The apparatus used for controlling the gauges in the described experiments was of the design as offered by the American Steam Gauge and Valve Manufacturing Company, of Boston, Mass., the accuracy of which was controlled by the United States Bureau of Standards and found to be correct within a fraction of one per cent.

(*Continued in the next number.*)

THE MANUFACTURE AND TESTING OF CARBONIC ACID CYLINDERS.[1]

By John C. Minor, Jr.

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The manufacture of liquefied carbonic acid was begun in this country about thirty years ago and has expanded to an industry of considerable magnitude. While its uses are of a varied nature, it is as the essential ingredient of carbonated beverages that carbonic acid has become an important article of commerce.

Until very recently there were no traffic regulations in this country covering the shipment of compressed gases, nor was there—unless perhaps in isolated cases—any effort on the part of manufacturers of such gases to procure gas cylinders of any distinctive type or particular quality. It was considered sufficient that the cylinders had—by a custom inherited from Germany—passed a hydrostatic test of 3700 pounds per square inch.

In 1896 a British Parliamentary Committee made a lengthy investigation of questions relative to the safe transportation of compressed gases, and certain regulations were recommended in its report but did not become official. They mainly summarized what was in most respects the prevailing British practice and when later they were largely embodied in the British railroad transportation requirements but little difficulty was found in complying with them.

In Germany there were at that time Governmental regulations regarding the filling and testing of such cylinders, but only within comparatively recent years were these extended to cover the manufacture of the cylinders.

In this country the transportation of all dangerous or inflammable articles is now carried on under the regulations of the Bureau of Explosives of the American Railway Association as approved by the Interstate Commerce Commission. The Bureau, through its chief, Col. B. W. Dunn, first took up the matter of compressed and liquefied gases early in 1909.

There had already been some careful and extensive work done on this subject by Prof. R. T. Stewart, of the University of Pittsburg. In his paper, "The Physical Properties of Carbonic Acid and the Conditions of its Economic Storage for Transportation," read in December, 1908, before the American Society of Mechanical Engineers—and from which the writer has freely drawn—are to be found in condensed and usable form valuable data relative to the physical properties of carbonic acid.

The National Tube Company of Pittsburgh had also instituted a preliminary investigation of the subject and when, at the suggestion of the Bureau of Explosives, the manufacturers of liquefied gases determined upon an investigation of the cylinder question, every facility was offered them by that company to make it complete and to it is due the credit of much of the cylinder data here presented.

Before considering the cylinders themselves several facts regarding carbonic acid may be noted. This product may appear in transit either in liquid form, or as a vapor, or in both conditions, together. Its critical temperature is 88.4° F., above which it cannot exist in liquid form. At any temperature below this, all of the cylinder may be filled with the liquid gas or a part of it may be filled with the liquid and the remainder with the saturated vapor. Just as long as there is saturated vapor present, the pressure will be constant for a fixed temperature without reference to the proportion of liquid present, but when the cylinder becomes entirely filled with the liquid the pressure will no longer be constant for a fixed temperature.

It is obvious that the condition, whether gaseous, liquid, or both, that obtains below the critical temperature within the cylinder and the pressure thereby exerted on its walls is dependent on the relation existing between the total capacity of the cylinder and the amount of carbonic acid which it contains. This relation is expressed by Professor Stewart in his table appended hereto, as the density and represents the proportion of filling in pounds of carbonic acid per pound of water capacity, being for each condition tabulated, the combined densities of the liquid and its saturated vapor and being equal in each case to their combined weights divided by the weight of their combined volumes of water at its maximum density; that is, a density of 0.75 would mean that a cylinder which could hold 100 lbs. of water had 75 lbs. of carbonic acid in it, or a cylinder with a water capacity of 80 lbs. contained 60 lbs. of carbonic acid.

Reference to this table of Professor Stewart will show for any given proportion of filling or density, the pressure exerted by carbonic acid within the cylinder for any given temperature and which it must under all conditions safely resist. These pressures are increased by about 60 lbs. per sq. in. for each per cent. of air present. Manifestly, strength to resist pressure is only one feature of a properly designed cylinder and ability to withstand rough handling in transportation and to resist fragmentation on fracture are other important elements in the problem of producing a safe cylinder.

Carbonic acid gas cylinders are made in this country by three different processes.

In the plate process, a circular plate, of a thickness and diameter corresponding to the size of cylinder to be manufactured, is heated and punched into a half spherical cup (Fig. 1). This cup is then pushed

[1] Paper presented at Annual Meeting, American Institute of Chemical Engineers, Washington, December, 1911.

TABLE I.

PRESSURE EXERTED BY CARBONIC ACID ON WALLS OF CONTAINING VESSEL IN POUNDS PER SQ. IN.

FROM PROF. STEWARTS' PAPER.

Density Water at 39.2° F. = 1	Temperature in Degrees Fahrenheit									Temperature in Degrees Fahrenheit									
	32°	40°	50°	60°	70°	80°	90°	100°	110°	120°	130°	140°	150°	160°	170°	180°	190°	200°	212°
.50	504	565	650	744	849	965	1095	1245	1395	1550	1710	1870	2030	2185	2345	2505	2665	2825	3020
.51	504	565	650	744	849	965	1100	1250	1405	1565	1730	1895	2055	2220	2385	2550	2715	2880	3080
.52	504	565	650	744	849	965	1100	1255	1415	1580	1750	1915	2085	2255	2425	2595	2765	2930	3140
.53	504	565	650	744	849	965	1100	1260	1425	1600	1770	1940	2115	2290	2465	2640	2815	2990	3205
.54	504	565	650	744	849	965	1105	1265	1440	1615	1790	1970	2145	2325	2505	2685	2870	3050	3270
.55	504	565	650	744	849	965	1105	1270	1450	1630	1810	1995	2180	2365	2550	2735	2925	3110	3340
.56	504	565	650	744	849	965	1105	1280	1465	1650	1835	2025	2215	2405	2600	2790	2980	3175	3410
.57	504	565	650	744	849	965	1110	1290	1475	1670	1860	2055	2255	2450	2650	2845	3045	3245	3490
.58	504	565	650	744	849	965	1110	1300	1490	1690	1885	2090	2295	2495	2705	2905	3115	3320	3570
.59	504	565	650	744	849	965	1115	1310	1505	1710	1915	2125	2335	2545	2760	2970	3185	3395	3655
.60	504	565	650	744	849	965	1115	1320	1520	1735	1945	2160	2380	2595	2815	3035	3255	3470	3745
.61	504	565	650	744	849	965	1120	1330	1540	1760	1975	2200	2425	2645	2875	3100	3330	3555	3835
.62	504	565	650	744	849	965	1130	1340	1560	1785	2010	2240	2475	2700	2940	3170	3405	3640	3925
.63	504	565	650	744	849	965	1140	1355	1580	1815	2045	2285	2525	2760	3005	3240	3485	3725	4020
.64	504	565	650	744	849	965	1150	1375	1605	1845	2080	2330	2575	2820	3070	3315	3570	3815	4120
.65	504	565	650	744	849	965	1160	1395	1630	1875	2120	2375	2630	2885	3140	3395	3655	3910	4225
.66	504	565	650	744	849	965	1175	1415	1660	1910	2165	2430	2690	2960	3215	3480	3750	4010	4335
.67	504	565	650	744	849	965 B	1190	1440	1690	1950	2210	2485	2755	3025	3300	3570	3830	4120	4455
.68	504	565	650	744	849	975	1205	1465	1725	1995	2265	2545	2825	3105	3390	3670	3955	4235	4580
.69	504	565	650	744	849	990	1230	1495	1765	2040	2325	2615	2900	3190	3485	3775	4070	4355	4710
.70	504	565	650	744	849	1005	1255	1530	1810	2095	2385	2685	2985	3280	3580	3885	4190	4485	4850
.71	504	565	650	744	849	1025	1285	1570	1855	2150	2455	2760	3070	3375	3690	4000	4315	4620	5000
.72	504	565	650	744	849	1050	1320	1610	1910	2215	2530	2645	3165	3480	3800	4125	4450	4765	
.73	504	565	650	744	849	1080	1360	1660	1970	2290	2610	2940	3265	3585	3925	4260	4590	4910	
.74	504	565	650	744	849	1110	1405	1720	2035	2365	2700	3040	3375	3715	4055	4400	4740		
.75	504	565	650	744	849	1145	1460	1785	2110	2450	2790	3145	3495	3845	4195	4545	4895		
.76	504	565	660	744	870	1190	1515	1850	2190	2535	2890	3255	3620	3980	4340	4700			
.77	504	565	650	744	910	1240	1575	1925	2275	2635	3000	3380	3755	4120	4495	4865			
.78	504	565	650	744	955	1295	1645	2005	2370	2740	3120	3570	3895	4275	4665				
.79	504	565	650	744	1005	1355	1715	2090	2470	2850	3245	3650	4050	4440	4840				
.80	504	565	650	744	1060	1425	1795	2185	2575	2975	3385	3800	4210	4615					
.81	504	565	650	750	1120	1500	1885	2290	2695	3110	3530	3960	4390	4800					
.82	504	565	650	800	1190	1585	1985	2405	2825	3235	3685	4130	4575	5000					
.83	504	565	650	860	1260	1675	2095	2530	2965	3410	3835	4315	4775						
.84	504	565	650	935	1340	1780	2215	2665	3115	3575	4040	4510	4985						
.85	504	565	650	1020	1445	1895	2345	2815	3285	3760	4240	4720							
.86	504	565	685	1110	1530	2020	2490	2980	3465	3960	4450	4950							
.87	504	565	765	1210	1665	2155	2650	3160	3665	4175	4680								
.88	504	565	855	1325	1800	2310	2825	3360	3880	4410	4935								
.89	504	565	960	1450	1950	2485	3020	3565	4110	4655									
.90	504	655	1080	1595	2120	2675	3235	3800	4355	4915									
.91	A. 504	765	1215	1755	2305	2880	3470	4050	4625										
.92	530	880	1360	1925	2505	3115	3720	4320	4910										
.93	620	1005	1625	2120	2740	3375	3995	4610											
.94	725	1145	1715	2340	2990	3645	4280	4920											
.95	855	1320	1935	2590	3255	3935	4585												
.96	1010	1515	2175	2860	3545	4240	4910												
.97	1200	1740	2440	3150	3850	4565													
.98	1435	2000	2745	3480	4195	4915													
.99	1700	2305	3065	3825	4555														
1.00	2010	2635	3415	4200	4940														

through a series of round dies over an inside mandrel governing the inside diameter (Fig. 2).

In this manner, this cup is elongated and reduced in diameter and thickness of wall until the proper dimensions are obtained. The bottom of this cup has the thickness of the original plate, with a slight reduction caused by the several heats through which it has passed, and in the last elongating operation it may be dished or flattened to enable the cylinder to stand upright. The elongated cup is now cut to length and the open end swaged between hammer dies into the shape of a bottle-neck.

After this operation the cylinder is annealed and heat treated as the case may be, and then finished up by threading the neck and testing in accordance with specifications.

FIG. 1.—CUPPED PLATES.

FIG. 2.—HOT DRAW BENCH.

In the spinning process a hot, finished, seamless tube, with both ends open, is heated at one end and by a process of "spinning" the end of the tube is closed and welded in the center so as to form a homogeneous bottom in the tube.

The spinning process itself is very simple. The spinning machine is a type of lathe with a hollow spindle, so adapted that cylinders or tubes to be spun may be put into it and chucked, with the end which is to be worked extending outside of the chuck. This end having been heated, the tube is put into the lathe which is then rotated at from 1200–1400 revolutions per minute. At that speed, a tool is brought to bear against the rotating end of the tube. This tool, sweeping the end of the tube in a half-circle, forces its sides to meet in the center, where the high heat, caused by the friction of the tool against the tube, produces a perfect weld in the center.

The bottom thus formed is then dished or flattened, or a loose ring may be shrunk around it to enable the cylinder to stand upright. The necked end is produced as already described under the plate process.

In the lap-weld process, now obsolete, a lap-weld tube of the proper dimensions is used and one end is necked down over a plug about 4 in. in diameter by 1 in. thick. This plug is welded into the neck end of the cylinder, thus forming the head. The bottom is formed by welding a half spherical cup into the bottom end, with the concave side of the cup out, thus enabling the cylinder to stand on its bottom. The annealing. testing, etc., as above described, also applies to this cylinder.

In the plate process, cylinders from 3″ diameter up to 20″ diameter are made.

In the spinning process, cylinders from 1″ diameter up to 6″ diameter are made.

In the lap-weld process, cylinders from 3″ diameter up to 8″ diameter have been made.

There are in use in this country for conveying carbonic acid several sizes of cylinders of both the seamless and lap-welded types, of which the larger part are the 5-1/2″ × 51″ and 5-1/2″ × 48″ lap-welded and the 8-1/2″ × 51″ seamless cylinders. The 5-1/2″ cylinders are filled with 20 lbs. of gas giving a filling density of 0.66 for those of 48″ length and of 0.57 for those 51″ long. The 8-1/2″ cylinders are filled with 50 lbs. of gas giving a filling density of 0.57.

The present paper is devoted only to the subject of the seamless cylinders, as the tendency in high-pressure work, *i. e.*, 1,000 lbs. and over, has been to develop that type in preference to the lap-welded cylinder.

In the preparation of regulations to govern the transportation—and later, the manufacture—of cylinders it was necessary to assume a maximum temperature to which cylinders in transit might be exposed. In Germany the revised regulations set this at 104° F. but in this country it was fixed by the Bureau of Explosives at 130° F.

Reference to Professor Stewart's table shows that with the fillings mentioned above and a temperature of 130°, the 5-1/2″ × 48″ cylinder would have a pressure of 2210 lbs. per sq. in., while the pressure in the 5-1/2″ × 51″ and the 8-1/2″ × 51″ cylinders would be 1860 lbs.

The British standard as recommended by the Parliamentary Committee in 1896 is as follows:

Carbon—Not to exceed 0.25 per cent.

Iron—Not to be less than 99.00 per cent.

Elongation—On 8″ bar from finished cylinder not to be less than 15 per cent.

Tensile Strength—Not to be less than 63,000 lbs. nor more than 74,000 lbs.

All cylinders to be annealed before putting in service.

A large number of seamless cylinders of this character, known as the Linde cylinders, and used for compressed oxygen, have been made in this country under a slightly different specification, briefly as follows:

Carbon, not to exceed 0.25 per cent.

Manganese, not to exceed 0.60 per cent.

Phosphorus, not to exceed 0.04 per cent.

Sulphur, not to exceed 0.04 per cent.

Silicon, not to exceed 0.35 per cent.

Elongation, not less than 15 per cent.

Tensile strength, not less than 62,000 nor more than 76,000 lbs.

All cylinders to be annealed, and to pass a hydrostatic sketch test of 3600 lbs. per sq. in.

Representative cylinders to be submitted to a flattening test.

This, of course, is a mild, ductile steel and there had been a somewhat prevalent impression that a cylinder of such metal, if exploded from fire or other causes, would not fragment, but merely open up and thus greatly reduce the chance of personal injury and, indeed, it has been towards obtaining such a cylinder, if possible, that recent efforts have been mainly directed. It was recognized, however, that the large carbonic acid cylinders must carry a load of 50 lbs. of gas; that a maximum temperature of 130° was assumed against 104° on the other side; that our freightage distances and rates were very considerable; and that in view of all this we could not consider a cylinder which like the English or Linde type would weigh, when empty, about 170 lbs.

In view of the absence of data concerning cylinders already in use in this country, samples were selected at random from various parts of the country. The experiments performed consisted of:

1. Tensile tests of material cut in longitudinal direction. Data appended. (See Table II.)

2. Bending tests of samples cut in transverse direction. These were bent until fracture occurred and in all but a few instances the bend was through an arc of 180° about a mandrel whose diameter was less than four times the thickness of the specimen.

3. Transverse tests of whole cylinders (Fig. 3). Several representative cylinders were tested by placing them on two bars of iron, one inch wide and spaced nine inches on centers and applying a center load through a piece of shafting 2-1/2″ in diameter. These tests showed that a very considerable amount of distortion was endured before even the poorest

cracked. The low carbon cylinders did not crack at all.

4. Chemical analyses. Data of these are appended.

5. Hydraulic bursting tests (Fig. 4). Water was forced into the cylinders until rupture occurred. Two small lap-welded cylinders ruptured along the weld, each at a pressure of 4400 lbs. One large seamless cylinder burst at 5600 lbs. The form of fracture seemed characteristic in all, as shown by the photographs.

6. Fire tests. Cylinders were filled with their usual capacity of carbonic acid and placed in the open over a hot fire of oil-soaked wood. It took 8 to 12 minutes' direct exposure to produce rupture.

Cyl. No. 1 (Fig. 5). Large seamless type. Carbon, 0.56 The bottom was blown off, the cylinder split in halves and a piece about 6″ × 8″ blown off near shoulder.

Cyl. No. 2. Small lap-welded type. Carbon, 0.11. Ruptured along weld without fragmentation.

Cyl. No. 3. Large seamless type. Carbon, 0.63. Bottom blew off but no other fracture.

Cyl. No. 4 (Fig. 6). Large seamless type. Carbon, 0.55. Bottom blew off. Remainder flattened out.

Cyl. No. 5. Large seamless type. Result like No. 4 except two pieces of shoulder flew off.

7. Expansion tests. Three cylinders were subjected to hydraulic pressure in water jacket until sufficient pressure was applied to stress the material to its elastic limit. This was found to be about 4,000 lbs. in each case.

TABLE II.

PHYSICAL AND CHEMICAL TESTS ON CYLINDERS IN SERVICE

	t	d	EL	ULT	% EL 8″	% Red Area	C	P	S	Mn.	Si
Small Lapwelded Cylinders											
G	300	5.50	38070	59040	20.4	62.9	12	097	063	701	018
H	280	5.50	37970	57160	23.0	53.4	10	123	070	.492	.010
I	316	5.50	37970	57980	21.6	57.6	12	114	088	418	.007
J	300	5.00	38920	56320	21.6	58.7	10	123	096	420	.019
X	260	5.60	41340	59980	14.2	50.4	10	103	067	.456	.012
Y	278	5.60	38730	61020	23.0	52.6	11	110	076	.455	.008
AA	325	5.56	37670	60100	19.6	55.7	11	.110	073	.522	.009
AVERAGE	285	5.55	38670	58730	21.9	57.0	11	111	076	495	012
Large German Seamless	t	d	EL	ULT	% EL 8″	% Red Area	C	P	S	Mn.	Si
Q	280	9.56	61990	94340	20.0	42.9	45*	049	051	1.11	.160
R	285	8.00	61160	76580	14.1	39.3	14	094	066	1.18	.110
S	260	8.05	70830	96960	15.8	49.6	33	061	066	1.16	175
T	238	8.62	73080	87700	10.9	41.6	14	092	059	688	110
U	222	8.50	68560	95850	14.0	40.5	19	101	.063	971	.248
AVERAGE	256	8.35	66420	90280	14.9	42.8	25	079	059	1.02	160
Large American Seamless Open Hearth	t	d	EL	ULT	% EL 8″	% Red Area	C	P	S	Mn.	Si
C	220	8.18	58890	107100	13.5	28.1	64	035		641	
E							54	058		658	
L	250	8.60	66300	111150	11.6	26.9	50	016	.033	565	143
M	250	8.60	60570	102560	14.0	33.0	42	025	034	960	024
N	270	8.54	60820	122830	12.0	27.8	52	.092	.042	651	.071
O	240	8.55	72870	116920	10.8	21.4	60	034	049	707	134
P	225	8.66	89290	129890	6.3	24.6	67	019	042	578	110
V	230	8.70	65900	97210	16.2	34.6	45	.030	024	737	.023
W	248	8.62	69180	119900	11.2	19.6	47	039	030	794	.017
AVERAGE	242	8.63	67360	113430	11.9	27.0	53	.039	044	693	075
Large American Seamless Bessemer	t	d	EL	ULT	% EL 8″	% Red Area	C	P	S	Mn.	Si
B	232	8.60	64160	88920	15.2	41.8	21	110		758	
K	230	8.55	71470	90100	13.8	41.4	15	107	056	755	.180
Z	250	8.60	58710	93350	16.0	44.1	15	.110	.066	.928	.196
AVERAGE	237	8.58	64780	90790	15.0	42.4	17	109	061	813	188

These tests were made on cylinders which had been in service for from three to seventeen years and were conducted at the laboratories of the Rensselaer Polytechnic Institute at Troy and in the field at Saratoga.

No one of the lap-welded cylinders shows in any feature a marked departure from the general average of the lot except Cyl. G. which has 0.701 manganese against an average of 0.495, a fact which does not appear to be reflected in any physical feature of the cylinder.

The high phosphorus in all of this group averaging 0.111 is a marked characteristic and as a prejudicial hardener opens this type to criticism. Nevertheless, the broken specimens showed a fairly reasonable degree of ductility.

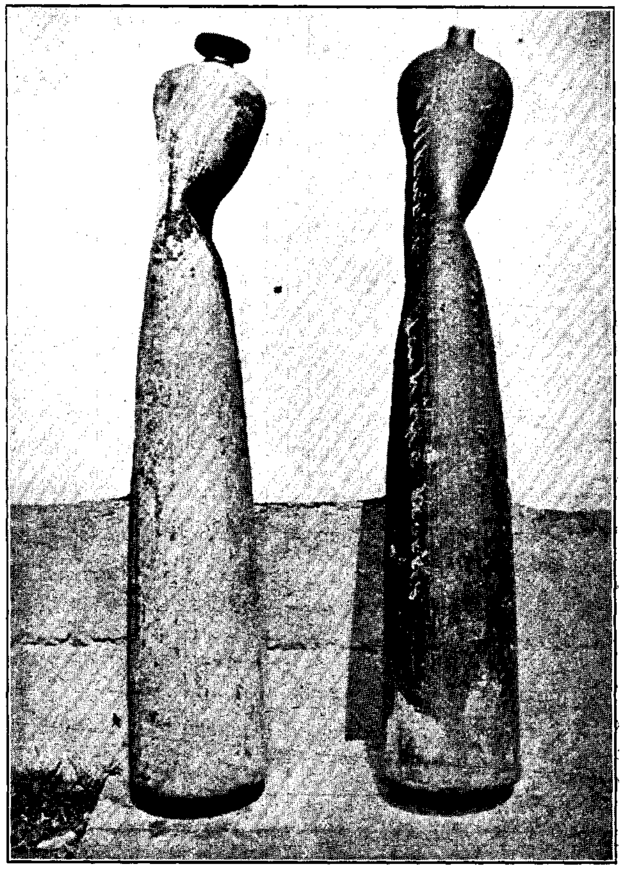

FIG. 3.—TRANSVERSE TESTS.

The German cylinders showed very different steel from that offered in this country for cylinders. They vary from 0.14–0.45 carbon, run high in silicon—from 0.110–0.248—and with one exception are very high in manganese, averaging 1.02. These high manganese cylinders, whether of German or American make, not only show satisfactory ductility but exhibit high values of ultimate reduction of the fractured section.

There was disclosed by these tests an irregularity of chemical contents and corresponding physical results which are not desirable in metal which it is possible to standardize, but it was felt that they justified the general observation that the cylinders might be considered safe for transportation under such pressures as would in no case produce stresses greater than $^3/_4$ of the elastic limit. They also emphasized the desirability of ascertaining and prescribing the most suitable metal for this work.

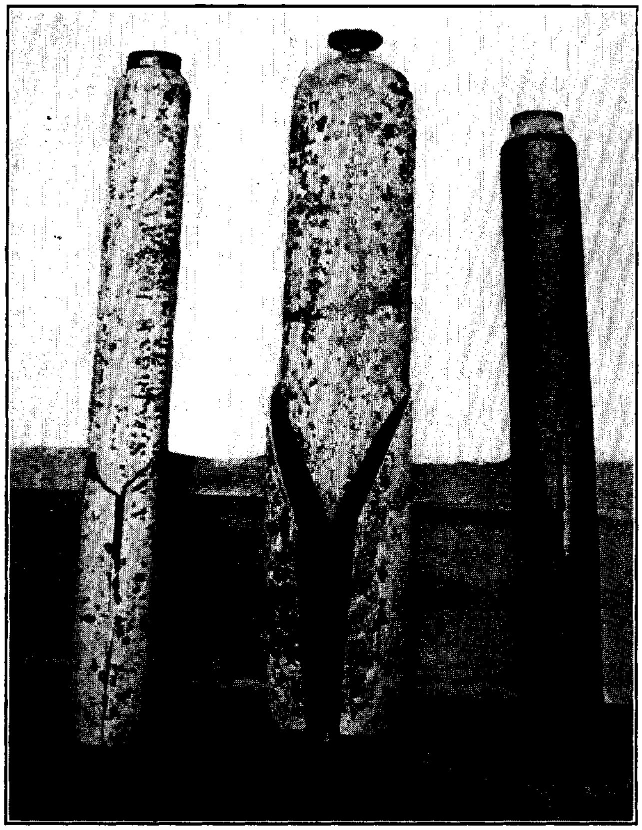

FIG. 4.—HYDRAULIC TESTS.

Work was then directed along this line and the following specifications tentatively adopted. In view of the results subsequently obtained in the various tests briefly outlined below they were later incorporated, through the Bureau of Explosives, in the Regulations of the Interstate Commerce Commission, becoming effective October 1st, 1911.

SPECIFICATIONS FOR SEAMLESS STEEL CARBONIC ACID GAS CYLINDERS AS APPROVED BY THE BUREAU OF EXPLOSIVES, AMERICAN RAILWAY ASSOCIATION.

Cylinders are to be made seamless, of steel of uniform quality, to comply in the present state of the art with the following specifications:

CHEMICAL ANALYSIS.

Carbon is not to exceed	0.55 per cent.
Phosphorus is not to exceed	0.04 per cent.
Sulphur is not to exceed	0.05 per cent.

PHYSICAL TESTS.

Elastic limit is not to be less than 50,000 pounds, nor more than 65,000 pounds per square inch on specimen cut longitudinally from a representative finished cylinder after annealing.

Elongation is not to be less than 10 per cent. on an 8″ length of longitudinal test specimen cut from a representative finished cylinder after annealing.

FLATTENING TEST.

For each lot of 200 a representative finished cylinder, after annealing, is to withstand, without cracking, flattening between rounded knife edges to a thickness four times the thickness of the wall of the cylinder. The knife edges are to be of wedge shape, converging at an angle of 60°, the point being rounded off with a radius of one-half inch. If any one cylinder from any lot fails to pass this test, two others from the same lot will be selected, and these must pass it in order to have the lot accepted. If it should appear that failure in the test was due to improper annealing, the manufacturer has the privilege of re-annealing the lot and repeating the test.

One out of each 200 cylinders is to be subjected to the above chemical, physical and flattening tests.

ANNEALING.

All cylinders after finishing are to be uniformly and properly annealed; dirt and scale are to be removed before painting.

FIG. 5.—FIRE TEST, CYLINDER NO. 1.

HYDROSTATIC TEST.

Every finished and annealed cylinder is to be subjected to hydrostatic test in a water jacket or other apparatus of approved form, whereby an interior pressure of not less than 3,000 pounds per square inch will be applied. The permanent expansion shall not exceed 5 per cent. of the whole volumetric expansion at this pressure.

THICKNESS.

The wall of cylinders of both 5-1/2" and 8-1/2" outside diameter is not to be less than 0.25" thick and this is to be verified on each cylinder before necking down.

FIG. 6.—FIRE TEST, CYLINDER NO. 4.

WEIGHT.

The standard 8 1/2" × 51" cylinder, without cap, shall weigh not less than 105 pounds, nor more than 115 pounds.

INSPECTION.

The purchaser shall provide for inspection at the mills by a competent and disinterested authority, who shall be provided with a copy of the order containing all information relating thereto other than price. The inspector shall keep complete records of the various melts from which the steel is taken for the manufacture of the cylinders. Chemical analyses of these melts must be supplied to him by the manufacturer, or if desired by the purchaser, he will procure samples from which other chemica analyses may be made. The heat number shall be stamped on these plates at the steel mill by the inspector, and his stamp, when placed on a completely finished cylinder, shall be taken as certifying that such cylinder comes within the above physical and chemical specifications.

The Inspector shall witness the hydrostatic and flattening tests of all cylinders and shall certify to the maker, the purchaser and the Chief Inspector of the Bureau of Explosives, No. 24 Park Place, New York City, the serial numbers of all cylinders which pass them successfully. He shall stamp his initials on such cylinder immediately beneath the serial number, and the initials of the owner shall be stamped on the flange or ring of the cylinder.

The hydrostatic and flattening tests shall be made by the manufacturer, but under the direction and supervision of the inspector, or other representative of the purchaser.

GENERAL CONSTRUCTION.

All plates from which cylinders are made shall be free from seams, cracks, laminations or any defects which may prove injurious to the finished cylinder.

The manufacture of the cylinders must be completed with the best appliances and according to the best modern methods. All finished cylinders must show reasonably smooth and uniform surface finish, inspection of inside surface to be made before necking down; the threading of tap and of flange must be even and without checks, and the cylinders must show no defects of workmanship or material likely to result in any appreciable weakness of the finished cylinder. A close inspection of each completed cylinder shall be made to discover the existence of any defect before acceptance.

Extensive investigations were carried out by the National Tube Co. at McKeesport on cylinders made to these and to other specifications, involving explosion of the cylinders by air pressure, the destructive medium consisting of one part of water to twenty-five parts of air at atmospheric pressure.

Appended (Fig. 7) is a photograph of ten high carbon cylinders thus exploded. These were from

FIG. 7.—AIR TESTS, HIGH CARBON CYLINDERS.

a lot closely approximating the above specifications.

They averaged on the unannealed cylinders as follows:

Carbon	0.041
Phosphorus	0.021
Sulphur	0.030
Manganese	0.63
Elastic limit	52,000—55,000 lbs.
Tensile strength	95,000–100,000 lbs.
Elongation	12–14 per cent.
Reduction of area	16–22 per cent.
Weight	95 lbs.

The average yield point of six cylinders before annealing was 3,400 lbs.—after annealing 2,900 lbs. Four cylinders Nos. 7, 8, 9 and 10 were not annealed. They burst at pressures from 5,500–5,800 lbs. per sq. in. The others were annealed to temperatures varying from 1440°–1800° F. and burst at pressures of from 5,050–5,900 lbs. per sq. in. The fragmentation was poor and showed no appreciable difference between the annealed and the un-annealed cylinder.

In comparison with these results very gratifying results had been obtained at McKeesport on exploding with the same air mixture the low carbon Linde cylinders and especially some cylinders made of chrome vanadium steel. Photographs of both are appended.

The Linde cylinders shown (Fig. 8) averaged as follows:

Silicon	0.192
Sulphur	0.016
Phosphorus	0.015
Manganese	0.50
Carbon	0.23
Elastic limit	36,000 lbs.
Tensile strength	65,000 lbs
Elongation in 8″	27 per cent.
Reduction of area	50 per cent.

All were annealed to 1590° F. Seven of the ten cylinders had no permanent set at 3,300 lbs. pres-

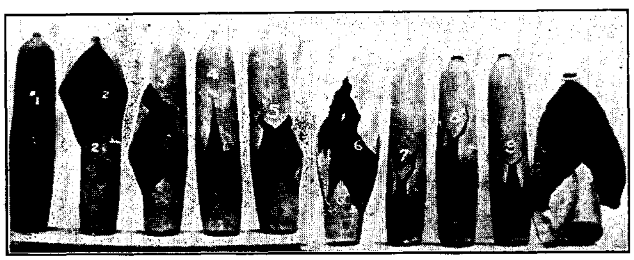

FIG. 8.—AIR TESTS, LINDE CYLINDERS.

sure. Five yielded at 3,600 lbs. All burst at pressures from 6,550–7,000 lbs. and excepting one, which broke in two pieces, there was no fragmentation, the cylinders merely opening up.

The first lot of vanadium cylinders was made up with a 3/16″ wall and the weight averaged 77 lbs. against 95 lbs. for the old high carbon cylinders. The cylinders averaged as follows:

Carbon	0.20
Phosphorus	0.049
Manganese	0.60
Silicon	0.031
Chrome	1.05
Vanadium	0.15
Elastic limit	63,500–68,800
Tensile strength	84,000–93,000
Elongation	8.25–16.5 per cent.
Reduction of area	41.8–50.4 per cent.

It should be noted that this test was taken from one of the untreated cylinders. This treatment comprised annealing to 1500°, tempering and re-annealing to about 1000°, and produced quite uniform results. One cylinder which before treatment showed 15 per cent. permanent set at 3,500 lbs., showed after treatment none at 4,000 lbs. and only yielded at 6,250 lbs. The yield points varied from 5,500–6,650 lbs. and the bursting pressures from 6,200–7,100 lbs. per sq. in. One cylinder broke in two pieces but the others stayed whole.

Another lot of vanadium cylinders (Fig. 9) was made exactly like the first except that the wall was

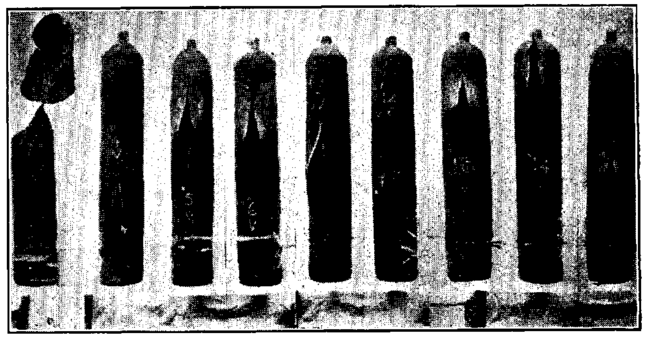

FIG. 9.—AIR TESTS, VANADIUM CYLINDERS.

made 1/4″ thick, bringing the weight up to 105 lbs. Before treatment all showed less than 5 per cent. permanent set at 3500 lbs. pressure. One cylinder was not treated. It had 8 per cent. permanent set at 4,200 lbs. and burst at 6,350 lbs. pressure. Two were annealed but not tempered. One burst at 5,400 lbs. and the other at 6,000 lbs. Seven were annealed, tempered, and re-annealed, and burst at pressures varying from 6,450–8,500 lbs. The cylinder which had no treatment burst in two pieces but all the others simply opened up a longitudinal split and stayed whole.

The photographs show clearly the remarkable results obtained on exploding the vanadium cylinders with air, in comparison with other cylinders burst by the same process. It was, however, difficult to understand why the first lot mentioned, supposed to represent improvement over existing conditions, should have shattered worse than did the type of cylinders in service when the latter were burst with carbonic acid over a fire.

Therefore three cylinders were taken (Fig. 10): One of those made up to the new specifications (N),

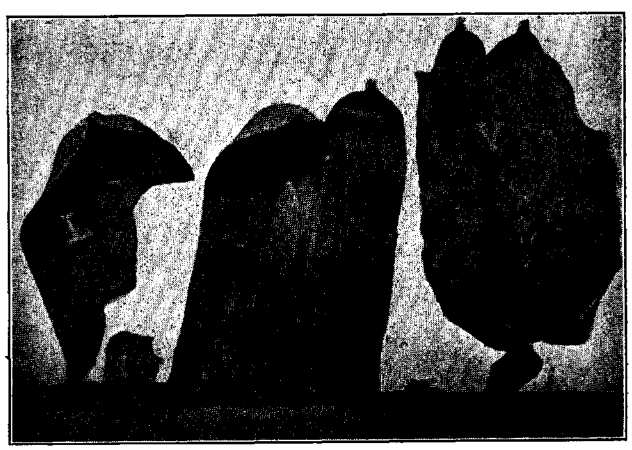

FIG. 10.—FIRE TESTS.

a Linde low carbon cylinder (L), and a vanadium cylinder (V). Each was filled with carbonic acid to a density of 0.57 and burst over an open fire at Saratoga. The photograph shows the result. The new high carbon cylinder, as usual with this type, had its bottom blown off, the remainder opening out in one piece. The vanadium cylinder opened up in about the same fashion and at least one good sized piece flew off. The Linde cylinder blew into at least three pieces, only two-thirds of it being found after the explosion.

Another cylinder, No. 1 B, made to the new specifications, was also blown up over fire with very similar results. Its composition was:

Carbon	0.43
Phosphorus	0.010
Manganese	0.625

Another test was of a German cylinder, No. 1 A, about four years old, which on explosion broke in two pieces. Its composition was:

Carbon	0.43
Phosphorus	0.044
Sulphur	0.046
Manganese	1.11
Silicon	0.204

It will be observed that these fire tests gave results differing considerably from those obtained at McKeesport with the mixture of air and water and they were therefore continued at McKeesport, being preceded by several air tests.

Two cylinders made to the new specifications were exploded with air. One burst at 5,500, the other at 5,900 lbs. pressure—no pieces flying and in each case showing two vertical cracks joined by a longitudinal one. A light weight vanadium cylinder opened up one short crack at 5,300 lbs., and a Linde cylinder, at 7,100 lbs., opened up a longitudinal crack extending at each end in two oblique directions.

The fire tests at McKeesport were made on cylinders R-4, R-6, R-7 and R-8 of the following composition:

Carbon	0.41
Sulphur	0.030
Phosphorus	0.021
Manganese	0.63

Also on Cylinder H, of the composition:

Carbon	0.59
Sulphur	0.031
Phosphorus	0.020
Manganese	0.69

These were all unannealed. Both types on explosion gave about the same result and, for some reason, appreciably different from that obtained at Saratoga in the fire tests heretofore mentioned. The method of applying the heat at McKeesport was such as to require from one-half hour to an hour to produce explosion, whereas at Saratoga it took about ten minutes.

It had, therefore, been demonstrated by these tests, that no type of seamless cylinder yet available could withstand explosion from heat without fragmentation and that the new specifications would furnish a satisfactory cylinder, and they were therefore formally adopted.

In comparison with the varied results obtained in this investigation, it is of interest to note some of those in the tests of the first two lots made to order after the new specifications became official.

Test cylinders (Fig. 11) from order No. 6,210 averaged:

Carbon	0.45
Phosphorus	0.019
Sulphur	0.034
Elastic limit	54,700
Tensile strength	84,600
Elongation	18 per cent.
Weight	112 lbs.

Cylinder B-3 burst under air at 5,600 lbs. and B-4 at 5,000 lbs. Neither had any permanent set at 3,000 lbs.

FIG. 11.—TESTS ON ORDER NO. 6210.

Test cylinders (Fig. 12) from order No. 5,623 averaged:

Carbon	0.45
Phosphorus	0.017
Sulphur	0.034
Elastic limit	55,700
Tensile strength	90,900
Elongation	15.5 per cent.

Cylinder B_1 burst under air at 5,200 lbs., B_2 at 5,650 lbs. and B_3 at 5,600 lbs.

It will therefore be seen that on the whole there is reason for the belief that the new specifications mark a decided advance in the making of carbonic acid cylinders.

Both the new specifications and the Interstate Commerce regulations require a hydrostatic stretch test and the latter provide for its repetition every five years at a pressure not less than one and a quarter times the interior pressure that would result from heating the cylinder in its maximum charged condition to a temperature of 130°. A cylinder must be condemned if the permanent expansion exceeds 5 per cent. of the total expansion.

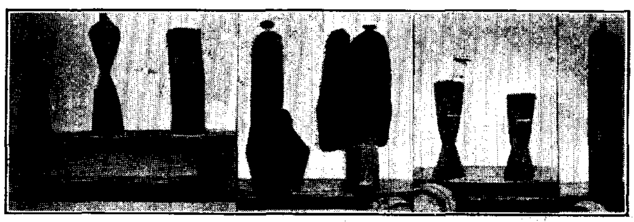

FIG. 12.—TESTS ON ORDER NO. 5623.

Two methods may be used to conduct such tests with the required accuracy. In the water jacket method the cylinder to be tested is filled with water and submerged in a large tube or jacket through whose removable, but water-tight, cover passes the pipe connecting the cylinder with the high-pressure pump. The jacket is provided with a graduated glass tube like a gauge glass, to act as an expansion indicator, and is completely filled with water, after which the level in the glass tube is noted. The test pressure is then applied to the cylinder and the levels noted during and after the application, the water in the jacket being forced into the glass tube as the cylinder expands and receding to its former level after removal of pressure if there has been no permanent expansion. The other method (Fig. 13) involves the use of the Sturke-Watson-Stillman testing machine and dispenses with a water-jacket. This machine consists essentially of a screw displacement piston which forces enough water into an already filled cylinder to produce the desired pressure.

Attached to the pump cylinder are two graduated glass tubes, one serving as the expansion indicator, the other, back of the stuffing box, as the leakage indicator. The exact delivery of the pump per turn of screw is known and provision made for registering each turn or fraction thereof.

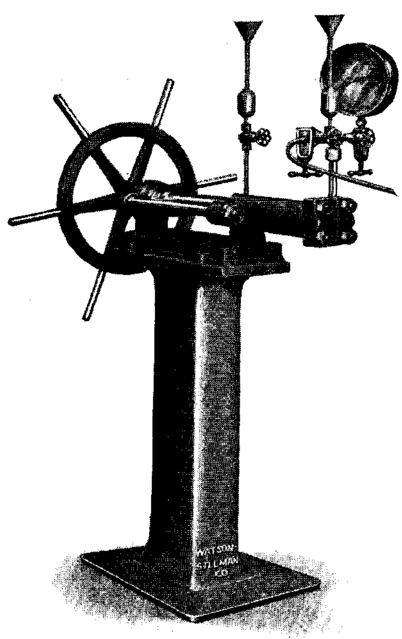

Fig. 13.

Assuming the cylinder under test to be full of water and all connections between it and the pump free of air, a reading is made of both indicators and the position of the piston accurately noted on the graduated scale provided for that purpose. The expansion indicator is then closed off with a valve, and the hand wheel turned until the desired pressure is attained after which the piston is carefully returned to exactly its original position and the valve to the expansion indicator re-opened. It is plain that if the cylinder suffered any permanent expansion its water-containing capacity must have been increased. The extent of this is measured by noting the new level—if such there is—in the expansion indicator after opening the valve.

In calculating the total expansion, proper allowance must be made for the compressibility of the water in both pump and cylinder and for the volume displaced as indicated on the graduated scale.

This method requires more care than the water-jacket method, but when properly conducted is more expeditious and avoids not only the discomforts attendant upon the raising of cylinders from immersion in water but also the necessity of any lifting whatsoever.

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New York City.

THE COMPOSITION OF SOME MINE GASES, AND A DESCRIPTION OF A SIMPLE METHANE APPARATUS.[1]

By G. A. Burrell.

Received Dec. 15, 1911.

The Bureau of Mines has, in the study it has been making of mine gases, examined samples taken under different conditions, some of which are here presented, also some analytical results obtained in related experimental work.

No. 1 Series.

No. 1 Sample: Incomplete combustion of methane. Original mixture contained 10.03% CH_4.

Products found after explosion	10.16% CO_2
	2.13% CO
	1.39% H_2
	86.32% N_2
	0.00% O_2
	0.00% C_2H_4
	0.00% CH_4

No. 2 Sample: Incomplete combustion of methane. Original mixture contained 10.94% CH_4.

Products found after explosion	8.35% CO_2
	4.47% CO
	3.66% H_2
	83.52% N_2
	0.00% O_2
	0.00% C_2H_4
	0.00% CH_4

In these experiments pure methane was prepared and mixed with air in such proportion that not enough of the latter was present for the complete combustion of the methane. The mixtures were then exploded and the products of combustion examined. The most explosive proportion of methane and air contains 9.47 per cent. of methane. When the latter is increased above this figure certain products are formed about which there has been some disagreement. Some investigators have gone on record as saying that no carbon monoxide is formed. According to these experiments the carbon monoxide and hydrogen increase, and the carbon dioxide decreases as the methane content of the original mixture is raised. Olefine hydrocarbons, acetylene, or unburned methane were not found in the products of combustion. The carbon monoxide and carbon dioxide formed satisfies the carbon originally present

[1] Paper read at the December Meeting of the Coal Mining Institute of America by permission of the Director of the U. S. Bureau of Mines.