AVOIDANCE OF FAILURE OF STEEL CYLINDERS CONTAINING CO AND CO/CO_2 MIXTURES

Doc 95/21

Revision of Doc 95/12

EUROPEAN INDUSTRIAL GASES ASSOCIATION AISBL

AVENUE DE L'ASTRONOMIE 30 • B – 1210 BRUSSELS
Tel: +32 2 217 70 98
E-mail : info@eiga.eu • Internet : http://www.eiga.eu

AVOIDANCE OF FAILURE OF STEEL CYLINDERS CONTAINING CO AND CO/CO_2 MIXTURES

Prepared by WG-2 Gas Cylinders and Pressure Vessels

As part of a programme of harmonisation of industry standards, the European Industrial Gases Association (EIGA) has published EIGA Doc 95, Avoidance of Failure of Steel Cylinders Containing CO and CO/CO2 Mixtures. This publication was jointly produced by members of the International Harmonisation Council.

This publication is intended as an international harmonised publication for the worldwide use and application by all members of the International Harmonisation Council whose members include the Asia Industrial Gases Association (AIGA), Compressed Gas Association (CGA), European Industrial Gases Association (EIGA), and Japan Industrial and Medical Gases Association (JIMGA). Regional editions have the same technical content as the EIGA edition, however, there are editorial changes primarily in formatting, units used and spelling. Regional regulatory requirements are those that apply to Europe.

EUROPEAN INDUSTRIAL GASES ASSOCIATION AISBL
Avenue de l'Astronomie 30 B 1210 Brussels Tel +32 2 217 70 98
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Amendments to 95/12

Section	Change
	Editorial to align style with IHC associations
Title	Changed publication title to “Avoidance of Failure of Steel Cylinders Containing CO and CO/CO2 Mixtures”
2	Clarified the scope of the publication
3	Addition of definitions section
4.4	Changed title to “Pressure limitations in other steel cylinders” and added note regarding US and Canadian regulations Erratum of March 2021 concerning the equivalent temperature in Fahrenheit: in subparagraphs (a) and (b), is the maximum settled pressure ([2]) at 15 °C (59°F)
4.5	Changed title to “Moisture limitations”

Note: Technical changes from the previous edition are underlined

[2] The maximum pressure in the cylinder at a uniform temperature of 15°C (70 °F) after filling.

1 Introduction

This publication was originally published in 1993 after a number of incidents where steel cylinders violently ruptured.

Incidents have occurred in the past with carbon monoxide and carbon monoxide/carbon dioxide mixtures cylinders. These incidents led to either leak or rupture of the cylinders. During 1990 two incidents leading to violent ruptures were reported in Asia and North America, and a similar one in South Africa in 1991.

Following reports of earlier incidents, investigations were performed, and results from some of them were published in the 1976-1979 period [1, 2, 3]. [1]

These investigations concluded that:

- Low alloy carbon steels are sensitive to cracking in a carbon dioxide-carbon monoxide-water environment (stainless steels and aluminium alloys are not sensitive to this cracking phenomenon);

- It is believed that the three components carbon dioxide, carbon monoxide, and free water are needed at the same time to lead to this cracking phenomenon, i.e., cylinders that have contained sufficient moisture to have raised the dew point of the gas above the operational temperature. See also ISO 11114-1, *Gas Cylinders - Compatibility Of Cylinder And Valve Materials With Gas Contents - Part 1: Metallic Materials* [4];

NOTE - A content of at least 13% of chromium is necessary to make the steel immune to this stress corrosion cracking (SCC) phenomenon [1, 2, 3].

- Cracking occurs over a wide range of carbon dioxide/carbon monoxide ratios and down to very low partial pressures;

- Cracking has been observed down to applied loads of 25% to 30% of the yield stress;

- Probability for cracking decreases as temperature increases; and

- The mechanism is understood to be local dissolution of iron due to the carbonic acid formed between water and carbon dioxide, with general corrosion being inhibited by carbon monoxide. This phenomenon leads normally to transgranular cracks with branching. See Fig. 1 typical example. This phenomenon has nothing to do with hydrogen embrittlement, which normally leads to intergranular cracks. Therefore, the recommendations of EIGA Doc 100, *Hydrogen Cylinders and Transport Vessels*, do not apply [5].

Since the first publication of this document in 1993 new incidents, with steel cylinders filled at high pressure have occurred. These incidents and recent experience confirm that a very low moisture level shall be ensured.

NOTE—By ensuring a low moisture level, the conversion of carbon monoxide to carbon dioxide can be minimized.

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

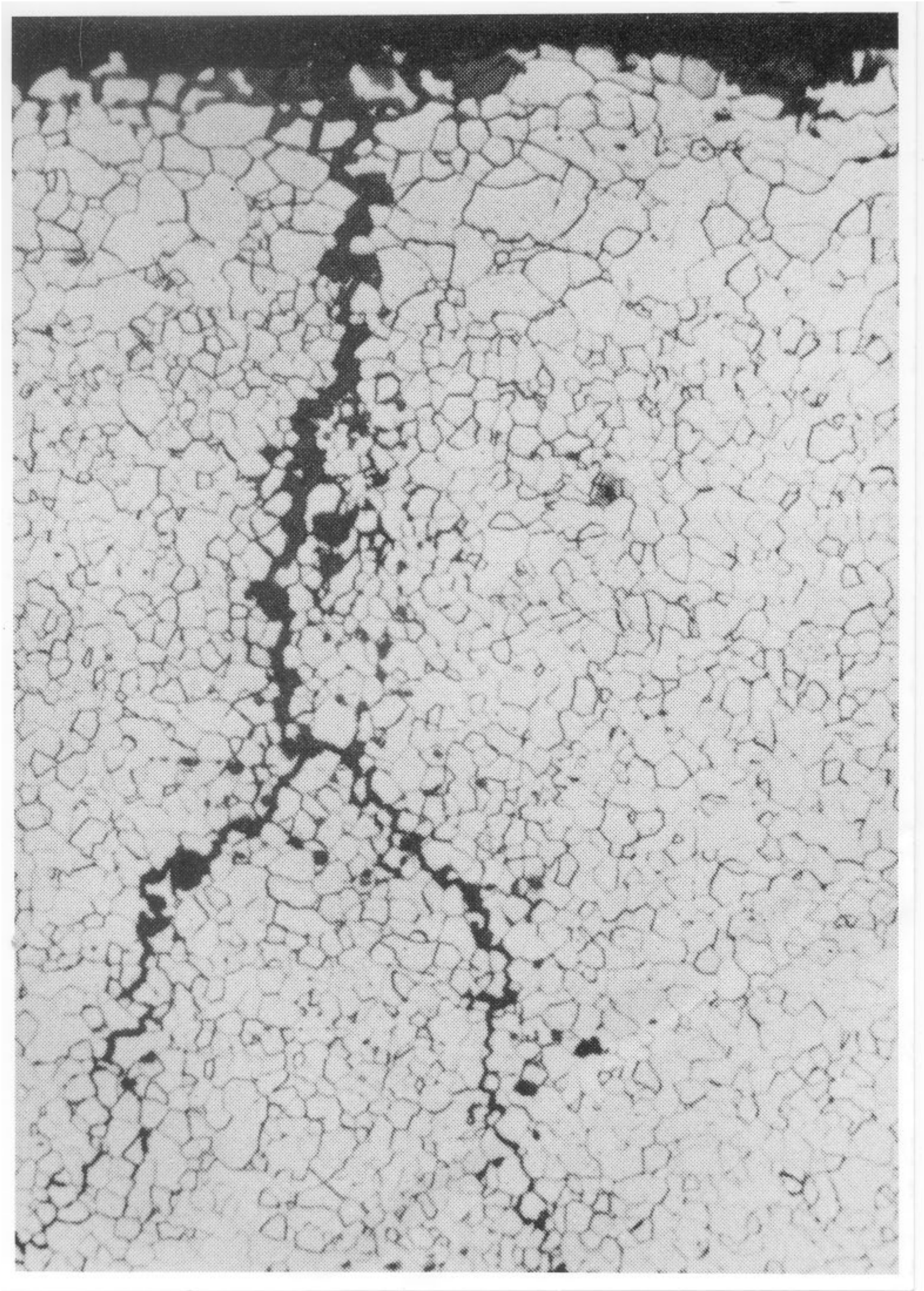

Figure 1—Branching crack-tip in a tempered martensitic structure

2 Scope

This publication covers the selection of gas cylinders including seamless, welded, and non-refillable cylinders, used for carbon monoxide and for carbon monoxide/carbon dioxide mixtures, e.g., laser gases. For purposes of this publication, cylinder(s) also means tubes unless otherwise stated. Intentionally made mixtures containing less than 5 ppmV carbon monoxide or 5 ppmV carbon dioxide are not affected by this publication.

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 Low alloy carbon steels

Steels with additions of up to a few percent of alloying elements such as chromium, molybdenum, nickel, manganese, etc., e.g., 1% chromium, 0.3% molybdenum.

4 Recommendations

4.1 Aluminium alloy cylinders

Aluminium alloy cylinders may be used for carbon monoxide and are strongly recommended for carbon monoxide/carbon dioxide mixtures. They may be filled to the maximum working pressure of the cylinder according to the relevant specification.

4.2 Stainless steel cylinders

Stainless steel cylinders may be used for carbon monoxide and carbon monoxide/carbon dioxide mixtures. They may be filled at the maximum working pressure.

4.3 High-strength steel cylinders

High-strength steel cylinders, such as ISO 9809-2, shall not be used, as they have an actual tensile strength of the materials (Rm) greater than or equal to 1100 MPa.

4.4 Pressure limitations in other steel cylinders

Wherever possible, moisture should be controlled, but when the absence of moisture cannot be guaranteed (as per 4.5), the following requirements for steel cylinders (except high strength steel cylinders, see 4.3 shall be observed.

a) The maximum settled pressure [2] at 15 °C (59 °F) ≤ 100 bar (1450 psi);

b) $\dfrac{\text{The maximum working pressure of the cylinder}}{\text{Maximum settled pressure}^{(2)}\text{ at 15 °C (59 °F)}} \geq 1.5$; and

c) A quality system shall be established to make sure that the above “limited” pressure is not exceeded.

Note—In the United States, for certain steel cylinders, the maximum settled pressure[2] is 1000 psi at 70 °F [6]. In Canada, the pressure in certain containers is limited to 6.9 MPa (69 bar) at 15°C.See CSA B340, Clause 5.2.5 [7].

4.5 Moisture limitations

For steel cylinders (except high-strength steel, see 4.3 where pressure is not limited (see 4.4), the water vapour content of the final product in each cylinder shall not exceed:

- a value of 5 ppmV for a maximum working pressure of 200 bar (2900 psi)
- a value of 7 ppmV for a maximum working pressure of 150 bar (2180 psi)

For cylinders with a maximum working pressure greater than 200 bar (2900 psi) a value lower than 5 ppmV shall apply.

However, experience has shown that it is difficult in practice to guarantee on every cylinder such a dryness level. Consequently, this solution shall only be used provided that appropriate procedures guaranteeing the moisture level are in place at the first use, after retest and at each filling of the cylinders.

NOTE—U.S. DOT regulations require that carbon monoxide and carbon monoxide/carbon dioxide mixtures in steel cylinders shall be dry and sulfur free. See Title 49 of the U.S. *Code of Federal Regulations* 173.302a(c) [6]. .

NOTE—For pure carbon monoxide some EIGA companies have good experience over the past 30 years using normalized steel cylinders with a maximum yield strength, Re less than 390 MPa (56.6 ksi) and a maximum working pressure not exceeding 150 bar (2180 psi) when limiting the moisture content to a maximum of 20 ppmV.

5 Inspection recommendations

When changing carbon monoxide or carbon monoxide/carbon dioxide mixture cylinders to another service, specific precautions shall be taken. For more information and recommendations for change of service, see CGA C-10, *Guideline to Prepare Cylinders and Tubes for Gas Service and Changes in Gas Service* or ISO 11621, *Gas Cylinders -- Procedures For Change Of Gas Service* [8, 9]. Steel cylinders suspected to have been exposed to a carbon monoxide-carbon dioxide–water environment in conditions not meeting the previous recommendations shall be emptied before refilling and subjected to an appropriate non-destructive examination (NDE), such as ultrasonic examination as specified in ISO 18119, *Gas Cylinders - Seamless Steel And Seamless Aluminium-Alloy Gas Cylinders And Tubes - Periodic Inspection And Testing* for crack detection [10]. Some EIGA member companies report success in detecting defects in such cylinders as carbon monoxide/carbon dioxide service using acoustic emission testing. These techniques require fully trained and experienced personnel to perform

[2] The maximum pressure in the cylinder at a uniform temperature of 15°C (70 °F) after filling.

such testing. In case of any doubt, it is recommended to perform a hydraulic test at cylinder test pressure, see ISO 18119 [10].

6 References

Unless otherwise specified, the latest edition shall apply.

[1] Kowaka and Nagata, Stress Corrosion Cracking of Mild and Low Alloy Steels in CO-CO_2 – H_2O Environments, CORROSION, Vol. 32, No. 10, 1976

[2] Brown, Harrison and Wilkins, Electrochemical investigation of stress corrosion cracking of plain carbon steel in the CO_2 –H_2O system
NACE publn., SCC and hydrogen embrittlement of iron base alloys, 1977

[3] Berry and Payer, Internal SCC by aqueous solutions of CO and CO_2 , American Gas Journal, 1979

[4] ISO 11114-1*, Gas Cylinders - Compatibility Of Cylinder And Valve Materials With Gas Contents - Part 1: Metallic Materials,* International Organization for Standardization. www.iso.org

[5] EIGA Doc 100*, Hydrogen Cylinders and Transport Vessels*, European Industrial Gases Association. www.eiga.eu

[6] *Code of Federal Regulations*, Title 49 (Transportation), U.S. Government Printing Office. www.gpo.gov

[7] CSA B340, *Selection and use of cylinders, spheres, tubes, and other containers for the transportation of dangerous goods, Class 2*, CSA Group. www.csagroup.org

[8] CGA C-10, *Guideline to Prepare Cylinders and Tubes for Gas Service and Changes in Gas Service*, Compressed Gas Association, Inc. www.cganet.com

[9] ISO 11621, *Gas Cylinders -- Procedures For Change Of Gas Service*, International Organization for Standardization. www.iso.org

[10] ISO 18119, *Gas Cylinders - Seamless Steel And Seamless Aluminium-Alloy Gas Cylinders And Tubes - Periodic Inspection And Testing* , International Organization for Standardization. www.iso.org