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WALL STRESS REQUALIFICATION CRITERIA FOR HIGH PRESSURE SEAMLESS STEEL CYLINDERS

EIGHTH EDITION

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NOTE—Technical changes from the previous edition are underlined.

NOTE—Appendix A (Informative) is for information only.

NOTE—Appendices B and C (Normative) are requirements.

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1 Introduction

Compressed gas cylinders manufactured in accordance with U.S. Department of Transportation (DOT) or Transport Canada (TC) specifications can remain safe unless damaged by corrosion, accident, or abuse.¹ A cylinder shall be accepted or rejected for special filling limits on the basis of the criteria set forth in this publication. Other methods for qualification may be used such as the satisfactory completion of an ultrasonic examination or acoustic emission test, conducted in accordance with a current DOT special permit or TC equivalency certificate.

2 Scope

This publication contains detailed methods of determining average wall thickness that can be applied to the requalification of seamless, high pressure cylinders conforming to Specifications ICC-3, ICC/DOT-3A, DOT-3AX, DOT-3AA, DOT-3AAX, and DOT-3T as well as the equivalent Canadian specifications. The water jacket hydrostatic test shall be performed in accordance with CGA C-1, *Methods for Pressure Testing Compressed Gas Cylinders and Tubes* [1].² The visual inspection shall be performed in accordance with CGA C-6, *Standard for Visual Inspection of Steel Compressed Gas Cylinders* [2].

The flow chart contained in Appendix A graphically illustrates the service life control procedures described in this publication. The procedures required to qualify cylinders for special filling limits in accordance with DOT and TC regulations are provided in Appendices B and C, respectively.

The suggestions contained in this publication do not apply to cylinders manufactured under specification DOT-3HT, CTC-3HT, or TC-3HTM. Because of the special provisions of this specification, separate recommendations covering service life and standards for visual inspection of these cylinders are contained in CGA C-8, *Standard for Requalification of DOT-3HT, CTC-3HT, and TC-3HTM Seamless Steel Cylinders* [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.

3.2 Technical definitions

3.2.1 Requalification

Test(s) required to be performed on a cylinder to determine its suitability for continued service.

¹ In 1967, DOT was established and, among other things, assumed responsibility for the safety regulations formerly administered by the Interstate Commerce Commission (ICC) over explosives and other dangerous articles. These are now known as the Hazardous Materials Regulations of DOT and specifications for cylinders are included in these regulations. Wherever reference is made to DOT cylinders, it is equally applicable to similar cylinders marked ICC and the same cylinders made to Canadian regulations, which may be marked TC, CTC (Canadian Transport Commission), BTC (Board of Transport Commissioners for Canada), or CRC (Canadian Railway Commission).

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

4 Basic considerations

A cylinder's service life is controlled by hydrostatic test in a water jacket or other approved apparatus (Title 49 of the U.S. *Code of Federal Regulations* [49 CFR] Part 180.205(g) and CSA B339, *Cylinders, spheres, and tubes for the transportation of dangerous goods*, clause 24.2), through limiting the permanent expansion to 10% of total expansion (49 CFR 180.205(i)1(iv) and CSA B339, clause 24.2.1.3) [4, 5].

Cylinders meeting the wall stress and elastic expansion requirements set forth in this publication and used in certain dry gas service may be requalified every 10 years instead of every 5 years (49 CFR 180.209(b) or CSA B339, clause 24.2) [4, 5].

DOT regulations also permit the qualification of cylinders for charging to 10% in excess of their marked service pressure by the use of the water jacket method for limiting the cylinder wall stress through the maximum elastic expansion limit (49 CFR 173.302a(b)) [4]. See Appendix B.

TC regulations also limit the cylinder wall stress through a maximum elastic expansion limit to qualify cylinders for charging to their marked service pressure as determined by the water jacket or direct expansion method. See Appendix C.

The direct method of applying wall stress limitations is to measure the wall thickness with any suitable method such as mechanical gauges or electronic, ultrasonic, or radiographic thickness measuring instruments. However, the most practical method is the use of elastic expansion obtained by the water jacket hydrostatic test. This is done by establishing a maximum allowable elastic expansion and rejecting cylinders that show elastic expansions at a test pressure that exceeds the computed rejection limit.

Experiments have proven the direct relationship between the elastic expansion of the cylinder and the average wall stress as expressed in the Clavarino formula. The average wall thickness has also been proven to be directly related to the average wall stress as expressed in the Bach formula. These values are interrelated by a proportionality constant, which is commonly referred to as the K factor.

The K factor is a constant indicating the flexibility of the cylinder ends, which varies with cylinder design. Since the K factor is constant, it is very important to segregate cylinders of different design and use the appropriate K factor.

Certain cylinders are of such design and method of fabrication that it is unlikely that a K factor and the elastic expansion measurement would be used to requalify them for charging to 10% in excess of their marked service pressure. These cylinders have a sidewall thickness at the time of manufacture that corresponds to an average wall stress above the upper limits set forth in 49 CFR 173.302a(b) (i.e., for DOT-3AA cylinders designed to 70 000 psi wall stress exceeding the 67 000 psi average wall stress limit) [4]. They are qualified under the maximum wall stress limits, since the minimum wall thickness has been established through measurement by the cylinder manufacturer. To determine whether cylinders of this type remain qualified for charging to 10% in excess of their marked service pressure at time of requalification, measurement of minimum wall thickness as described in this section is required. Cylinders manufactured from sheet or plate, rather than from a billet or tubing, are most likely to fall in this category. When there is doubt, the cylinder manufacturer should be contacted. The minimum wall thickness allowed can be calculated from the following formula:

$$t = \frac{D}{2} \left[1 - \sqrt{\frac{S - 1.3P}{S + 0.4P}} \right]$$

Where:

S = Maximum wall stress limitation (49 CFR 173.302a(b)) [4]

P = 5/3 times marked service pressure

D = Outside diameter

t = Minimum wall thickness allowed

5 Rejection elastic expansion values

Rejection elastic expansion (REE) values may be used from the following sources:

- REE stamped at the time of manufacture. Normally, this value is calculated by the manufacturer during the design of the cylinder;
- REE obtained from the manufacturer. This value is calculated by the manufacturer, but not stamped on the cylinder;
- REE found in Table 1 for the cylinder size and design to be evaluated; and
- REE determined by experimental testing and measurement of typical sample cylinder representative of a manufacturer's design. Average wall stress shall be used. See Sections 6 and 7.

6 Sources of K factors

If a K factor is required, it shall be obtained from one of the following three sources:

- Select the K factor from Table 1. Various cylinder designs are described by the data in the table;
- Contact the cylinder manufacturer for the K factor, if the cylinder design is not contained in Table 1; or
- Calculate the K factor if it cannot be obtained from either of the two previously listed sources. The following procedure may be used:

a) Select at least three cylinders typical of the design

b) Determine the following properties of each cylinder:

D = Outside diameter in inches (in)

t = Wall thickness in inches (in)

V = Internal volume in cubic centimeters (cc)

EE = Elastic expansion in cubic centimeters (cc)

P = Test pressure in pounds per square inch (psi)

Suggested methods to determine the previously listed properties:

D – Using pi-tape, measure the diameter in six or more locations on the cylinder. The average of those readings is the cylinder's outside diameter.

t – Two convenient methods are:

(1) By ultrasonic thickness measuring device. Take readings over the entire sidewall at locations equidistance apart on approximately 3 in centers. The average of those readings is the wall thickness; or

(2) By weight of steel. Cut the ends off the cylinder approximately 6 in from the point of curvature. Weigh the shell and calculate t by the following formula:

$$t = \frac{D}{2} - \sqrt{\frac{D^2}{4} - \frac{W}{.890 \times L}}$$

Where:

D = Outside diameter in inches (in)

W = Weight in pounds (lb)

L = Length in inches (in)

V – Weigh cylinder empty and full of water three or more times. Determine contents in weight of water for each test. The average of those tests in pounds multiplied by the specific volume of water is the internal volume. The specific volume shall be for the actual water temperature (454.06 cc/lb at 60 °F).