



CGA G-3—2023 SULFUR DIOXIDE

SEVENTH EDITION

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Full document details: CGA G-3-2023

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Work Item 21-029
Specialty Gases Committee

NOTE—Technical changes from the previous edition are underlined.

SEVENTH EDITION: 2023
SIXTH EDITION: 2017
FIFTH EDITION: 1995
FOURTH EDITION: 1988
THIRD EDITION: 1964

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1 Introduction

This publication is one of a series compiled by the Compressed Gas Association, Inc. (CGA) in response to demand for information relating to the properties, transportation, storage, and handling of compressed gases.

2 Scope

The purpose of this publication is to provide information regarding the properties, manufacture, shipping, storage, handling, and use of sulfur dioxide. It also describes related regulatory requirements and safe practices in the United States and Canada. This information is intended to complement but not supplant national, state, provincial/territorial, municipal, and insurance company codes and requirements.

The information in this publication is intended for the use of sulfur dioxide shippers, carriers, distributors, repackagers, consumers, equipment designers or installers, safety administrators, and others desiring an introductory knowledge of the subject. Anyone requiring more detailed or specialized information should consult their sulfur dioxide supplier. See also the references listed in Section 16.

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.

3.2 Technical definitions

3.2.1 ACME thread

Standard thread having a profile angle of 20 degrees and a flat crest, which is used on power screws.

3.2.2 Adapter

Device or pipe fittings that allows for connection to different size, style, or misalignment of coupling.

3.2.3 Butt joints

Joint between two members aligned approximately in the same plane.

3.2.4 Cargo tank

Bulk packaging that:

- is a tank intended primarily for the carriage of liquids or gases and includes appurtenances, reinforcements, fittings, and closures;

- is permanently attached to or forms a part of a motor vehicle, or is not permanently attached to a motor vehicle but which, by reason of its size, construction or attachment to a motor vehicle is loaded or unloaded without being removed from the motor vehicle; and
- is not fabricated under a specification for cylinders, intermediate bulk containers, multi-unit tank car tanks, portable tanks, or tank cars.

3.2.5 Category “M” fluids

Fluid service in which the potential for personnel exposure is judged to be significant and in which a single exposure to a very small quantity of a toxic fluid, caused by leakage, can produce serious irreversible harm to persons on breathing or bodily contact, even when prompt restorative measures are taken [1].¹

3.2.6 Design pressure

Maximum allowable working pressure as defined by American Society of Mechanical Engineers (ASME) *Boiler and Pressure Vessel Code* [2].

3.2.7 Emergency “A” Kit

Capping kit for sealing leaking valves on 150 lb cylinders in chlorine or sulfur dioxide service.

3.2.8 Emergency “B” Kit

Capping kit for sealing leaking valves on one ton containers in chlorine or sulfur dioxide service.

3.2.9 Emergency “C” Kit

Capping kit for sealing leaking valves on rail cars in chlorine or sulfur dioxide service.

3.2.10 Filling density

Percent ratio of the weight of gas in a packaging to the weight of water that the container will hold when full at 60 °F (16 °C).

3.2.11 Fusible metal insert

Part of a safety device designed to melt in a fire situation at a specified temperature resulting in releasing pressure before vessel failure.

3.2.12 Hammerlock union

Threaded connecting device designed to be tightened or loosened by the use of a hammer rather than a wrench.

3.2.13 Hydrostatic pressure

Water pressure to which vessels are subjected to ensure their integrity.

3.2.14 Portable tank

Bulk packaging (except a cylinder having a water capacity of 1000 lb [454 kg] or less) designed primarily to be loaded onto, or on, or temporarily attached to a transport vehicle or ship and equipped with skids, mountings, or accessories to facilitate handling of the tank by mechanical means.

NOTE—It does not include a cargo tank, tank car, multi-unit tank car tank, or trailer carrying 3AX, 3AAX, or 3T cylinders.

3.2.15 Post-weld heat-treated

Heating a pipe, vessel, or fitting after welding to relieve stresses built up from the welding operation.

3.2.16 Pressure relief device (PRD)

Pressure- or temperature-actuated device used to prevent the pressure from rising above a predetermined maximum and thereby prevent the rupture of a normally charged cylinder when subjected to a standard fire test as defined in U.S Department of Transportation (DOT) and/or Transport Canada (TC) regulations [3, 4].

3.2.17 Reportable quantity (RQ)

Minimum amount of hazardous substance which when known to have been discharged into the environment within a 24-hour period, either accidentally or intentionally, shall be reported immediately to the National Response Center (NRC) in Washington, DC.

¹ References are shown by bracketed numbers and are listed in order of appearance in the reference section.

3.2.18 Rupture disk

Part of a PRD designed to burst open within a specifically designed differential pressure range.

3.2.19 Service pressure

Authorized pressure marked on a container.

3.2.20 Throttle valve

Valve used to control or adjust the flow of material through a pipe.

3.2.21 UN identification number

Four-digit identification number assigned to each hazardous material description by the international regulatory organizations.

3.2.22 Weld neck flange

Pipe flange with neck designed to butt weld onto a pipe.

4 Manufacture, properties, and uses**4.1 Manufacture**

Sulfur dioxide is produced commercially by the liquefaction of gases from the combustion of elemental sulfur, the roasting or smelting of sulfide ores, and from the reaction of liquid sulfur with sulfur trioxide. The gas strength produced varies greatly from process to process, which results in differing energy inputs being required to achieve liquefaction.

In the case of weaker gas concentrations, a concentrating stage is usually necessary before liquefaction to reduce the energy input. The gases from typical metallurgical roasting or smelting operations are unsuitable for direct liquefaction. Therefore, the cleaned gas is contacted with an absorbing liquid which selectively absorbs the sulfur dioxide. The liquid is then subjected to appropriate temperature and pressure conditions to release the sulfur dioxide gas, which is dried and liquefied. This approach is also used for gases resulting from the combustion of elemental sulfur, although it is possible to produce gas that is sufficiently high in sulfur dioxide content to make direct liquefaction feasible.

With the advent of oxygen-enriched flash smelting processes, there was a resultant increase in sulfur dioxide content of the metallurgical gases produced. In these processes, sulfur dioxide is generated at a concentration of 70% to 80%, after which it undergoes a series of gas cleaning stages before liquefaction.

In another process, the reaction of liquid sulfur with sulfur trioxide produces sulfur dioxide gas, which is then liquefied.

4.2 Properties**4.2.1 Composition****4.2.1.1 Molecular structure**

Sulfur dioxide is a compound formed by the combination of the elements sulfur and oxygen. On a weight basis, the proportion of the elements is approximately one-part sulfur to one-part oxygen, or more exactly, 50.05% to 49.95%, respectively. This is derived from the chemical symbol for sulfur dioxide (SO_2) and the atomic weights of each component:

S = 32.064 g/mole

O = 15.999 g/mole

4.2.1.2 Specifications

The liquefied gas, when produced, is colorless, of high purity, and sold as technical grade or Food Chemicals Codex (FCC) grade. The usual impurities for which analysis is conducted are moisture and nonvolatile residue.

4.2.2 Physical properties

At standard conditions of temperature and pressure, sulfur dioxide is a colorless gas with a characteristic pungent odor. It can be cooled and compressed to a colorless liquid, which, at one atmosphere, boils at 14 °F (–10 °C) and freezes at –104.6 °F (–75.9 °C). See Table 1. When heated above its critical temperature of 315.4 °F (157.4 °C), sulfur dioxide exists only as a gas regardless of pressure. Between the melting and the critical points, liquid sulfur dioxide exerts a vapor pressure which increases with rising temperature. See Table 2. If no other gases are present, the vapor pressure within the container varies with temperature as shown in Figure 1. The expansion of liquid sulfur dioxide with an increase in temperature is shown in Figure 2.

Sulfur dioxide liquid is heavier than water, having a specific gravity of 1.436 at 32 °F (0 °C). As a gas, sulfur dioxide is more than twice as heavy as air, its relative density being 2.2638 at atmospheric pressure and 32 °F (0 °C). One pound of the gas occupies 5.47 ft³ (0.155 m at 32 °F (0 °C) at 1 atm (101.325 kPa).²

The relation of temperature to the vapor pressure, volume, and density of sulfur dioxide in containers is shown in Table 2.

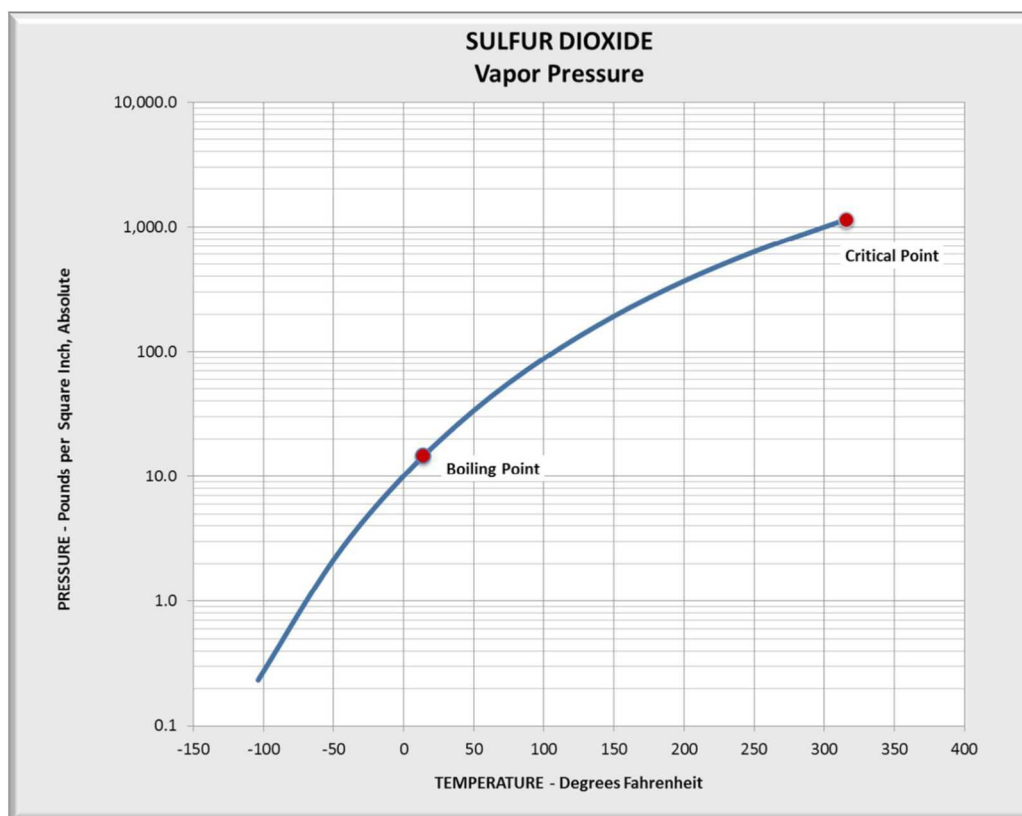
Table 1—Physical properties of sulfur dioxide

	U.S. Units	SI Units
Molecular symbol	SO ₂	SO ₂
Molecular weight	64.06	64.06
Boiling point at 1 atm ¹⁾	14.0 °F	–10.0 °C
Critical density	32.6 lbs/ft ³	520 kg/m ³
Critical pressure	1143 psia	7880 kPa, abs
Critical temperature	315.4 °F	157.4 °C
Dielectric constant of liquid at 32 °F (0 °C)	15.6	15.6
Freezing point at 1 atm ¹⁾	–104.6 °F	–75.9 °C
Latent heat of fusion at –103.9 °F (–75.5 °C)	49.70 Btu/lb	115.5 kJ/kg
Latent heat vaporization at 70 °F (21.1 °C)	155.5 Btu/lb	361.5 kJ/kg
Liquid density at 70 °F (21.1 °C) and 49.1 psia (339 kPa, abs)	86.06 lb/ft ³	1379 kg/m ³
Refractive index of the liquid at 68 °F (20 °C)	1.410	1.410
Refractive index of the gas at 59 °F (15 °C)	1.000686	1.000686
Specific conductance of liquid sulfur dioxide at 95 °F (35 °C)	1.5 x 10 ^{–8} mhos/cm	1.5x 10 ^{–8} mhos/cm
Specific gravity of vapor compared to dry air at 32 °F (0 °C) and 1 atm ¹⁾	2.2638	2.2638
Specific gravity of liquid at 32 °F (0 °C) and 23.7 psia (163 kPa, abs) compared to water at 39.2 °F (4 °C)	1.436	1.436
Specific heat of gas at 77 °F (25 °C) and 1 atm ¹⁾ C _p C _v	0.149 Btu/(lb)(°F) 0.116 Btu/(lb)(°F)	0.622 kJ/(kg)(°C) 0.485 kJ/(kg)(°C)
Specific volume of gas at 70 °F (21.1 °C) and 1 atm ¹⁾	5.99 ft ³ /lb	0.374 m ³ /kg
Surface tension of liquid at 59 °F (15 °C) and 39.7 psia (274 kPa, abs)	1.30 x 10 ^{–4} lb/in	23.64 dynes/cm
Triple point	–103.9 °F at 0.2429 psia	–75.5 °C at 1.675 kPa, abs
Vapor density at 32 °F (0 °C) and 1 atm ¹⁾	0.1810 lb/ft ³	2.927 kg/m ³
Viscosity of liquid at 32 °F (0 °C) and 28.45 psia (196.16 kPa, abs)	2.64 x 10 ^{–4} lb/(ft)(sec)	3.929 x 10 ^{–4} Pa · s
Viscosity of vapor at 32 °F (0 °C) and 14.22 psia (98.05 kPa, abs)	7.79 x 10 ^{–6} lb/(ft)(sec)	11.593 x 10 ^{–6} Pa · s
¹⁾ One atmosphere (atm) = 760 mm of mercury or 14.696 psia (101.325 kPa, abs).		

² psi, bar, and kPa shall indicate gauge pressure unless otherwise noted as (psia; bar, abs; and kPa, abs) for absolute pressure or (psid; bar, dif; and kPa, dif) for differential pressure. All kPa values are rounded off per CGA P-11, *Guide to Metric Practice in the Compressed Gas Industry* [5].

Table 2—Properties of sulfur dioxide at various temperatures [6]

Temperature		Vapor pressure		Volume (cu ft per lb)		Density (lb per cu ft)		Latent heat of vaporization (Btu/lb)
(°F)	(°C)	(psia)	(psi)	Liquid	Vapor	Liquid	Vapor	
−40	−40.0	3.12	−11.57	.01044	22.2	95.79	.04505	178.4
−20	−28.9	5.88	−8.81	.01062	12.5	94.16	.08000	174.4
0	−17.8	10.26	−4.43	.01082	7.35	92.42	.13605	170.3
10	−12.2	13.3	−1.39	.01092	5.77	91.58	.17331	168.3
20	− 6.7	16.9	2.2	.01103	4.59	90.66	.21786	166.3
30	−1.1	21.3	6.6	.01114	3.70	89.77	.27027	164.2
40	4.4	26.6	11.9	.01125	3.02	88.89	.33113	162.2
50	10.0	32.9	18.2	.01137	2.48	87.95	.40323	160.0
60	15.6	40.3	25.6	.01149	2.05	87.03	.48780	157.8
70	21.1	49.1	34.4	.01162	1.70	86.06	.58824	155.5
80	26.7	59.8	44.6	.01175	1.42	85.11	.70423	153.1
90	32.2	71.0	56.3	.01189	1.20	84.10	.83333	150.7
100	37.8	84.1	69.4	.01204	1.02	83.06	.98039	148.2
110	43.3	99.1	84.4	.01219	0.868	82.03	1.15207	145.7
120	48.9	116.3	101.6	.01235	0.746	80.97	1.34048	143.0
130	54.4	135.8	121.1	.01251	0.646	79.94	1.54799	140.0
140	60.0	157.7	143.0	.01269	0.554	78.80	1.80505	137.1

**Figure 1—Vapor pressure of liquid sulfur dioxide (U.S. units) [6]**

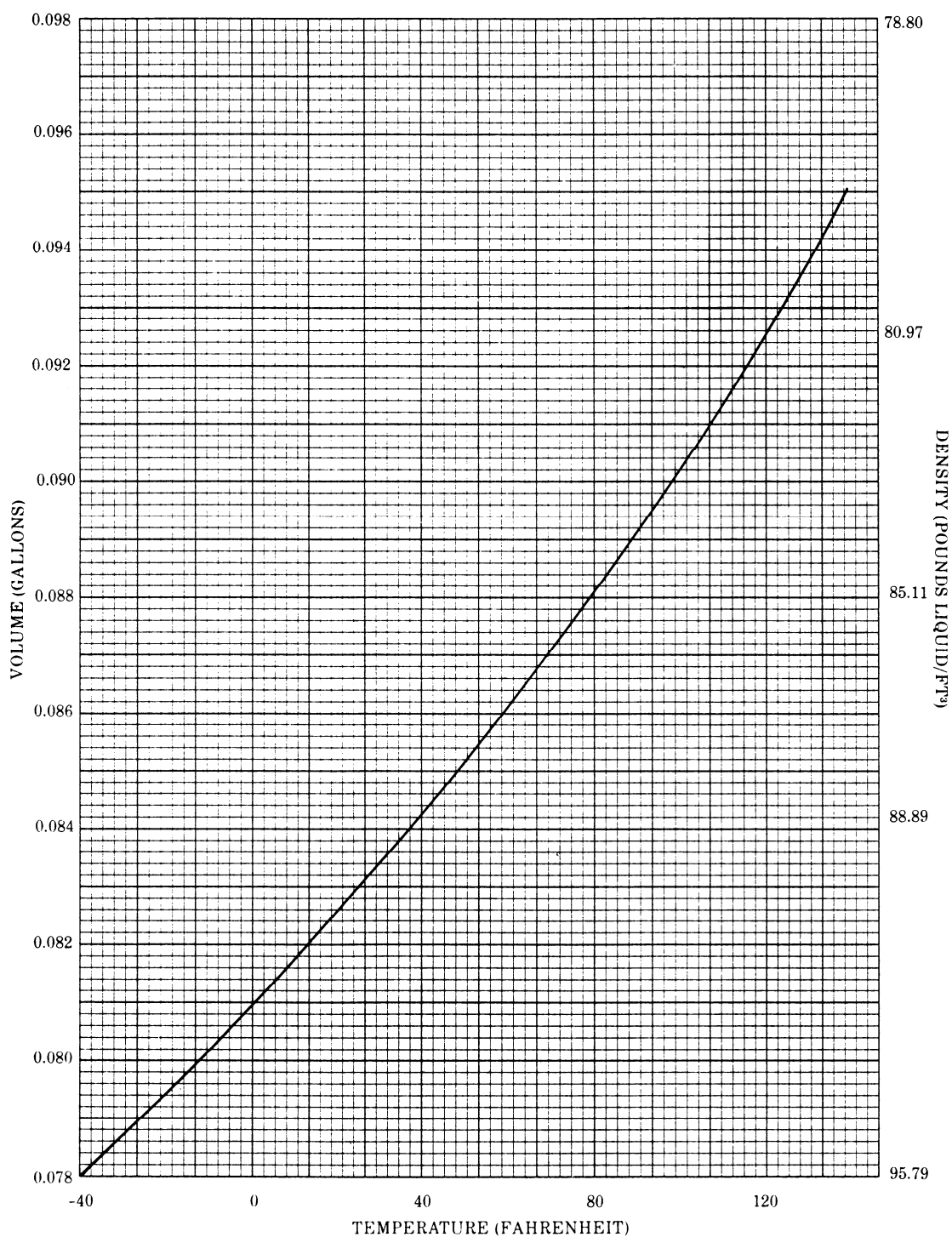


Figure 2—Specific volume and density versus temperature curve for liquid sulfur dioxide

4.2.3 Thermodynamic properties

The thermodynamic properties of saturated sulfur dioxide are depicted in Figures 3, 4, 5, and 6.

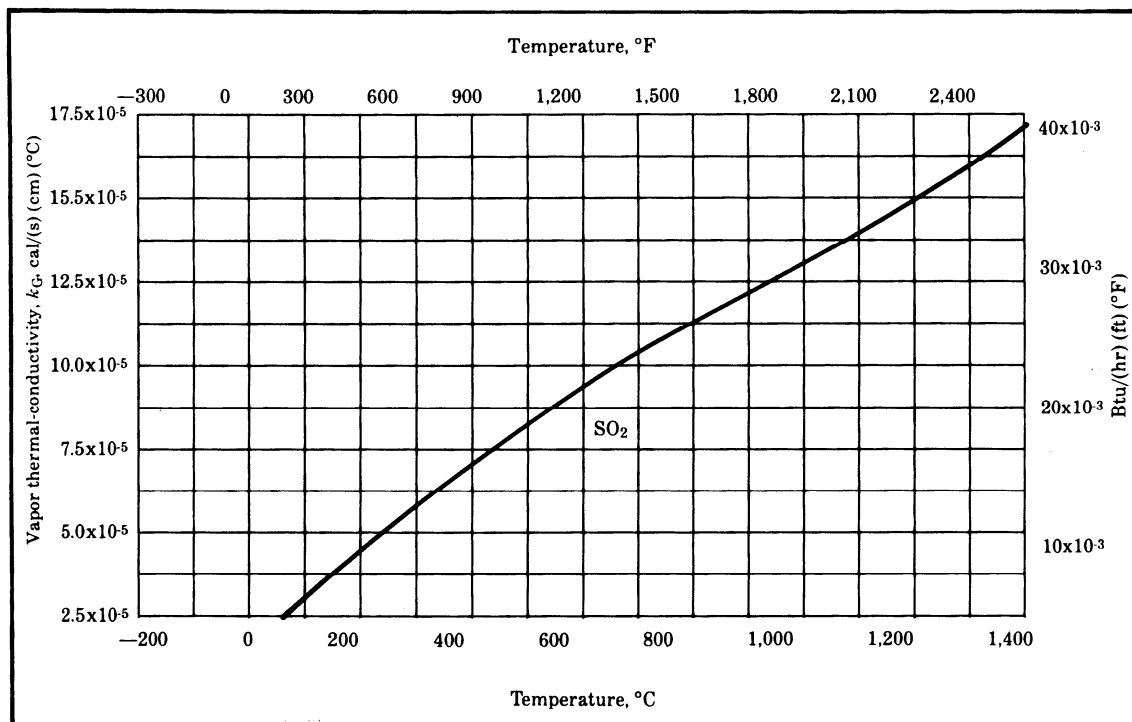


Figure 3—Thermal conductivity of sulfur dioxide vapor

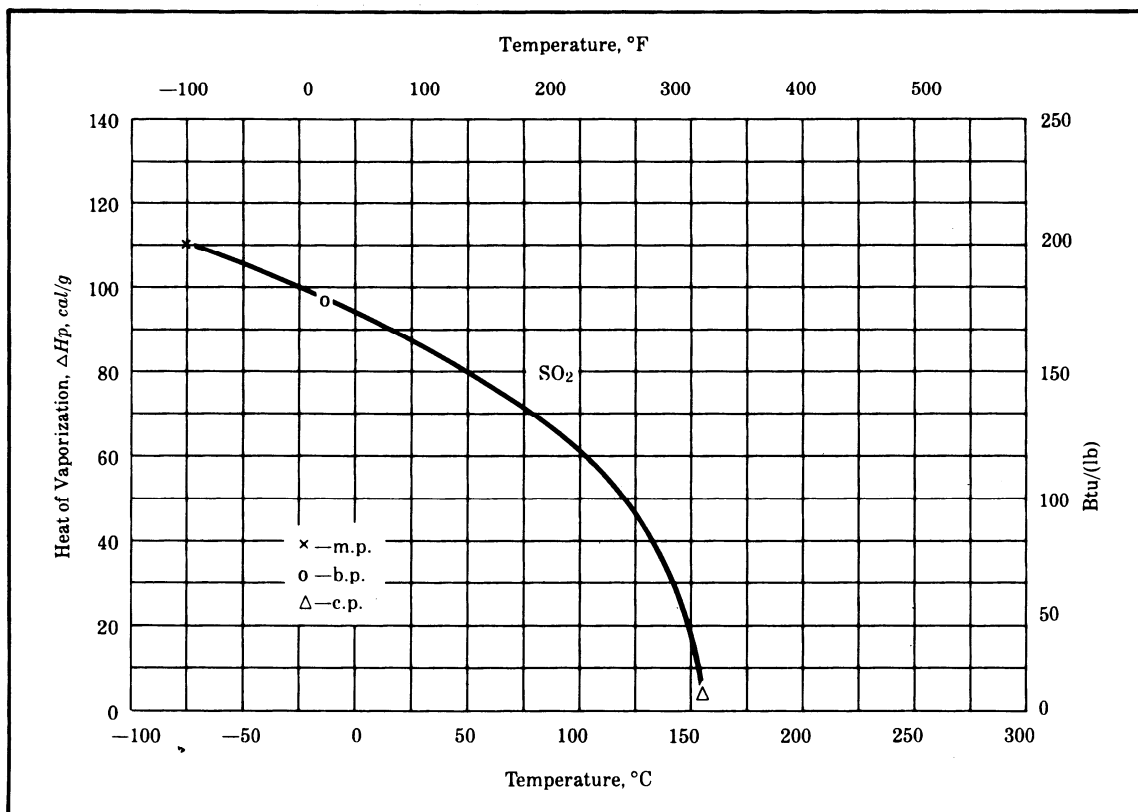


Figure 4—Heat of vaporization of sulfur dioxide

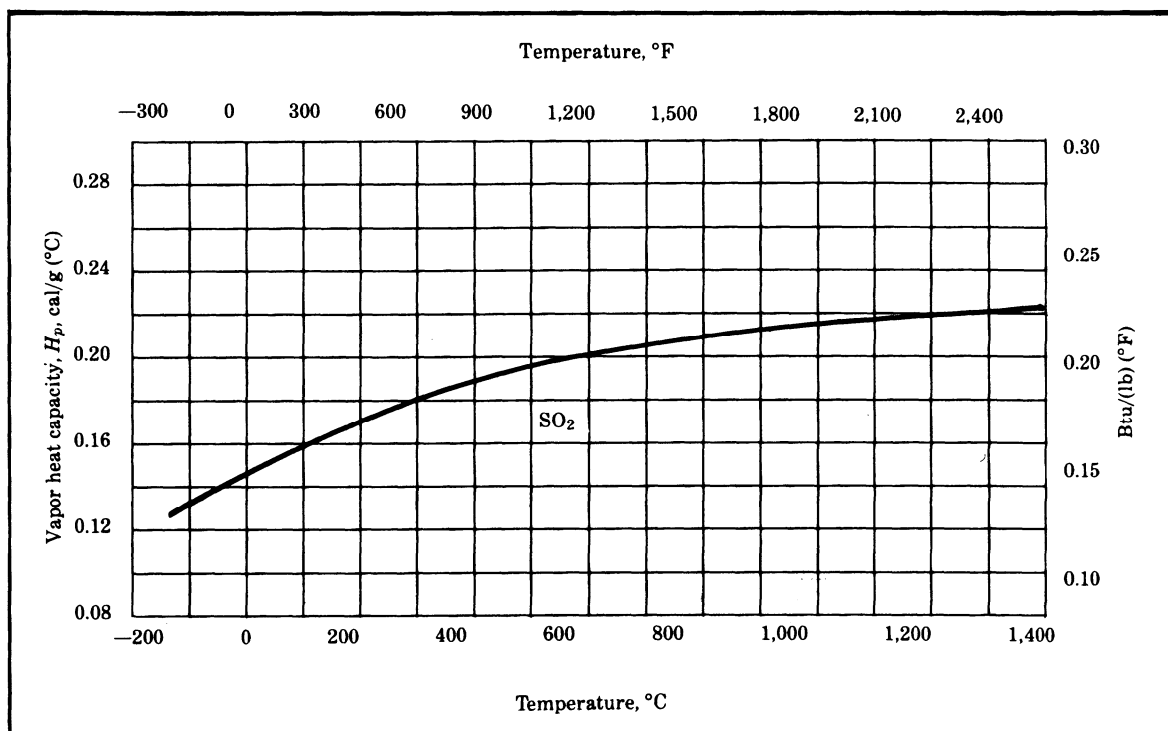


Figure 5—Heat capacity of sulfur dioxide vapor

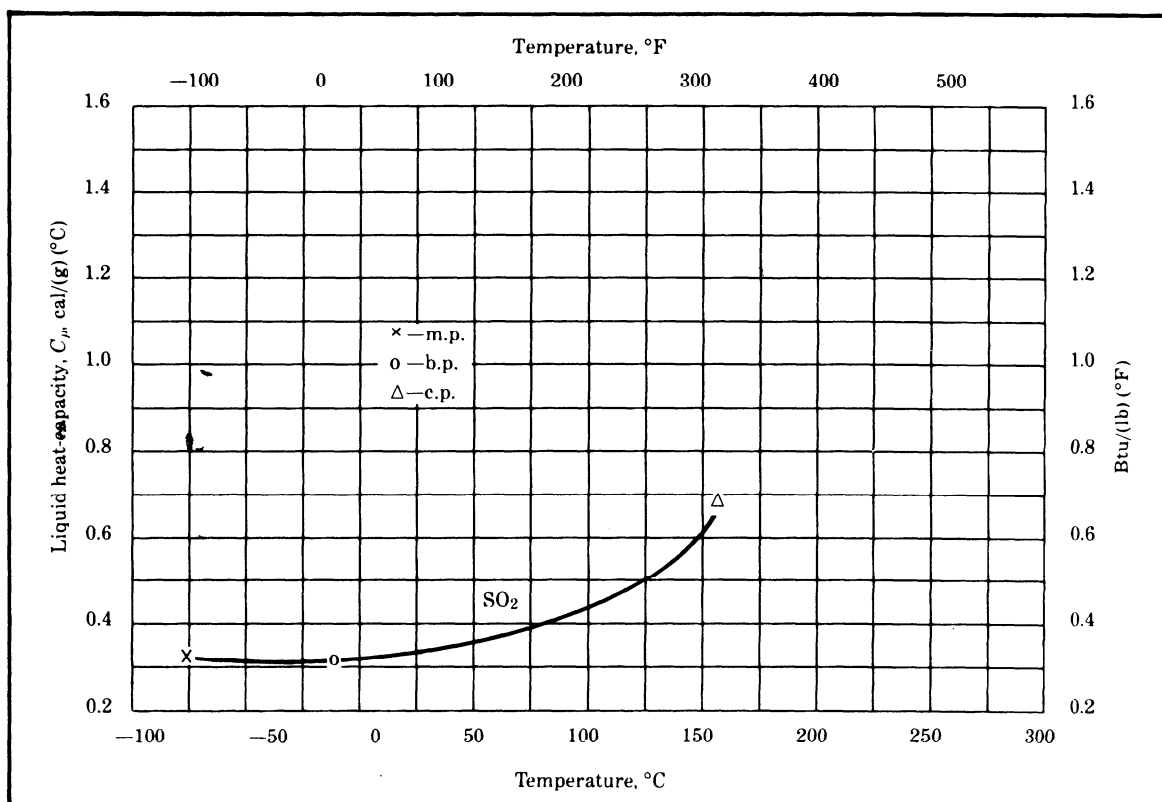


Figure 6—Heat capacity of sulfur dioxide liquid

4.2.4 Chemical properties

Sulfur dioxide is not flammable or explosive in either the gaseous or liquid state. Sulfur dioxide is a relatively stable chemical. Temperatures above 3632 °F (2000 °C) are required to bring about detectable decomposition of sulfur dioxide.

Dry sulfur dioxide is not corrosive to most ordinary metals. However, in the presence of even small amounts of water, sulfur dioxide becomes corrosive to most metals. Materials that may be considered for these corrosive conditions include lead, glass, certain plastics, and certain alloys. See Section 12 for materials of construction.

NOTE—For the purpose of this publication, a water content of 100 ppm by weight or less will be considered dry sulfur dioxide for commercial usage.

Sulfur dioxide is soluble to some extent in water, with up to 18.6% by weight dissolving at 32 °F (0 °C) to form a solution known as sulfurous acid (H_2SO_3). Since the vapor pressure of sulfur dioxide in water increases with rising temperature, the solubility of sulfur dioxide in water decreases as the temperature rises, as shown in Table 3.

Water has a slight solubility in liquid sulfur dioxide, which increases with increasing temperature. See Table 4.

Sulfur dioxide acts as an excellent reducing agent, and its applications often depend on this property. Most of the reducing reactions of interest take place in aqueous solution. It can also act as an oxidizing agent as typified by its reaction with hydrogen sulfide to form elemental sulfur.

Table 3—Solubility of sulfur dioxide in water at various temperatures and 760 mm Hg pressure

Temperature		Percent sulfur dioxide ¹⁾ by weight in solution	Pounds sulfur dioxide per U.S. gallon of solution	Kilograms sulfur dioxide per cubic meter of solution
(°C)	(°F)			
0	32	18.6	1.55	185.73
4	39.2	16.6	1.38	165.36
10	50.0	14.0	1.17	140.20
15	59.0	11.9	0.99	118.63
16	60.8	11.5	0.96	115.03
17	62.6	11.2	0.93	111.44
18	64.4	10.8	0.90	107.84
19	66.2	10.5	0.87	104.25
20	68.0	10.1	0.84	100.65
21	69.8	9.8	0.82	98.26
22	71.6	9.5	0.79	94.66
23	73.4	9.2	0.76	91.07
24	75.2	8.9	0.74	88.67
25	77.0	8.6	0.72	86.28
30	86.0	7.3	0.61	73.09
35	95.0	6.1	0.51	61.11
40	104.0	5.1	0.42	50.33
¹⁾ Schoenfeld, F., <i>Absorption Coefficients of Sulfur Dioxide, Chlorine, and Hydrogen Sulfide</i> , Justus Liebig's Annalen der Chemie, 1855, 95(1): 1-23 [7].				

Table 4—Solubility of water in liquid sulfur dioxide [8]

Temperature		Solubility (grams water per 100 grams sulfur dioxide)	Pressure (mm mercury)
(°C)	(°F)		
30	86.0	2.68	3400
22	71.6	2.29	2700
15	59.0	1.88	2100
5	41.0	1.50	1400
0	32.0	1.20	1100
−10	14.0	0.81	760
−20	−4.0	0.55	510
−30	−22.0	0.37	300
−50	−58.0	0.22	87

4.3 Commercial uses

Sulfur dioxide's chemical and physical properties result in its use in a diversity of applications. In addition to its oxidizing and reducing properties, it is an excellent solvent for many chemicals, and it acts as a preservative in numerous food applications.

The following industries make use of sulfur dioxide:

- Petroleum—To remove aromatic and high sulfur constituents from paraffins and naphthenic hydrocarbons and as a solvent in sulfonation reactions;
- Pulp and paper—As a reductant in the onsite generation of chlorine dioxide bleach; as a pulping medium in the manufacture of sulfite pulp, and in the bleaching of groundwood and thermomechanical pulps with sodium dithionite;
- Glass—To impart fracture, weathering, and abrasion resistance, to render glass containers resistant to alkaline contents, and as an antiseize agent;
- Sweeteners—Clarification and decolorization of cane and beet juices, removal of color from corn syrups, and as enzyme stabilizer and buffer in the manufacture of high fructose corn syrup. Sulfur dioxide is also used to control fermentation and facilitate softening in corn wet-milling;
- Wine production—Used in the sterilization, decolorization, and stabilization process;
- Mining—As a leachant in the form of sulfurous acid, as a reducing agent in the separation of vanadium from uranium, as a precipitant for recovering copper cyanide from leach solutions, and as a reductant in the recovery of bromine and iodine from seawater and brines;
- Water and wastewater treatment—To remove excess chlorine following chlorination treatment;
- Clay production—To generate sodium dithionite, which is used in bleaching clay;
- Electric power generation—As a raw material to condition flue gas to facilitate removal of particulate matter in coal burning units;
- Textiles—As a sour in bleaching and as an antichlor;
- Farming—As a grain fumigant; and
- Chemical—In the manufacture of dithionites, sulfolane, polysulfones, sulfites, bisulfites, sulfoxylates, thiosulfates, resins, plastics and miscellaneous sulfur-organic compounds.

Miscellaneous uses for sulfur dioxide include animal glue and gelatin manufacture, chrome leather tanning, chromium waste recovery, production of foundry sand molds, and soybean oil recovery. At one time, sulfur dioxide was widely used as a refrigerant.

5 General regulations

Municipal, county, state, and provincial/territorial regulations exist in many localities affecting the transportation, storage, and handling of sulfur dioxide. It is important that persons involved with any of these activities consult the current regulations of all regulatory agencies having jurisdiction for complete information.

5.1 United States

In the United States, the transportation of sulfur dioxide by rail, highway, air, and water is regulated by federal authority under rules promulgated by Pipeline and Hazardous Materials Safety Administration (PHMSA) of the U.S. Department of Transportation (DOT). These rules, which include specifications for the construction, marking, and qualification of shipping containers, are published in Title 49 of the U.S. *Code of Federal Regulations* (49 CFR) Parts 100 to 180 [3].

Additionally, common, contract, and private motor carriers having interstate operations shall comply with the 49 CFR Parts 390 to 397, which contain the DOT motor carrier safety regulations governing the safety of operations and equipment, and the qualification of driver employees [9].

The bulk carriage of hazardous materials by water is governed by Title 46 of the U.S. *Code of Federal Regulations* (46 CFR) Chapter 1, Subchapters D, I, N, and O [10].

Responsibility for enforcement of these rules is exercised by the various modal agencies within the DOT as follows:

- Federal Aviation Administration (FAA) with respect to the shipment of hazardous materials by aircraft;
- United States Coast Guard (USCG) with respect to the shipment of hazardous materials by vessels;
- Federal Highway Administration (FHA) with respect to shipment of hazardous materials by highway vehicles;
- Federal Railroad Administration (FRA) with respect to the shipment of hazardous materials by railroad; and
- Office of Hazardous Materials Safety (OHMS) in all other respects.

The storage and in-plant handling of sulfur dioxide in the United States is governed by federal authority and regulated by the U.S. Department of Labor (DOL) through the Occupational Safety and Health Administration (OSHA) as authorized by the *Williams-Steiger Occupational Safety and Health Act* (OSHA Act) of 1970. These regulations are published in Title 29 of the U.S. *Code of Federal Regulations* (29 CFR) Part 1910 [11].

The CFR is a codification of the general and permanent rules which were first published by the executive departments and agencies of the federal government. The Federal Register publishes revisions to the CFR, and therefore these two publications shall be used together to determine the latest version of any given rules.

5.2 Canada

In Canada, the movement of sulfur dioxide by rail, highway, air, and water is governed by Transport Canada's (TC) *Transportation of Dangerous Goods (TDG) Regulations* [4]. Pipelines are governed by the National Energy Board (NEB).

5.3 International

Publications of organizations issuing regulations governing the international transportation of sulfur dioxide are as follows:

- Water transport—*International Maritime Dangerous Goods (IMDG) Code* by the International Maritime Organization (IMO) [12]; and
- Air transport—*Technical Instructions for the Safe Transport of Dangerous Goods by Air* by the International Civil Aviation Organization (ICAO) [13].