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CYLINDER SERVICE LIFE SEAMLESS STEEL HIGH PRESSURE CYLINDERS

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1 Introduction

1.1

Compressed gas cylinders manufactured in accordance with U.S. Department of Transportation (DOT) or Transport Canada (TC). [1] Specifications should remain safe unless damaged by corrosion, accident, or abuse. A cylinder shall be accepted or rejected for service on the basis of the expansion data obtained by hydrostatic test, and visual inspection.

1.2

This pamphlet contains detailed methods of determining average wall thickness that can be applied to the retesting of seamless, high pressure cylinders conforming to Specifications ICC 3, ICC/DOT 3A, 3AX, 3AA, 3AAX and DOT 3T. The water jacket hydrostatic test shall be made in accordance with Compressed Gas Association publication C-1, *Methods for Hydrostatic Testing of Compressed Gas Cylinders* [1]. [2] The visual inspection shall be made in accordance with CGA publication C-6, *Standards For Visual Inspection of Steel Compressed Gas Cylinders* [2].

1.3

This publication provides the procedures required qualifying cylinders for filling to 10% in excess of their marked service pressure in accordance with 49 CFR 173.302(c) of the DOT Regulations (see Appendix B) [3]. A cylinder is no longer qualified for filling to 10% in excess of its marked service pressure when the wall stress limitations contained in 49 CFR 173.302(c) are exceeded [3].

1.4

The flow chart contained in Appendix A graphically illustrates the service life control procedures described in this pamphlet.

1.5

The suggestions contained in this pamphlet do not apply to cylinders manufactured under specification DOT (ICC) 3HT. 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 publication C-8, *Standard for Requalification of DOT (ICC) 3HT Cylinders* [4].

2 Basic considerations

2.1

Service life control by hydrostatic test in a water jacket or other approved apparatus is a requirement of DOT Regulations, 49 CFR 173.34(e)(1)(3), through limiting the permanent expansion to 10% of total expansion [3]. The Regulations also permit using the water jacket method only for limiting the cylinder wall stress and wall thickness through maximum elastic expansion limit to qualify cylinders for charging to 10% in excess of their marked service pressure (49 CFR 173.302(c)-See Appendix B) [3]. Cylinders meeting these wall stress and elastic expansion requirements and also used in certain dry gas service can be retested every ten years instead of every five years. Reference 49 CFR 173.34(e)(15) [3].

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[1] In 1967 the Department of Transportation was established and among other things assumed responsibility for the safety regulations formerly administered by the Interstate Commerce Commission 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," "BTC" (Board of Transport Commissioners for Canada) or "CRC" (Canadian Railway Commission).

[2] References in this document are shown by bracketed numbers and are listed in their order of appearance.

2.2

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

2.3

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.

2.4

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.

2.5

Certain cylinders are of such design and method of fabrication that the use of a "K" factor and the elastic expansion measurement in order to requalify for charging to 10% in excess of their marked service pressure is unlikely. These cylinders had sidewall thickness at time of manufacture which corresponds to average wall stress above the upper limits set forth in 49 CFR 173.302(c) (i.e., for DOT 3AA-cylinders designed to 70 000 psi wall stress exceeding the 67 000 psi average wall stress limit) [3]. They were 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 retest, measurement of minimum wall thickness, as described in 2.2 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 (173.302(c)).
P = 5/3 times marked service pressure.
D = Outside diameter.
T = Minimum wall thickness allowed.

3 Sources of "K" factors

If a "K" factor is required, it should be obtained from one of the following 3 sources:

3.1

Select the "K" factor from table 2. Various cylinder designs are described by the data in the table.

3.2

Contact the cylinder manufacturer for the "K" factor, if the cylinder design is not contained in table 2.

3.3

Calculate the "K" factor if it cannot be obtained from the two sources listed above. The following procedure can be used:

3.3.1

Select at least three (3) cylinders typical of the design.

3.3.2

Determine the following properties of each cylinder:

D = Outside diameter in inches.
t = Wall thickness in inches.
V = Internal volume in cubic centimeters (cc).
EE = Elastic expansion in cubic centimeters.
P = Test pressure in pounds per square inch (psi).

3.3.3

Suggested methods to determine the above listed properties

D - Using II-tape, measure diameter in six or more locations. The average of those readings is the diameter.

t - Two convenient methods are:

(1) By ultrasonic thickness measuring device. Take readings over the entire sidewall at locations equidistanced apart on about 3 inch centers. The average of those readings is the wall thickness.

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

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

D = Outside diameter in inches
W = Weight in pounds
L = Length in inches.

V – Weigh cylinder empty and full of water three (3) 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 must be for the actual water temperature (454.06 cc per pound at 60 °F).

EE – Determine the elastic expansion in the water jacket hydrostatic test. Run at least three (3) tests on each cylinder. The average of those readings is the EE.

P - Is the test pressure for the particular cylinder design in psi?

3.3.4

Determine "K" factor by solving the following formula, using the values for various properties as determined above.

$$K = \frac{EE \times (D^2 - d^2)}{P \times V \times D^2}$$

$d = D - 2t$

4 Determination of elastic expansion rejection limits

4.1

The most practical method of determining limiting wall stresses at the present time, and the method recommended for use by the average cylinder owner is the indirect method based upon computing the limiting wall stress from the elastic expansion at test pressure by means of the water jacket hydrostatic test.

4.2

This is done by setting up a maximum allowable elastic expansion according to the Bach and Clavarino formulas and rejecting any cylinders that show elastic expansions at test pressure that exceeded the computed rejection limit.

4.3 The Bach Formula

The limiting wall stress has been established at minimum test pressure, and the allowable minimum wall thickness which will develop this wall stress can be readily computed from the Bach formula which is given below:

$$S = P \times \left[\frac{1.3D^2 + 0.4d^2}{D^2 - d^2} \right]$$

Where

S = Wall stress at test pressure, in pounds per square inch.
P = Test pressure in pounds per square inch.
D = Outside diameter inches.
d = Inside diameter in inches.

This formula may also be written:

$$\frac{S}{P} = \frac{1.3D^2 + 0.4d^2}{D^2 - d^2} = \frac{1.3(D/d)^2 + 0.4}{(D/d)^2 - 1}$$

The computations for this formula have already been worked out, and the results are tabulated in Table 1 for the major range covered by ICC/DOT cylinders.

4.4 The Clavarino Formula

The Clavarino formula expresses the relationship between the elastic expansion and the cylinder O.D. and I.D. and from this, the wall thickness can be computed.

$$EE = PKV\ (16.387) \times \left[\frac{D^2}{D^2 - d^2} \right]$$

Where

EE = Elastic expansion (total less permanent) in c.c.
P = Test pressure in pounds per square inch.
K = Factor (from Section 3, above).
V = Internal volume in cubic inches
16.387 = Number of cc in 1 cubic inch.
D = Outside diameter in inches.
d = Inside diameter in inches.
t = Wall thickness = 1/2 (D -d).

4.5

Example: As an example, determine the elastic expansion rejection limit for the following cylinder:

Chrome/moly (413OX) steel cylinder stamped ICC/DOT 3AA 2015

d = 9.00 inches (outside diameter)
L = 51.0 inches (length)
V = 2640 cubic inches
S = 67 000 psi (ICC/DOT limitation for filling to 10% in excess of the marked service pressure, reference 49 CFR 173.302(c)) [3]
k = 1.24×10^{-7} (for sources for "K" factor, see Section 3)
P = 3360 psi (5/3 x 2015)

Therefore, substituting in the Bach formula:

$$S = P \times \left[\frac{1.3D^2 + 0.4d^2}{D^2 - d^2} \right]$$

$$67\ 000 = 3360 \times \left[\frac{1.3(9.0)^2 + 0.4d^2}{(9.0)^2 - d^2} \right]$$

D = 8.6157" and t = 0.192"

Where t = Wall Thickness = $(D\text{-}d)/2$

Instead of the laborious computation involved, a simpler method is to use the figures of Table 1 as follows:

$$\frac{S}{P} = \frac{67\ 000}{3360} = 19.9405$$

from table 1,

$$\frac{D}{d} = 1.0446$$

d = 8.6157"

and t = 0.192"

To determine the elastic expansion rejection limit, substitute in the Clavarino formula: [3]

$$EE = PKV\,(16.387) \times \left[\frac{D^2}{D^2 - d^2} \right] = (3360)(1.24 \times 10^{-7})(2640)(16.387) \times \left[\frac{(9.0)^2}{(9.0)^2 - (8.6157)^2} \right] = 216 \text{ cc}$$

Cylinders that exceed the 216 cc limitation on retest are th6refore considered as thin wall rejects and are rejected for further service at 10% in excess of their marked service pressure.

4.6

A simplified way of determining the elastic expansion rejection limit is to solve the combined Bach/Clavarino formula as follows:

[3] This equation appears in 49 CFR 173.302(c) under Note 1 and is used to calculate the elastic expansion rejection limit using the average wall stress limitation. (See Appendix B) [3].

Using the known values from 4.5 above and substituting

$$EE = KV\,(16.387) \times \left[\frac{S + .4P}{1.7}\right]$$

$$EE = (1.24 \times 10^{-7})\,(2640)\,(16.387)\ \times \left[\frac{67\,000 + .4(3360)}{1.7}\right] = 216\,cc$$

4.7

For those cylinder users not desiring to calculate their own "K" factors and elastic expansion rejection limits, values are provided in table 2 for many commonly used cylinder types and sizes. The "K" factors and water volumes used in the calculations of elastic expansion rejection limits were the lowest values reported from the various cylinder manufacturers and are generally for cylinders with bottoms convex to pressure (bumped-back bottoms). These values vary with the method of cylinder manufacture and end design.

5 References

[1] CGA C-1, *Methods for Hydrostatic Testing of Compressed Gas Cylinders*, 4221 Walney Rd., 5th Floor, Chantilly, VA 20151.

[2] CGA C-6, *Standards For Visual Inspection of Steel Compressed Gas Cylinders*, Compressed Gas Association, Inc., 4221 Walney Rd., 5th Floor, Chantilly, VA 20151.

[3] *Code of Federal Regulations*, Title 49 CFR Parts 100-199 (Transportation), Superintendent of Documents, U.S. Government Printing Office, Washington, DC 20402.

[4] CGA C-8, *Standard for Requalification of DOT (ICC) 3HT Cylinders*, Compressed Gas Association, Inc., 4221 Walney Rd., 5th Floor, Chantilly, VA 20151.

Table 1—Solutions of Bach stress formula

$$\frac{S}{P} = \frac{1.3\,D^2 + 0.4\,d^2}{D^2 - d^2} = \frac{1.3\,(D/d)^2 + 0.4}{(D/d)^2 - 1}$$

	S/P at intervals of .0001 *D/d*									
D/d	.0000	.0001	.0002	.0003	.0004	.0005	.0006	.0007	.0008	.0009
1.010	85.877	85.035	84.210	83.401	82.607	81.829	81.065	80.316	79.580	78.858
1.011	78.150	77.453	76.770	76.098	75.438	74.790	74.153	73.527	72.911	72.306
1.012	71.710	71.125	70.549	69.983	69.426	68.877	68.337	67.806	67.283	66.769
1.013	66.262	65.763	65.271	64.787	64.310	63.840	63.377	62.921	62.472	62.029
1.014	61.592	61.161	60.737	60.318	59.905	59.498	59.097	58.701	58.310	57.925
1.015	57.544	57.169	56.799	56.433	56.073	55.716	55.365	55.018	54.675	54.337
1.016	54.002	53.673	53.347	53.025	52.707	52.393	52.083	51.776	51.473	51.174
1.017	50.878	50.576	50.297	50.011	49.729	49.450	49.174	48.901	48.631	48.364
1.018	48.101	47.840	47.582	47.326	47.074	46.824	46.577	46.333	46.091	45.852
1.019	45.615	45.318	45.149	44.920	44.693	44.468	44.246	44.026	43.808	43.592
1.020	43.379	43.167	42.958	42.751	42.545	42.342	42.141	41.942	41.744	41.549
1.021	41.355	41.163	40.973	40.785	40.599	40.414	40.231	40.050	39.870	39.692
1.022	39.515	39.341	39.167	38.996	38.826	38.657	38.490	38.324	38.160	37.997
1.023	37.836	37.676	37.517	37.360	37.204	37.050	36.896	36.744	36.594	36.444
1.024	36.296	36.149	36.004	35.859	35.716	35.574	35.433	35.293	35.154	35.016
1.025	34.880	34.774	34.610	34.477	34.344	34.213	34.083	33.954	33.826	33.698
1.026	33.572	33.447	33.323	33.199	33.077	32.956	32.835	32.715	32.597	32.479
1.027	32.362	32.245	32.130	32.016	31.902	31.789	31.677	31.566	31.456	31.346
1.028	31.238	31.129	31.022	30.916	30.810	30.705	30.601	30.497	30.394	30.292
1.029	30.191	30.090	29.990	29.891	29.792	29.694	29.597	29.500	29.404	29.309
1.030	29.214	29.120	29.027	28.934	28.841	28.750	28.659	28.568	28.478	28.389
1.031	28.300	28.212	28.125	28.038	27.951	27.865	27.780	27.695	27.611	27.527
1.032	27.444	27.361	27.279	27.197	27.116	27.035	26.955	26.875	26.796	26.717
1.033	26.639	26.561	26.484	26.407	26.331	26.255	26.179	26.104	26.029	25.956
1.034	25.882	25.808	25.735	25.663	25.591	25.519	25.448	25.377	25.307	25.237
1.035	25.168	25.098	25.030	24.961	24.893	24.826	24.758	24.692	24.625	24.559
1.036	24.493	24.428	24.363	24.298	24.234	24.170	24.106	24.043	23.980	23.917
1.037	23.855	23.793	23.732	23.670	23.610	23.549	23.489	23.429	23.369	23.309
1.038	23.251	23.192	23.134	23.076	23.018	22.960	22.903	22.846	22.790	22.734
1.039	22.678	22.622	22.566	22.510	22.456	22.402	22.347	22.293	22.240	22.186
1.040	22.133	22.080	22.027	21.975	21.923	21.871	21.819	21.767	21.716	21.665
1.041	21.615	21.564	21.514	21.464	21.415	21.365	21.316	21.267	21.218	21.170
1.042	21.121	21.073	21.025	20.978	20.930	20.883	20.836	20.790	20.743	20.697
1.043	20.651	20.605	20.559	20.514	20.469	20.424	20.379	20.334	20.290	20.246
1.044	20.202	20.158	20.115	20.071	20.028	19.985	19.942	19.899	19.857	19.815
1.045	19.773	19.731	19.689	19.648	19.606	19.565	19.524	19.484	19.443	19.403
1.046	19.362	19.322	19.282	19.243	19.203	19.164	19.125	19.085	19.047	19.008
1.047	18.969	18.931	18.893	18.855	18.817	18.779	18.742	18.704	18.666	18.630
1.048	18.593	18.556	18.514	18.483	18.447	18.410	18.374	18.338	18.303	18.267
1.049	18.232	18.196	18.161	18.126	18.091	18.057	18.022	17.987	17.953	17.919
1.050	17.885	17.852	17.818	17.785	17.752	17.719	17.685	17.652	17.619	17.585
1.051	17.552	17.520	17.488	17.456	17.424	17.392	17.359	17.327	17.295	17.263
1.052	17.231	17.200	17.169	17.139	17.108	17.077	17.046	17.015	16.985	16.954
1.053	16.923	16.893	16.864	16.834	16.804	16.775	16.745	16.715	16.685	16.656
1.054	16.626	16.597	16.569	16.540	16.512	16.483	16.454	16.426	16.397	16.369
1.055	16.340	16.313	16.285	16.258	16.230	16.203	16.175	16.148	16.120	16.093
1.056	16.065	16.038	16.012	15.985	15.959	15.932	15.905	15.879	15.852	15.826
1.057	15.799	15.773	15.748	15.722	15.696	15.671	15.645	15.619	15.593	15.568
1.058	15.542	15.517	15.492	15.467	15.442	15.418	15.393	15.368	15.343	15.318
1.059	15.293	15.269	15.245	15.221	15.197	15.173	15.149	15.125	15.101	15.077
1.060	15.053	15.030	15.007	14.983	14.960	14.937	14.913	14.890	14.867	14.844
1.061	14.822	14.800	14.777	14.755	14.732	14.710	14.687	14.665	14.642	14.620
1.062	14.597	14.575	14.554	14.532	14.510	14.489	14.467	14.445	14.423	14.402
1.063	14.380	14.359	14.338	14.317	14.296	14.275	14.253	14.232	14.211	14.190
1.064	14.169	14.149	14.128	14.108	14.087	14.067	14.047	14.026	14.006	13.985
1.065	13.965	13.945	13.925	13.906	13.886	13.866	13.846	13.826	13.807	13.787
1.066	13.767	13.748	13.729	13.709	13.690	13.671	13.652	13.633	13.614	13.594
1.067	13.575	13.556	13.538	13.519	13.500	13.482	13.463	13.444	13.425	13.407
1.068	13.388	13.370	13.352	13.334	13.316	13.298	13.280	13.262	13.244	13.226
1.069	13.208	13.190	13.173	13.155	13.138	13.120	13.102	13.085	13.067	13.050
1.070	13.032	13.015	12.998	12.981	12.964	12.947	12.929	12.912	12.895	12.878
1.071	12.861	12.844	12.828	12.811	12.795	12.778	12.761	12.745	12.728	12.712
1.072	12.695	12.679	12.663	12.646	12.630	12.614	12.598	12.582	12.565	12.549
1.073	12.533	12.517	12.502	12.486	12.470	12.455	12.439	12.423	12.407	12.392
1.074	12.376	12.361	12.345	12.330	12.315	12.300	12.284	12.269	12.254	12.238
1.075	12.223	12.208	12.193	12.178	12.163	12.149	12.134	12.119	12.104	12.089
1.076	12.074	12.060	12.045	12.031	12.016	12.002	11.987	11.973	11.958	11.944
1.077	11.929	11.915	11.901	11.887	11.873	11.859	11.844	11.830	11.816	11.802
1.078	11.788	11.774	11.760	11.747	11.733	11.719	11.705	11.691	11.678	11.664
1.079	11.650	11.637	11.623	11.610	11.596	11.583	11.570	11.556	11.543	11.529
1.080	11.516	11.503	11.490	11.477	11.464	11.451	11.437	11.424	11.411	11.398
1.081	11.385	11.372	11.359	11.347	11.334	11.321	11.308	11.295	11.283	11.270
1.082	11.257	11.245	11.232	11.220	11.207	11.195	11.182	11.170	11.157	11.145
1.083	11.132	11.120	11.108	11.096	11.084	11.072	11.059	11.047	11.035	11.023
1.084	11.011	10.999	10.987	10.975	10.963	10.952	10.940	10.928	10.916	10.904

Table 2—Standard elastic expansion and K-factor limits

Unless otherwise calculated

2a—Industrial high pressure seamless steel cylinders

Nominal oxygen capacity (cu ft)	ICC/DOT Spec.	Service pressure (psi)	Test pressure (psi)	Nominal dimensions [1] Outside diameter (in.)	Length (in.)	"K" factor (x 10^{-7})	Elastic expansion rejection limit (cc)
20	[5] 3AA	2015	3360	5 1/4	13 3/4	1.27	16.7
20	3AA	2015	3360	5 1/4	13 7/8	1.27	18.2
20	3AA	2015	3360	5 1/4	14 7/8	1.25	19.8
40	3A	2015	3360	6 1/4	21	1.30	32.7
40	3AA	2015	3360	6 3/4	18 1/2	1.28	41.3
55	3A	2015	3360	5 3/8	37	1.30	45
55	3AA	2015	3360	5 3/4	32	1.30	57
55	3A	2015	3360	7	25	1.28	47
80	3A	2015	3360	7	32 1/2	1.27	63
80	3AA	2015	3360	7	32 1/2	1.26	80
80	3A	2215	3700	7 1/8	30	1.27	58
80	3AA	2215	3700	7 1/8	30	1.27	73
110	3A	2015	3360	7	43	1.27	88
110	3A CR-MO [3]	2015	3360	7	43	1.27	110
110	3AA	2015	3360	7	43	1.26	110
125	3A CR-MO [3]	2265	3775	7	43	1.27	110
125	3AA	2265	3775	7	43	1.26	110
150	3AA	2015	3360	7 3/8	46 1/8	1.24	133
200	3A	1800	3000	9	51	1.30	179
200	3A CR-MO [3]	1800	3000	9	51	1.30	225
200	3AA	1800	3000	9	51	1.30	225
200	3A	2000	3360	9	51	1.29	178
220	3A	2015	3360	9	51	1.29	178
220	3A CR-MO [3][4]	2015	3360	9	51	1.24	216
220	3AA	2015	3360	9	51	1.24	216
250	3A CR-MO [3][4]	2260	3775	9	51	1.30	227
250	3A CR-MO [3][4]	2265	3775	9	51	1.30	227
250	3AA	2265	3775	9	51	1.24	216
250	3A	2400	4000	9	51	1.30	181
250	3A CR-MO [3]	2400	4000	9	51	1.30	227
250	3AA	2400	4000	9	51	1.30	227
260	3AA	2400	4000	9 1/4	51	1.30	236
300	3A CR-MO [3]	2400	4000	9 1/4	55	1.30	257
300	3AA	2400	4000	9 1/4	55	1.27	251
400	3AA	2400	4000	10 5/8	56	1.30	343
400	3AA	3500	5835	9 1/4	51	1.30	229
400	3AA	3600	6000	9 1/4	51	1.30	230
435	3AA	6000	10000	9 1/2	51	1.29	209
500	3AA	4500	7500	9 3/8	51	1.28	226
560	3AA	5000	3330	9 3/4	51	1.28	227
660	3AA	6000	10000	9 3/4	51	1.28	226
800	3AA	7500	12500	10 1/4	51	1.28	224

NOTES

1) Dimensions of cylinders and tubes are nominal figures and may vary slightly with various cylinder manufacturers.

2) For data on cylinders not listed or for additional information, contact the original cylinder manufacturer.

3) Prior to 1948, the designation "3AA" was not used to indicate cylinders made from alloy steels and made to higher wall stresses than 3A cylinders. Therefore, the elastic expansion rejection limits listed for cylinders made of chrome-moly or alloy steels must not be used to indicate the suitability of a cylinder for further services unless the cylinder can be identified as being made from chrome-moly or alloy steel.

4) All Taylor-Wharton/Harrisburg Steel manufactured "W.D." (War Department) cylinders 9" O.D. x 51 inches long and stamped 3A2260 or 3A2265, and 91/4" O.D. x 55 inches long and stamped 3A2400, were manufactured from 4130 chrome-moly steel and qualify under the "3AA" specification. However, "W.D." cylinder 9" O.D. x 51" long stamped 3A1800, 3A2015 or 3A2400 may be either "3A" or "3AA" cylinders and shall be handled per note 3

5) Marison Co. began producing this cylinder model in 1986 and each cylinder is stamped "REE 16.7.

2b—Medical high pressure seamless steel cylinders

Letter size cylinder	ICC/DOT Spec.	Service pressure (psi)	Test pressure (psi)	Nominal dimensions Outside diameter (in.)	Nominal dimensions Length (in.)	"K" factor $(x\ 10^{-7})$	Elastic expansion rejection limit (cc)
B	3AA	2015	3360	3 1/4	13	1.3	7.2
D	3AA	2015	3360	4 1/4	16 3/4	1.29	14.5
E	3AA	2015	3360	4 1/4	25 3/4	1.24	23.1
M	3A	2015	3360	7	43	1.27	88
M	3AA	2015	3360	7	43	1.26	110
G	3A	2015	3360	8 1/2	51	1.30	159
G	3AA	2015	3360	8 1/2	51	1.30	200
H	3A	2015	3360	9	51	1.29	178
H	3AA	2015	3360	9	51	1.24	216
H	3AA	2265	3775	9	51	1.24	216

NOTE—Industrial gas cylinders are frequently used in medical gas service. Refer to table 2a for data.

2c—Tube trailer high pressure seamless steel cylinders

ICC/DOT Spec.	Service pressure (psi)	Test pressure (psi)	Nominal dimensions Outside diameter (in.)	Nominal dimensions Length (in.)	"K" factor $(x\ 10^{-7})$	Elastic expansion rejection limit (cc)
3A	2400	4000	9 5/8	12-0	1.25	557
3A	2400	4000	9 5/8	20-6	1.25	978
3A	2400	4000	9 5/8	21-0	1.25	1000
3A	2400	4000	9 5/8	24-0	1.25	1137
3AA	2400	4000	9 5/8	24-0	1.26	1497
3A	2400	4000	9 5/8	28-0	1.26	1352
3AA	2400	4000	9 5/8	32-0	1.26	2016
3AA	2500	4170	9 5/8	21-0	1.26	1326
3A	3600	6000	9 5/8	21-0	1.25	946
3AA	5000	8330	9 5/8	21-0	1.25	1157
3AA	6000	10 000	9 5/8	21-0	1.25	1537
3AX	1800	3000	24	30-0	1.267	9211
3AAX	2400[2]	4000	22	32-10	1.2624	10676
3AAX	2400[2]	4000	22	34-4	1.2624	11202
3AAXSP5372	2400[3]	4000	22	32-10	1.2998	14553
3AAXSP5372	2400[3]	4000	22	34-4	1.2998	15096
3T	2400[4]	4000	22	18-6	1.2863	7880
3T	2400[4]	4000	22	19-0	1.2863	8088
3T	2400[4]	4000	22	34-4	1.2863	15114
3T	2400[4]	4000	22	36-0	1.2863	15892
3T	2400[4]	4000	22	40-0	1.2863	17715
3T	2850	4750	22	34-4	1.2998	15084
3T	2850	4750	22	36-0	1.2998	15846
3T	2850	4750	22	40-0	1.2998	17649

NOTES

1 Dimensions of cylinders and tubes are nominal figures and may vary slightly with various cylinder manufacturers.

2 Cylinders having stamped service pressure (SP) other than 2400 psi are to have REE calculated using the following formula:

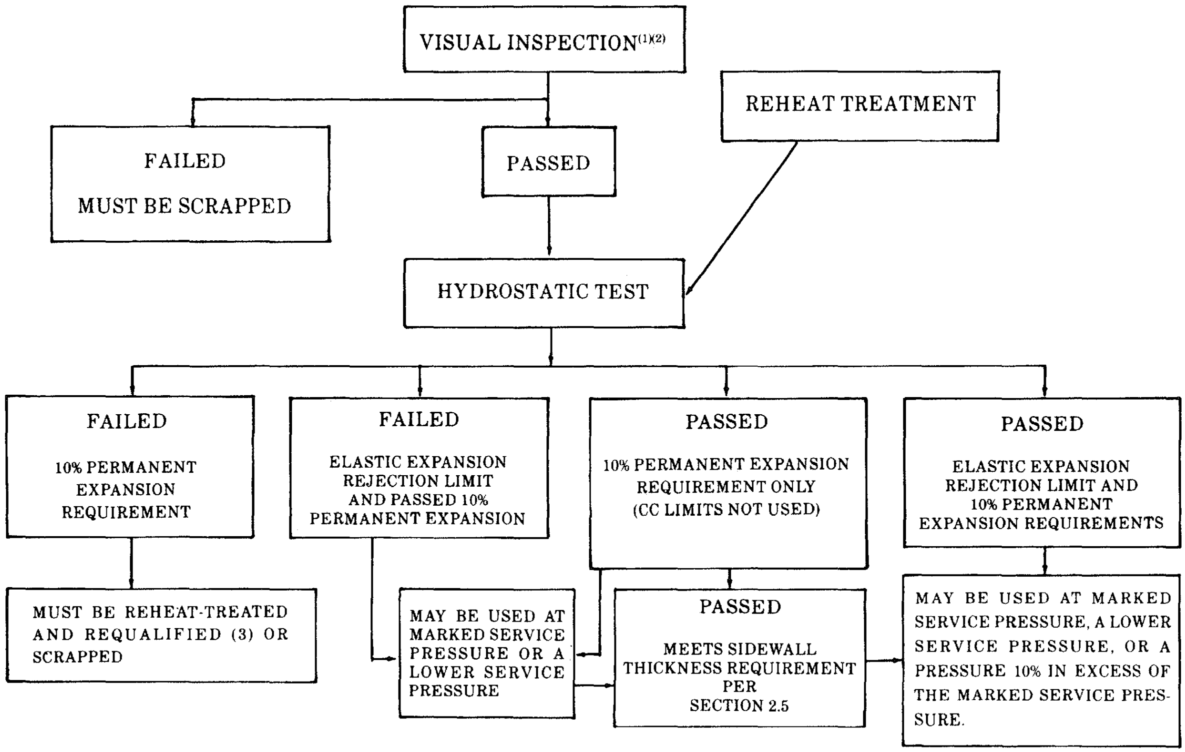
REE = 0.002103V (67,000 + 0.4 P) where P = Test Pressure (SP x 5/3)
V = Cylinder Volume (cu. ft.)

3 Cylinders manufactured to Special Permit No. 5372 (issued March, 1968) having a.431" minimum wall which preceeded cylinders manufactured to DOT 3T specification (8-73) having a.415" minimum wall.

4 Cylinders having stamped service pressures (SP) other than 2400 psi are to have REE calculated using the following formula:

REE 0.002143V (87,000 + 0.4 P) where P = Test Pressure (SP x 5/3)
V = Cylinder Volume (cu. ft.)

Appendix A—Flow chart for service life control



(1) Visual inspection must be conducted in accordance with Compressed Gas Association C-6 [2].

(2) May be conducted after the hydrostatic test depending on the existing shop practice.

(3) Reheat-treated cylinders must be requalified in accordance with 49 CFR 173.34 [3].

Appendix B—DOT Hazardous Materials R 173.302(c) special filling limits

(c) *Special filling limits for specifications 3A, 3AX, 3AA, 3AAX, and 3T cylinders.* Specifications 3A, 3AX, 3AA, 3AAX, and 3T (§§ 178.36, 178.37, 178.45 of this subchapter) cylinders may be charged with compressed gases, other than liquefied, dissolved, poisonous, or flammable gases to a pressure 10 percent in excess of their marked service pressure, provided:

(1) That such cylinders are equipped with frangible disc safety relief devices (without fusible metal backing) having a bursting pressure not exceeding the minimum prescribed test pressure.

(2) That the elastic expansion shall have been determined at the time of the last test or retest by the water jacket method.

(3) That either the average wall stress or the maximum wall stress shall not exceed the wall stress limitation shown in the following table: (See notes 1 and 2) [3].

Type of steel	Average wall stress limitation	Maximum wall stress limitation
Plain carbon steels over 0.35 carbon and medium manganese steels	53 000	58 000
Steels of analysis and heat treatment specified in spec. 3AA	67 000	73 000
Steel of analysis and heat treatment specified in spec. DOT-3T	87 000	94 000
Plain carbon steels less than 0.35 carbon made prior to 1920	45 000	48 000

NOTE 1—The average wall stress shall be computed from the elastic expansion data using the following formula:

$$S = \frac{1.7EE}{KV} - 0.4P$$

where

S = wall stress, pounds per square inch;

EE = elastic expansion (total less permanent) in cubic centimeters;

K = factor x 10^{-7} experimentally determined for the particular type of cylinder being tested;

V = internal volume in cubic centimeters (1 cubic inch = 16.387 cubic centimeters);

P = test pressure, pounds per square inch.

Formula derived from formula of Note 2 and the following:

$$EE = PKV \times \frac{D^2}{D^2 - d^2}$$

NOTE 2—The maximum wall stress shall be computed from the formula:

$$S = P\frac{(1.3D^2 + 0.4d)^2}{D^2 - d^2} \text{ where}$$

S = wall stress, pounds per square inch;

P = test pressure, pounds per square inch;

D = *outside diameter, inches;*

d = *D - 2t, where t = minimum wall thickness determined by a suitable method.*

(4) That an external and internal visual examination made at the time of test or retest shows the cylinder to be free from excessive corrosion, pitting, or dangerous defects.

(5) That a plus sign (+) be added following the test date marking on the cylinder to indicate compliance with paragraphs (c) (2), (3) and (4) of this section.