1.04 | silicon tetrafluoride | |
| 2.10 | stibine | decomposes in a day |
| 1.33 | sulfur dioxide | |
| 1.49 | sulphur hexafluoride | |
| 2.71 | telurium hexafluoride | |
| 1.21 | 1,1,11,2-tetrafluoroethane (R134a) | |
| 1.10 | tetrafluoroethylene | stabilized d-limonene |
| | tetrafluorohydrazine | maximum cylinder pressure of 100 psig |
| 0.77 | tetrafluoromethane (R14) | |
| 1.38 | trifluoroacetylchloride | |
| 0.96 | trifluoromethane (R23) | |
| 0.97 | 1,1,1-trifluoroethane (R143a) | |
| 1.28 | trifluorochloroethylene | |
| 3.41 | tungsten hexafluoride | |
| 0.65 | vinyl fluoride | |

**Example:**

44 liter Air Liquide cylinder has internal volume of 44 liter. Ammonia has a ratio of 0.58 there the maximum fill would be 25.52 kgs (56 lbs)