CYLINDERS AND TUBES USED AS BUFFERS IN THE FILLING STATIONS

Barthélémy H.
Air Liquide, 75 quai d'Orsay, 75321 Paris cedex 07, France herve.barthelemy@airliquide.com
And Agnoletti. A.
Faber, 2 Borgata Padova, Castelfranco Veneto, TV 31033, Italie alberto.agnoletti@faber-italy.com

ABSTRACT (UP TO 300 WORDS)

Buffers are key components for hydrogen filling stations that are currently being developed. Type 1 or composite cylinders are used for this application. The type used depends on many parameters including pressure level, cost and space available for the filling station. No international standards exist for such high pressure vessels whereas many standards exist, covering Types 1,2,3 and 4 used for transport of gas or on-board fuel tanks. It is suggested to use the cylinders approved for transport or on-board applications as buffers. This solution appears to be safe if, at least, one issue is solved. The main difference is that transport or on-board cylinders are cycled from a low pressure to a high pressure during service whereas buffers are cycled from a relatively high pressure (corresponding to the vehicle's filling pressure) to the MAWP. Another difference is that buffers are cycled many times per day. For standards developers, requesting to systematically verify that buffers pass millions of cycles at low pressure amplitude would be impractical. Several standards and codes give formulae to estimate the number of shallow cycles when number of deep cycles are known. In this paper, we describe tests performed on all types of composite cylinders to verify or determine the appropriate formulae.

1.0 INTRODUCTION

Buffers are key components for hydrogen filling stations that are currently being developed. Type 1 or composite cylinders are used for this application (see Figure 1 below):

***Figure 1*-Composite Type 2 cylinders for stationary applications**

The type used depends on many parameters including pressure level, cost and space available for the filling station.No international standards exist for such high pressure vessels whereas many standards exist, covering Types 1,2,3 and 4 used for transport of gas or on-board fuel tanks. It is suggested to use the cylinders approved for transport or on-board applications as buffers. This solution appears to be safe if, at least, one issue is solved. The main difference is that transport or on-board cylinders are cycled from a low pressure to a high pressure during service whereas buffers are cycled from a relatively high pressure (corresponding to the vehicle's filling pressure) to the MAWP. Another difference is that buffers are cycled many times per day.

For standards developers, requesting to systematically verify that buffers pass millions of cycles at low pressure amplitude would be impractical. Several standards and codes give formulae to estimate the number of shallow cycles when number of deep cycles are known .In this paper, we describe tests performed on types 2 and 3 of composite cylinders to verify or determine the appropriate formulae.

2.0 Tests performed

The aim of the tests was to identify the relation between Pressure cycle amplitude and number of cycles to failure for different cylinder designs (Type1 and composite Type 2 and Type 3):

Figure 2 shows one of the type cylinder tested, figure 3, one of the composite type 2 cylinder and figure 4, one of the composite type 3 cylinder.

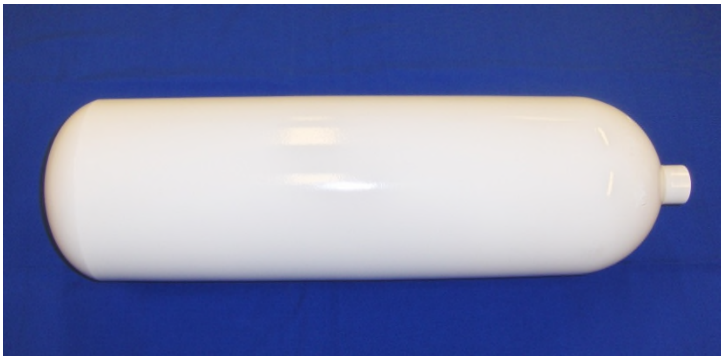

***Figure 2*- Type 1 cylinder designed to ISO 9809-1 for WP = 232 bar**

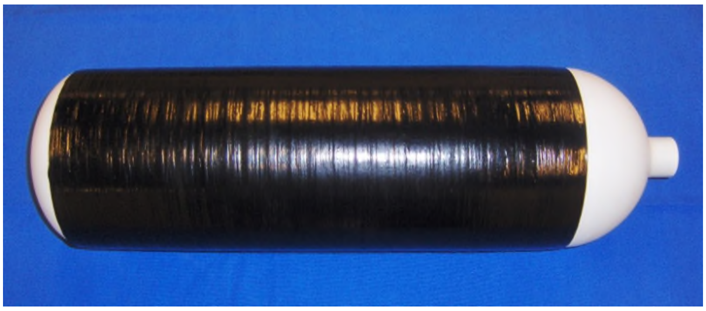

***Figure 3*-Composite Type 2 cylinder designed to ISO 11119-1 for WP = 232 bar**

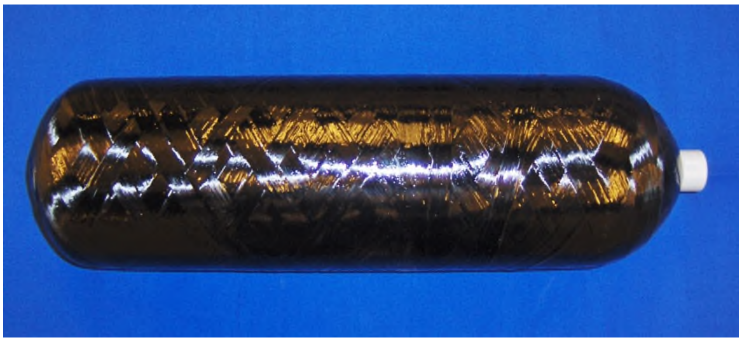

***Figure 4*- Composite Type 3 cylinder designed to ISO 11119-2 for WP = 232 bar**

The methodology adapted was as follows: for each cylinder design, 3 groups of 5 cylinders are taken from one batch and are pressure cycled at different pressure amplitude:

- 5 cylinders are pressure cycled from 20 to 450 bar,
- 5 cylinders are pressure cycled from 20 to 390 bar,
- 5 cylinders are pressure cycled from 20 to 300 bar,
- 5 cylinders are pressure cycled from 150 to 300 bar.

A total of 60 cylinders were pressure cycled.

3.0 Test results

The results are given in tables 1, 2 and 3 (table 1 for type 1 cylinders, table 2 for type 2 cylinders, table 3 for type 3 cylinders).

The results are also summarized in figures 5,6,7 (pressure amplitude versus number of cycles) and in figures 8,9, 10 (pressure amplitude versus the number of cycles expressed as a multiplication factor where 1 is equal to the average of cycles at a pressure amplitude of 430 bar), respectively for type 1, type 2 and type 3 cylinders.

Pressure range (bar)	Pressure amplitude (bar)	Number of cycles	Number of cycles (1 = average of cycles at pressure amplitude 430 bar)
20-450	430	13721	0.96
		19125	1.33
		10597	0.74
		14252	0.99
		14142	0.98
20-390	370	21448	1.49
		29881	2.08
		35786	2.49
		37791	2.63
		40216	2.80
20-300	280	124992	8.70
		128523	8.95
		236212	16.44
		210998	14.69
		243743	16.97
150-300	150	128020	8.91
		273878	19.06
		Stopped at 1000000	Stopped at 69.60
		Stopped at 1000000	Stopped at 69.60
		Stopped at 1000000	Stopped at 69.60

Table 1 **-Type 1 cylinders – Tests results**

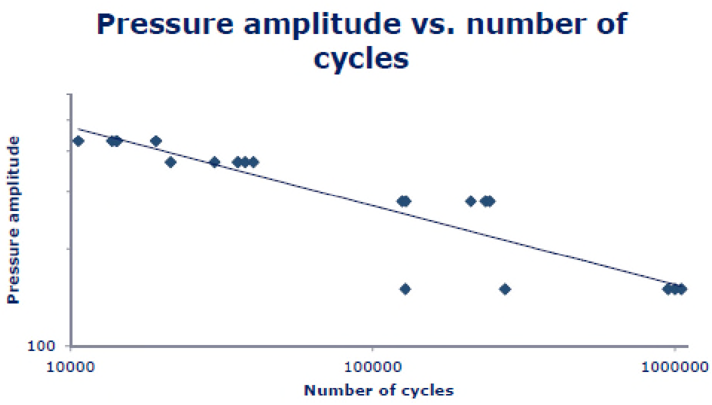

Figure 5 - **Type 1 cylinders/ Tests results**

Pressure range (bar)	Pressure amplitude (bar)	Number of cycles	Number of cycles (1 = average of cycles at pressure amplitude 430 bar)
20-450	430	6249	0.95
		7152	1.09
		5750	0.87
		6286	0.95
		7494	1.14
20-390	370	17118	2.60
		12143	1.84
		20879	3.17
		24030	3.65
		17804	2.70
20-300	280	37195	7.38
		33155	5.65
		33465	5.03
		48591	5.08
		42776	6.49
150-300	150	53935	8.19
		78796	11.96
		202248	30.71
		170423	25.88
		157080	23.85

Table 2 **– Type 2 cylinders – Tests results**

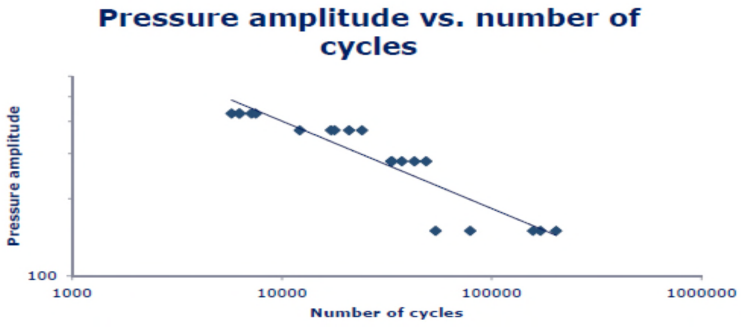

Figure 6 - **Type 2 cylinders/Tests results**

Pressure range (bar)	Pressure amplitude (bar)	Number of cycles	Number of cycles (1 = average of cycles at pressure amplitude 430 bar)
20-450	430	5856	0.98
		5338	0.89
		6464	1.08
		6697	1.12
		5495	0.92
20-390	370	13306	2.23
		14992	2.51
		12018	2.01
		12168	2.04
		14268	2.39
20-300	280	33083	5.54
		35451	5.94
		73244	12.27
		67746	11.35
		62782	10.52
150-300	150	138640	23.22
		199093	33.35
		89326	14.96
		271186	45.42
		346752	58.08

Table 3- **Type 3 cylinders – Tests results**

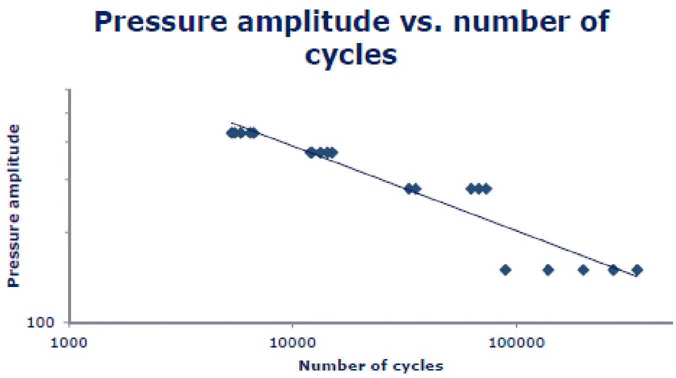

Figure 7 **-Type 3 cylinders/Tests results**

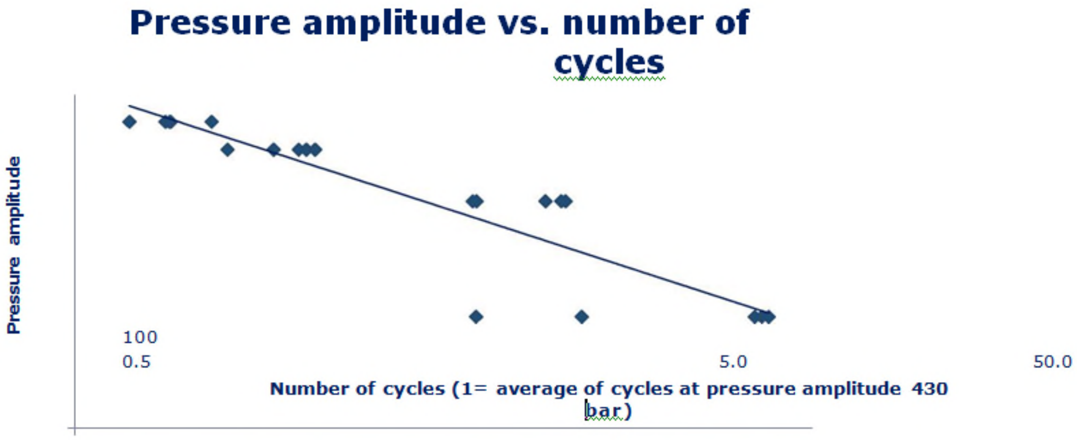

Figure 8 **-Type 1 cylinders /Tests results**

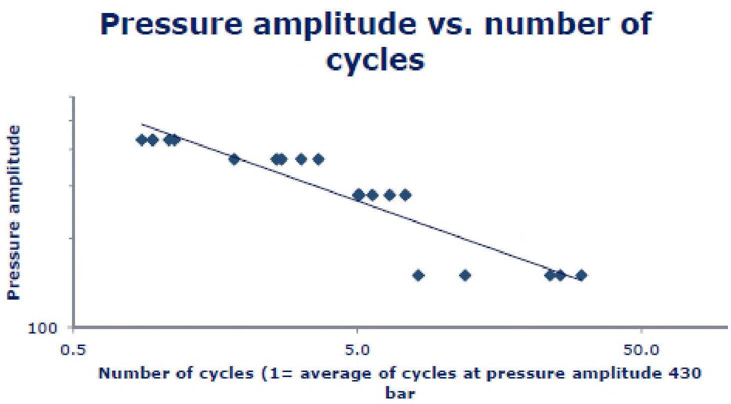

Figure 9 **-Type 2 cylinders /Tests results**

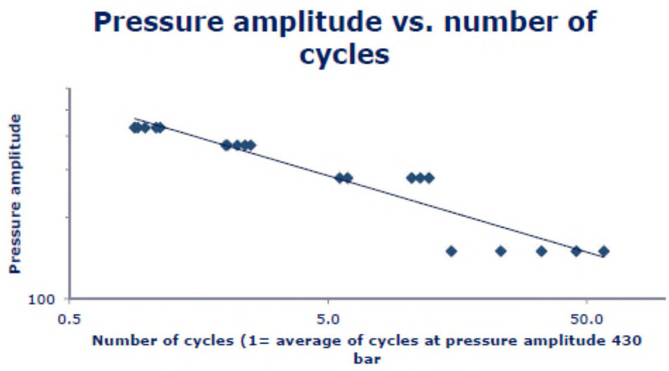

Figure 10 **-Type 3 cylinders / Tests results**

4.0 Analysis of the results

Finally, the results shown on figures 8,9 and 10 are summarized on a single curve given in figure 11:

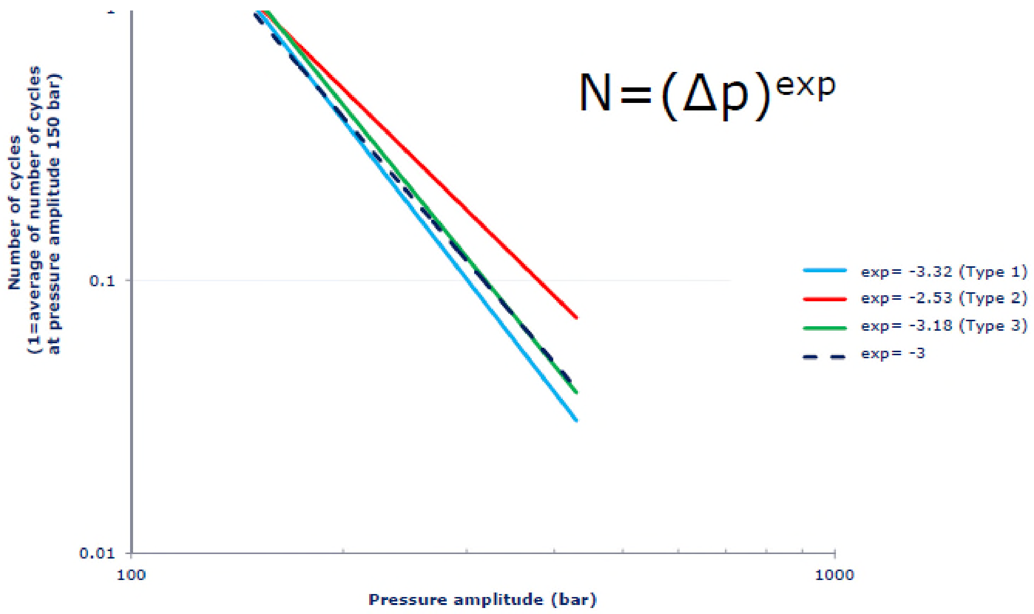

Figure 11 **– Comparison of Types 1,2 and 3 cylinders**

Figure 11 shows for the 3 types of composite cylinders the number of cycles N and the pressure amplitude ΔP. The number of cycles N can be expressed in accordance with the formula $N = (\Delta P)^{exp}$ (1). In these cases, we found:

Exp = - 3.32 for Type 1

Exp = - 2.53 for Type 2

Exp = - 3.18 for Type 3

The last version of ISO/CD/19884 prepared by ISO/TC 197/WG 15 proposes the following formula:

$$n_{eq} = \sum n_i \left(\frac{\Delta Pi}{\Delta P_{max}} \right)^3 \quad (2)$$

neq = number of shallow cycles equivalent to number of full cycles required in a given standard.

Note: For pressure vessels to ISO 11120 the number of full cycles shall be taken as 12 000 cycles at Ph.

For other standards or codes where no pressure cycle requirements exist, cycle tests will full pressure amplitude shall be carried out.

ΔPi = variation of pressure during a given actual (shallow) pressure cycle

ni = number of (shallow) pressure cycle corresponding to ΔPi

ΔPi max = pressure amplitude during the (full) cycle tests as specified in the reference standard

5.0 Conclusion

Tests have been performed on Type 1, and composite cylinders Type 2 and 3 (60 cylinders in total). The aim of the tests was to identify the relation between Pressure cycle amplitude and number of cycles to failure for different cylinder designs.

Cylinders were pressure cycled from 20 to 450 bar, from 20 to 390 bar, from 20 to 300 bar and from 150 to 300 bar.

The tests performed confirmed the validity of the formula used in ISO CD 19884 for the shallow and deep cycles, that is:

$$n_{eq} = \sum n_i \left(\frac{\Delta Pi}{\Delta P_{max}} \right)^3 \quad (2)$$