



SURFACE VEHICLE RECOMMENDED PRACTICE

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Recommended Practice for LNG Medium and Heavy-Duty Powered Vehicles

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FOREWORD

This SAE Recommended Practice is intended as a guide for standard practice and is subject to change in order to keep pace with experience and technical advances. Its purpose is to promote safety and efficiency by making available to sellers and buyers of commercial liquefied natural gas (LNG) powered medium and heavy-duty vehicles a recommended practice for construction, operation, and maintenance of such vehicles. Vehicles shall be defined as having a gross vehicle weight (GVW) rating of greater than 6350 kg (14 001 USA pounds), and all LNG vehicles used for public transit or commercial applications. The intent of this document is to cover these classes and application of vehicles only and specifically excludes automotive passenger vehicles.

The document was initially developed by the Manufacturer's LNG Technical Subcommittee of the ATA Foundation's Alternative Fuels Task Force, which was organized in 1994 to guide the trucking and cryogenic industries in their efforts associated with the use of LNG as an Alternate Fuel for use in heavy-duty trucks. Prior to the first Subcommittee meeting, some preliminary work had been performed by the LNG Onboard Fuel System Integration Committee (LOFSIC).

The first step in the SAE Subcommittee's work was to perform a Failure Modes and Effects Analysis (FMEA), facilitated by Failure Analysis Associates. This study identified Failure Scenarios and the Failure Mechanisms, which could potentially lead to the identified Failure Scenarios. It is the intent of these Recommended Practices to avoid the failure mechanisms identified by that study where possible, and to devise and recommend means of construction, operation, and maintenance, which would warn of an impending fault or failure, and/or mitigate the outcome, should a failure occur.

Concurrent with the FMEA, the SAE Subcommittee undertook an exhaustive review of existing codes, standards, recommended practices, and regulations pertinent to trucks and LNG in force or in preparation, so that the Recommended Practice would be consonant with such, whether in force or under preparation.

This SAE publication necessarily deals to some extent in generalities, since it is not possible to anticipate and address every individual set of conditions that might be found in constructing, operating, and maintaining LNG powered vehicles. It is intended to be a practical guide illustrating the application of recommended practices. The correct application of these practices in any actual field situation must rely on sound judgment and experience.

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1. SCOPE

This SAE Recommended Practice provides guidance for the construction, operation, and maintenance of LNG powered medium, heavy-duty vehicles and all LNG vehicles used for public transit or commercial applications.

1.1 Purpose

The purpose of this document is to establish a uniform practice for construction, operation, and maintenance of LNG powered vehicles and is subject to change to keep pace with experience and technical advances. The revised Failure Modes and Effects Analysis (FMEA) which influences this document is a separate document, available in part as an informative appendix (Appendix B).

2. REFERENCES

2.1 Applicable Publications

The following publications form a part of this specification to the extent specified herein. Unless otherwise indicated, the latest issue of SAE publications shall apply.

2.1.1 API Publication

Available from American Petroleum Institute, 1220 L Street NW, Washington, DC 20005-4070, Tel: 202-682-8000, www.api.org.

API 620 Design and Construction of Large, Welded, Low-Pressure Storage Tanks

2.1.2 ASME Publications

Available from the American Society of Mechanical Engineers, 22 Law Drive, P.O. Box 2900, Fairfield, NJ 07007-2900, Tel: 973-882-1170, www.asme.org.

ASME Boiler and Pressure Vessel Code Section VIII Pressure Vessels, Division 1

ASME B31.3 Process Piping

2.1.3 Compressed Gas Association Publication

Available from Compressed Gas Association, 4221 Walney Road, 5th Floor, Chantilly VA 20151-2923, Tel: 703-788-2700, www.cganet.com.

CGA G-4.1 Cleaning Equipment for Oxygen Service G4.1

2.1.4 Pipeline and Hazardous Materials Safety Administration Publication

Available from the Superintendent of Documents, U.S. Government Printing Office, Mail Stop: SSOP, Washington, DC 20402-9320, Tel: 202-512-0000, www.gpoaccess.gov/cfr/index.html.

49 CFR 178.57 Specification 4L Welded Insulated Cylinders

2.2 Related Publications

The following publications are provided for information purposes only and are not a required part of this document.

2.2.1 SAE Publication

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (inside USA and Canada) or 724-776-4970 (outside USA), www.sae.org.

SAE J703 Fuel Systems—Trucks and Truck Tractors

2.2.2 ANSI/FCI Publication

Available from IHS Global, 15 Inverness Way East, Englewood, CO 80112, Tel: 877-413-5184, www.global.ihs.com.

ANSI/FCI 70-2 Control Valve Seat Leakage

2.2.3 California Code of Regulations

California Department of Occupational Safety and Health – Pressure Vessel Unit (DOSH Title 8): Elihu Harris State Building, 1515 Clay Street, Suite 1302, Oakland, CA 94615, Tel: 510-622-4052, <http://ccr.oal.ca.gov/>, Donald Cook Principal Safety Engineer, dcook@hq.dir.ca.gov.

CCR Title 8 (Industrial Relations), Division 1 (Department of Industrial Relations), Chapter 4 (Division of Industrial Safety), Subchapter 1 (Unfired Pressure Vessel Safety Orders), Article 7 (Compressed and Liquefied Natural Gas System)

California Highway Patrol – Enforcement Division – Commercial Vehicle Section – 444 North 3rd Street, Suite 310, Sacramento, California 95614-0228, <http://ccr.oal.ca.gov/>, Cris Morgan, Tel: 916-445-1865, cmorgan@chp.ca.gov.

CCR Title 13 (Motor Vehicles), Division 2 (Department of California Highway Patrol), Chapter 4 (Special Equipment), Article 2 (Compressed and Liquefied Gas Fuel Systems), Section 935 (Liquefied Natural Gas) and Section 936 (Installation)

2.2.4 CCPS Publication

Available from the Center for Chemical Process Safety of the American Institute of Chemical Engineers, 3 Park Avenue, New York, NY 10016-5591, Tel: 212-591-7316, www.aiche.org/ccps/.

Guidelines for Evaluating the Characteristics of Vapor Cloud Explosions, Flash Fires and BLEVEs

2.2.5 Compressed Gas Association Publications

Available from the Compressed Gas Association, 4221 Walney Road, 5th Floor, Chantilly VA 20151-2923, Tel: 703-788-2700, www.cganet.com.

CGA S-1.2 Pressure Relief Device Standards—Part 2—Cargo and Portable Tanks for Compressed Gases

CGA S-1.3 Pressure Relief Device Standards—Part 3—Stationary Storage Containers for Compressed Gases

2.2.6 Federal Motor Carrier Safety Administration Publications

Available from the Superintendent of Documents, U.S. Government Printing Office, Mail Stop: SSOP, Washington, DC 20402-9320, Tel: 202-512-0000, www.gpoaccess.gov/cfr/index.html.

49CFR 393.65 All Fuel Systems

49CFR 393.67 Liquid Fuel Tanks

2.2.7 FEMA Publication

Available from Federal Emergency Management Agency, Publications Office, P.O. Box 2012, Jessup, MD 20794, Tel: 800-480-2520, www.fema.gov.

Handbook of Chemical Hazard Analysis Procedures

2.2.8 NFPA Publication

Available from the National Fire Protection Agency, 1 Batterymarch Park, Quincy, MA 02169-7471, Tel: 617-770-3000, www.nfpa.org.

NFPA 52 2006 Vehicular Fuel Systems Code 2006 (new document includes old NFPA 57 and 52) NFPA 70—National Electrical Code

2.2.9 Texas Administrative Code Publication

Available from Railroad Commission of Texas, Capitol Station, P.O. Box 12967, Austin, TX 78711-2967, Tel: 512-463-7110, [http://info.sos.state.tx.us/pls/pub/readtac\\$ext.ViewTAC](http://info.sos.state.tx.us/pls/pub/readtac$ext.ViewTAC).

Title 16 (Economic Regulation), Part 1 (Railroad Commission of Texas), Chapter 13 (Regulations for Compressed Natural Gas [CNG] and Liquefied Natural Gas [LNG])

3. DEFINITIONS

The following definitions were derived in assembling this document.

3.1 Family of Tanks – Containers

A group of tanks related by the following common characteristics or properties: same manufacturer, same insulation system and materials, same inner support system, identical design, mounted in the same manner, with piping components in the same or similar orientation, constructed with the same material types of the same strength and a volume not greater than 100% of the test tank provided that the inner and outer vessels are of the same thickness as the test tank.

3.2 LOX

Liquefied oxygen.

3.3 LNG

Liquefied natural gas.

3.4 Maximum Allowable Working Pressure (MAWP)

The highest pressure which can occur within a system prior to operation of the protecting relief valve.

3.5 Pressure Regulator

Any device used to reduce pressure (independent of flow) exclusive of engine control regulators.

3.6 Ullage – Ullage Space

Ullage is another word for vapor space. Vapor space between the liquid cryogen and top of the tank.

4. LNG ONBOARD FUEL SYSTEM DESIGN

NOTE: Refueling Site Construction.

Refueling Sites: The performance of the LNG onboard fuel system depends on the refueling station's engineering design and the equipment's ability to perform to the requirements of the onboard fuel system. Fuel flow, pressure, saturation, overfilling, under filling, hold times and safety shall be part of the coordinated functions of the LNG refueling station and onboard fuel system.

4.1 General Design Criteria

All materials used in fuel system devices, components, materials, devices or systems to protect the components from under hood temperatures which could be exposed to LNG or cold LNG vapors (during operating conditions) from the onboard fill receptacle forward to the engine interface shall be rated for a service temperature range of $-162\text{ }^{\circ}\text{C}$ ($-260\text{ }^{\circ}\text{F}$) to $+121\text{ }^{\circ}\text{C}$ ($+250\text{ }^{\circ}\text{F}$). All fuel system components underneath the hood or where they would be exposed to higher temperatures must be rated for at least $+121\text{ }^{\circ}\text{C}$ ($250\text{ }^{\circ}\text{F}$), or higher.

All metallic material shall be listed per ASME B31.3, *Process Piping*, and ASME *Boiler and Pressure Vessel Code*, or API 620, *Design and Construction of Large, Welded, Low-Pressure Storage Tanks*, Appendix Q. These materials shall not be used below the minimum design temperature established in these referenced standards.

All materials shall be selected or installed to minimize corrosion or to protect the material from corrosion. Stainless steels that do not resist chloride-induced pitting/corrosion cracking and sensitization-induced corrosion resistance reduction shall not be used. The use of all copper-zinc and copper-tin alloy families shall be restricted to those alloys that are metallurgically inhibited to prevent accelerated metallurgical deterioration from external environmental sources. The use of dissimilar metal junctions shall be minimized. Junctions shall provide good corrosion protection to reduce corrosion effects of such a materials combination on long-term corrosion.

All components of the fuel system shall be installed, supported, protected, and secured in order to minimize the possibility of damage, corrosion, or breakage due to expansion, contraction, vibration, strains, or wear and to preclude any loosening while in transit.

Piping or tubing passing through a panel or structural member shall be protected by devices that shall snugly fit the piping or tubing and the hole in order to prevent abrasion.

4.1.1 Device Mounting

All fuel system devices shall be installed so that their weight is not placed on, or supported by, the attached lines unless so designed by the system manufacturer.

4.1.2 Fuel System Cleanliness After Any Assembly or Repair

After assembly of the fuel system, the components between the tank and the engine shall be free of dust and debris before the system is put into service.

4.1.3 Pressure Tests

After the system has been completely assembled, it shall be tested for leaks while pressurized to the maximum operating pressure with nitrogen.

4.1.4 Pressure Relief Devices

Containers shall be equipped with pressure relief devices or pressure control devices required by DOT 4L as referenced in 49 CFR or ASME under which the containers were designed, fabricated and tested. The pressure relief device must be installed and located so that the cooling effect of the contents during venting will not prevent effective operation of the device. Primary and secondary relief device outlets shall be provided with a protective device to prevent the entrance and accumulation of dirt, debris, snow, ice, and/or water and must be designed to prevent the development of any dangerous excess pressure.

Automatic pressure regulating equipment shall be installed on fuel delivery systems that have operating pressures that exceed the engine operating pressure requirements between the vehicular fuel container and the engine to regulate the maximum allowable pressure of the fuel delivered to the engine.

Use of an equal method, design or choice of materials must be validated by engineering data. This data shall be available and considered within the Public Domain.

4.1.5 Design Ullage Space

The tank shall retain an appropriate ullage space according to vessel manufacturer's guidance during refueling such that the vessel shall not become overfilled when filled according to the manufacturer's recommendations. Ullage space sizing considerations shall address the thermodynamic properties of the system, beginning and end points of fuel conditions, stratification, tank thermal design, insulation, hold time and other factors.

Adequate vapor space (ullage) shall be maintained to ensure vapor space communication of devices (pressure relief's, vent, etc.) and allowance for liquid expansion, when the tank content is allowed to warm from it's initial 100% net full volume to the ending state defined by the primary pressure relief device, and when the initial fill condition is at the lowest point in the design filling temperature/pressure range. In no case shall the ullage be less than 10% of the gross water volume.

Tank System design that shall incorporate an ullage space or system capable of insuring adequate vapor space when filled properly to it's design "full" state, such that sufficient vapor space is provided to accommodate liquid expansion and maintaining the path to vapor communication for devices such as the vapor line, pressure relief devices or any components designed to operate in the vapor state and to provide specified "hold time". Note reference Appendix C for vapor space calculations and ullage space as a function of saturated pressure, temperature, relief valves, etc.

4.2 LNG Fuel Tanks

The inner and outer shells of fuel tanks shall be constructed of austenitic stainless steel, or equivalent. Tanks shall be equipped with a thermal insulation system that limits conduction, convection, and radiation. Insulation systems that use vacuum insulation may require maintenance as defined by the manufacturer. Insulation system design life shall be defined by the manufacturer. Insulation system shall be designed such that LNG product loss at static pressure shall be less than 1% per day at 34.5 KPa (5.0 psi)

Tanks shall be factory cleaned per CGA G-4.1 (1996), and in lieu of customer specification shall follow the numerical and written criteria of CGA 4.1

Vehicle LNG Tanks shall have a design hold time (build pressure without relieving) of 5 days after being filled net full and at the highest point in the design filling temperature/pressure range.

4.2.1 Design

Each tank shall be designed, fabricated, and tested in accordance with DOT 4L (Ref 49 CFR) or ASME Boiler Pressure Vessel Code requirements. The outer shell shall be provided with an overpressure safety device to vent the annular insulation space if pressure becomes excessive. Testing shall be performed at standard room temperature of not less than 18.3 °C (65 °F).

4.2.1.1 Container Gauges

All Containers shall be equipped with pressure gauges that are connected to the container at a point above the maximum liquid level.

4.2.1.2 Container Design/Markings

Containers shall be designed, fabricated, tested in accordance with the Regulations of the U.S. Department of Transportation (DOT) Specification 4L, or the "Rules for the Construction of Unfired Pressure Vessels," or ASME *Boiler and Pressure Vessel Code*, applicable at the date of manufacture. DOT 4L marking does not imply that the vessel is "certified" to DOT 4L, and these tanks cannot be used for the transport and sale of LNG or other fluids. Quality control systems at manufacturing sites must be approved by DOT and/or ASME. Tanks other than ASME shall be marked or stamped "SAE J2343".

4.2.1.3 Container Mounting

No part of the container or its appurtenances shall protrude beyond the sides or top of any vehicle where the container can be struck or punctured. Non-roof-mounted containers shall not be mounted ahead of the front axle or beyond the rear bumper on motor vehicles. Fuel containers shall not be mounted above any driver or passenger compartment, unless a spill pan is installed between the fuel containers and the compartment, with a liquid capacity equal to at least the capacity of the largest single fuel container of a multiple container installation consisting of three or more fuel containers, but not less than one-quarter the fuel capacity of the containers located above the compartment and capable of preventing liquid from entering the interior or dripping into any window, door or emergency exit way. Spill pans shall be designed in such a manner that rain water is not retained. The spill pan drain shall not be directed into any confined space, the engine compartment, muffler area, battery box or other hazardous location.

4.2.1.4 The lowest part of any container, or fuel system component, including protective guards, shall not be lower than the lowest edge of the vehicle differential housing under maximum suspension deflection. In no event shall the container or any fuel system component have less clearance from the surface of a level roadway than the clearance between the roadway and the lowermost portion of any rim of any wheel in contact with the roadway.

4.2.1.5 Container Mounting/Exhaust

Tanks mounted within 20 cm (8.0 in) of exhaust or other heat sources shall be shielded from radiant heating.

4.2.1.6 Container Roof Mounting

Where a container is installed above the operator or passenger compartment of a vehicle the requirements of the following shall apply:

- a. The container and its piping, fittings, and devices shall be protected from damage by the following:
 1. A guard rail or similar device that is designed to absorb the impact of a collision with a stationary object when the vehicle is moving either forward or backward at 8 km/hr (5 mph). The guard rail or similar device shall be free of projections that could damage the container or its devices and fittings.