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CARLETON ISO 9001

COMPOSITE PRESSURE VESSEL USERS GUIDE

COMPLETE REFERENCE MANUAL FOR INFORMATION REGARDING YOUR CARLETON PRESSURE VESSEL.

Pressure Vessel Users Manual
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Carleton Technologies Inc.

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TABLE OF CONTENTS

General Information About your Pressure Vessel

1.1 INTRODUCTION

CARLETON Composite Cylinders are very lightweight structural members designed to hold pressurized gas for a wide range of high-pressure applications. All our Pressure Vessels are primarily designed with safety and quality in mind. This design approach produces a product that is durable and very capable of being in service safely for the entire design life.

Being part of a high-pressure system your Composite Cylinder is considered hazardous material while pressurized. For this reason, these types of products are strongly controlled by local governing bodies, the Department of Transportation (DOT) in the USA, Transport Canada (TC) in Canada and the Pressure Equipment Directive (PED) or Transportable Pressure Equipment Directive (TPED) in Europe.

With all high-pressure systems, carefully follow all instructions provided to you by the system manufacturer on proper filling and operation. This manual is designed to provide additional information on your cylinder and guide you on how to properly maintain and operate your Composite Pressure Vessel.

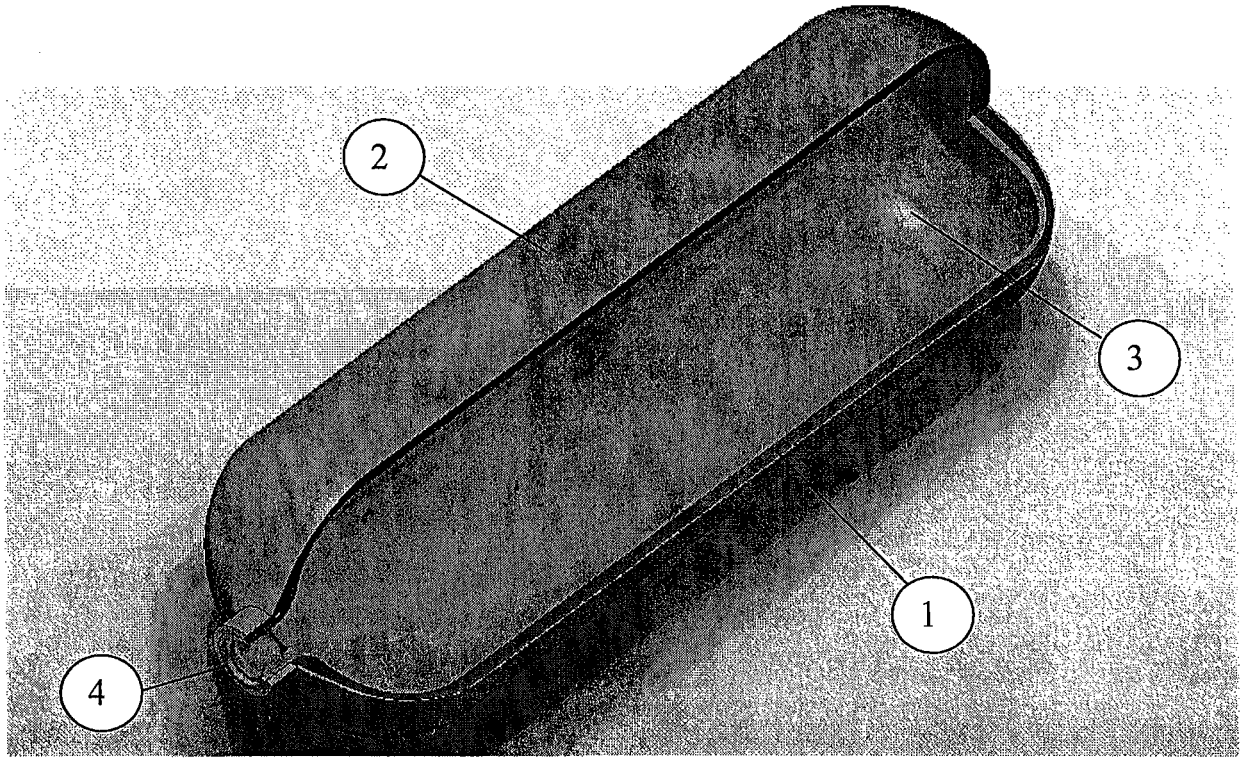
All of CARLETON's Cylinders are Designed and manufactured by the Pressure Technology Division.

IT IS YOUR RESPONSIBILITY TO BE AWARE OF AND COMPLY WITH ALL APPLICABLE LAWS AND REGULATIONS REGARDING THE FILLING AND OPERATION OF YOUR HIGH-PRESSURE SYSTEM. AT NO TIME WILL THIS MANUAL SUPERSEDE ANY GOVERNING BODY REGULATIONS.

1.2 MANUFACTURE

CARLETON cylinders are designed and manufactured in Maryland, United States of America. All composite pressure vessel designs encompass a common component structure in which an aluminum liner is overwrapped with resin impregnated reinforcing fibers. This reinforcement can be either carbon fiber or fiberglass.

In the case of a carbon fiber cylinder an external layer of fiberglass is added for impact and abrasion resistance. This glass layer also serves to embed the required Identification Label.



1- Epoxy impregnated high strength carbon fiber
2- Epoxy impregnated fiberglass
3- Aluminum liner
4- Machined port and threads

1.2.1 Aluminum Liner

This initial component is a thin walled aluminum cylinder that is made out of 6061 Alloy. The material is either flow formed or cold drawn into a specific design thickness open-ended cylinder. The open end is then "spun" or "swaged" to form the neck, close the volume and form the outer liner geometry.

After the external geometry is achieved, the liner is heat treated until a T6 condition is achieved. Following this operation the desired port features are machined and the internal port threads are cut.

1.2.2 Composite Reinforcement

Carbon Fiber Pressure Vessels

Carbon fiber pressure vessels use two different resin impregnated fiber types as the reinforcement over the aluminum liner. A layer of carbon fiber is followed a glass fiber layer to complete the reinforcement. Although the pressure vessel uses two different fibers, it is the carbon fiber layer, which is the main structural load carrier. Although the glass fiber layer contributes to the vessels strength, it is mostly used to protect the vital carbon fiber layer from impact and abrasion damage.

Glass Fiber Pressure Vessels

Glass fiber pressure vessels use a single fiber type as the composite reinforcement. They are composed of the aluminum liner and resin impregnated structural S-Glass. These pressure vessels carry the same degree of safety as a carbon cylinder but have a single material type as reinforcement which makes the cylinder more sensitive to surface damage.

REFER TO SECTION 4.3 FOR MORE INFORMATION ON SURFACE DAMAGE AND REJECTION CRITERIA.

1.3 MANUFACTURING PROCESS

CARLETON uses a computer numerical control filament-winding machine to precisely place the reinforcing fibers at desired angles and thickness over the outer surface of the liner.

Before the winding process begins, the external surface of the liner is coated with an insulating epoxy layer to protect it from possible galvanic corrosion –only on carbon fiber cylinders– . After this epoxy layer is cured, the reinforcement fiber is applied.

When the liner is ready to be "wound", each coated liner is placed on a computer controlled rotating spindle and the resin-impregnated fiber is delivered via a tension control system and arm set up. As the spindle rotates the liner, the fiber is precisely placed at the desired locations until the design is completed.

After winding is finished, the parts are then placed in an oven to ensure proper cure of the resin matrix. This cure process is very rigidly controlled via computer oven controllers, which ensure specific thermal profiles for proper cures.

After the cure profile has finished, the parts are allowed to cool down and then moved onto a finishing operation where they are painted or clear coated.

1.4 MANUFACTURING ACCEPTANCE INSPECTION AND TESTING

CARLETON performs several acceptance inspections and tests on every part before they are shipped to a customer in order to ensure you are receiving a safe, and reliable product.

Aluminum Liner

The Aluminum Liner material is tested per the requirements of DOT, TC, PED/TPED in order to ensure the mechanical properties -i.e. strength and elongation- are compliant with the design.

Before production begins, a representative sample of the finished liner lots undergoes a dimensional inspection to ensure compliance with design dimensions and thickness. After the liners have successfully passed these inspections then they can be used for production.

Composite Reinforcement

Just like the liner material, the reinforcement fibers and the epoxy resin used to impregnate them are also tested for required mechanical properties. This is done to verify that the actual strength of the fibers and resin fall within specified limits –minimum and maximum–. All fibers and resin systems are tested prior to production use on any part.

Finished Part

After the parts are wound, cured and finished they undergo an Autofrettage cycle to achieve a compressive state in the composite when no pressure is applied.

This compressive state is achieved by pressurizing the cylinder above the point where the aluminum would deform permanently and then releasing the pressure. The difference in rigidity between the composite and the aluminum allows the fiber reinforcement to slightly compress the liner, thus leaving it in compression while the fiber is in tension.

After Autofrettage, the vessels are then "Hydrotested" to ensure proper performance and safety upon operation. This test consists on pressurizing the Vessels to "Test Pressure" and recording the amount of volume they expanded both permanently and elastically. These expansions are then evaluated by a recognized "Third party Inspector" and after successful evaluation, the vessels are considered to be finished goods that can be safely used on high-pressure applications.

Performing a hydrostatic burst test and a pressure cycle test; both of which are performed by an outside "Third Party Inspector" further validates production cylinder lots.

The burst test consists of pressurizing the cylinder until failure occurs and recording the maximum hydrostatic pressure achieved, which is compared with required minimums set by the governing bodies.

The cycle test is performed by consecutively pressurizing and de-pressurizing the cylinder between zero and operating pressure for a predetermined number of cycles, which is determined by the governing bodies. The test unit is required to withstand all the required cycles without leaking in order to pass the test.

Following these acceptance tests a representative sample of finished vessels are then meticulously inspected to ensure compliance with required dimensions and weights.

YOU CAN REST ASSURED THAT YOUR CARLETON PRESSURE VESSEL HAS BEEN MANUFACTURED WITH THE UTMOST REGARD FOR QUALITY AND SAFETY.

Design Qualifications

2.1 Governing Bodies

The gas contained in high-pressure systems is considered hazardous material since the energy in the compressed gas has the potential to cause serious injury or death should a failure occur in the containment vessel. In order to establish appropriate levels of safety, governing bodies in most countries control their design and use. These government agencies set standards of design and manufacture in order to insure the safety of the public.

In the USA, the DOT has established several codes and regulations for pressure vessels. Carbon fiber cylinders are governed by DOT CFFC and Fiber Glass cylinders are governed by DOT FRP1. Both standards are appended to the Code of Federal Regulations 49 (49CFR), which establishes regulations on general high-pressure systems. In order to manufacture parts per DOT CFFC and FPR1 an exemption from specific sections of 49CFR is required. The exemption number is required on the identification label of all pressure vessels. CARLETON manufactures carbon fiber cylinders under exemption DOT E-11194 and fiberglass cylinders under DOT E-11005.

In Canada, Transport Canada is the governing body that controls the design, transportation and use of high-pressure systems under CAN/CSA B339-02. Carbon fiber cylinders are controlled by special permit –similar to DOT exemption– TC SU-5303. This standard establishes an equivalent level of safety as defined on CAN/CSA B339. Fiberglass cylinders are controlled by TC 3FCM, which is also included in CAN/CSA B339. Cylinders that have been manufactured per these TC standards will have the applicable standard marked on the permanent label.

Europe establishes pressure system standards depending on the application. For self-contained breathing apparatus (SCBA) the

standards are established by PED. For all other applications TPED is the set standard. Both of these governing entities assess the pressure vessels per a common test procedure established in EN12245. A pressure vessel that has been approved per PED will have a permanent "CE" mark on the label to identify compliance with the standard. In a similar manner TPED is identified by having a "π" mark.

2.2 Design Specifications

2.2.1 Design Life

Your pressure vessel has a maximum design life of 15 years from the date of manufacture; which is found on the identification label. Check with local authorities on what is considered the maximum cylinder life in your area since it can be different depending on your region.

PRESSURIZATION OF ANY CARLETON PRESSURE VESSEL PAST THIS 15-YEAR LIFE IS NOT ALLOWED.

2.2.2 Initial Design Qualification Testing

Before a pressure vessel design is accepted to be manufactured and released for use, it must undergo a series of structural assessment and performance tests in order to ensure its integrity and degree of safety. These test procedures are dependent on the governing body that is to accept the design.

The procedures and required levels of safety are defined in the respective governing body specification documents –DOT CFFC, CAN/CSA B339, EN12245– and try to test the cylinder under any possible "worst case scenario" in order to ensure the users safety.

Once the procedure is performed with successful results, the pressure vessel design is then recognized as being up to standard for use and is accepted by the particular governing body. Acceptance of test results is absolutely required for all designs.

Any qualified design is permanently identified on the pressure vessel by having the identifying mark of the governing body on the embedded label.

Some test examples required for DOT, TC, PED and TPED are:

DOT & TC

Testing is performed per DOT CFFC, FRP1 and TC B339.

- Hydrostatic burst test
- Pressure cycling test
- Gun fire resistance test
- Bonfire test
- Thermal shock test
- Drop test
- Environmental exposure test

PED & TPED

- Hydrostatic burst test
- Pressure cycling test
- Exposure to elevated temperature
- Drop test
- Resistance to flaw test
- Fire resistance test
- High velocity impact test
- Neck strength test

In order for any pressure vessel to able to carry a governing body identification mark, the design must have successfully passed the entire test procedures mentioned above.

Pressure Vessel Operation

3.1 General Information

Composite pressure vessels are designed to operate – store pressure (energy)– like a standard metallic pressure vessel with the same or greater amount of safety. They are however slightly more susceptible to damage while in operation due to scrapes, drops, harsh environments etc. While handling your cylinder, take necessary precautions to avoid dragging, scraping, dropping, scoring or exposing to harsh chemical environments as this could result in permanent damage that can cause your cylinder to be rejected and removed from operation.

Always pay close attention to the label date and record when the unit needs to be re-tested based on local governing body standards. This is vital, as a cylinder that is past due for hydro-test cannot be pressurized.

Always investigate local governing body standards to make sure you are compliant with the applicable local laws for the operation of high-pressure systems.

Composite cylinders are safe and durable products. But like any pressurized product, misuse or abuse can end in failure and possible personal injury or death.

- Protect the surface of your cylinder at all times.
- Inspect cylinder surface for any signs of damage.
- Never pressurize above the marked service pressure.
- Follow all instructions provided by your system manufacturer.
- Do not pressurize a cylinder that is past its re-test due date.
- Never obscure or try to remove the embedded label.
- Never pressurize a cylinder that is suspect of leaking.
- Never pressurize a cylinder that has been exposed to harsh chemical environments.

3.2 Valve Installation

Before installing a valve on your cylinder inspect both the valve and the cylinder to ensure proper matting of the parts. Doing so will ensure proper performance while pressurized.

Carefully inspect the valve threads to make sure they are clean and not damaged as torquing a damaged valve can damage the liner threads. Also make sure the matting surfaces are clean and free of damage as these can be potential leak paths.

A small amount of lubricant should be applied to the threads and "O" ring to help thread the valve more easily, protect the threads and assure proper sealing with the "O" ring.

Check with your system manufacturer for proper lubricant and installation procedure. Use of an incorrect lubricant in oxygen service could present a potential fire and/or explosion hazard.

Once the valve has been threaded completely, apply torque to the valve in order to create a proper seal between the sealing surfaces. CARLETON recommends applying the appropriate torque suggested by the system supplier.

In the absence of this torque value CARLETON recommends an applied torque per standard AS 5148. The recommended values are presented on Table 1 based on the cylinder's thread size.

Fitting Size	Thread Class	Aluminum Fitting
-	-	(Ft.lb)
5	.500-20	13
6	.5625-18	18
7	.625-18	37
8	.750-16	50
10	.875-14	90

Table 1

3.3 Cylinder Pressurization

UNDER NO CIRCUMSTANCE SHOULD THE INTERNAL PRESSURE EXCEED THE MARKED OPERATING PRESSURE ON THE LABEL.

PLEASE REFER TO LOCAL PRESSURIZATION GUIDELINES FOR SPECIFIC APPLICABLE SPECIFICATIONS REGARDING HOW TO PRESSURIZE YOUR CYLINDER.

If a cylinder is pressurized at a higher temperature –due to ambient conditions or fast filling- it will lose some of its pressure as the temperature decreases.

This final pressure after cooling is called settling pressure. It might be possible that in order to reach a required fill pressure, the cylinder will have to be topped several times until the required pressure is achieved.

Alternatively the cylinder could be pressurized at a slower rate, which will reduce this temperature/pressure variation.

DO NOT PRESSURIZE YOUR CYLINDER IF THERE ARE SIGNS OF STRUCTURAL DAMAGE.

3.4 Understanding the Embedded Label

In order to comply with governing body requirements, all cylinders have to be permanently marked. This is done by embedding a label under one of the layers of clear fiberglass.

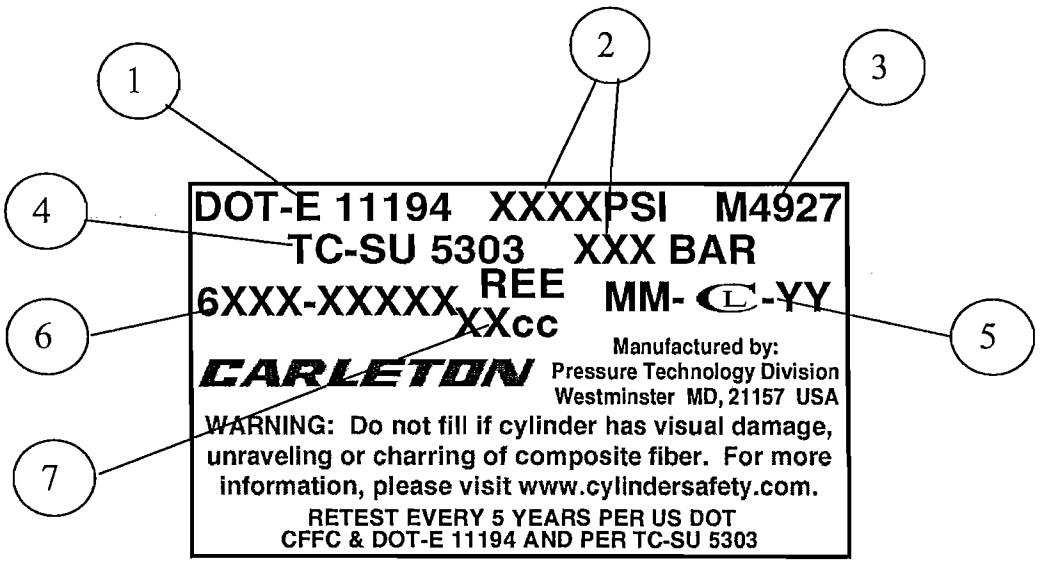
These labels contain a great amount of information that is required for the pressure vessels to be in operation.

CARLETON cylinders are identified in accordance with DOT CFFC, TC 3FCM, TC SU5303, PED & TPED.

IF AT ANY TIME THE LABEL BECOMES UNREADABLE, THE CYLINDER MUST BE REJECTED.

3.4.1 DOT & TC Requirements

DOT and TC have very similar requirements in the information that needs to be present in the embedded label.

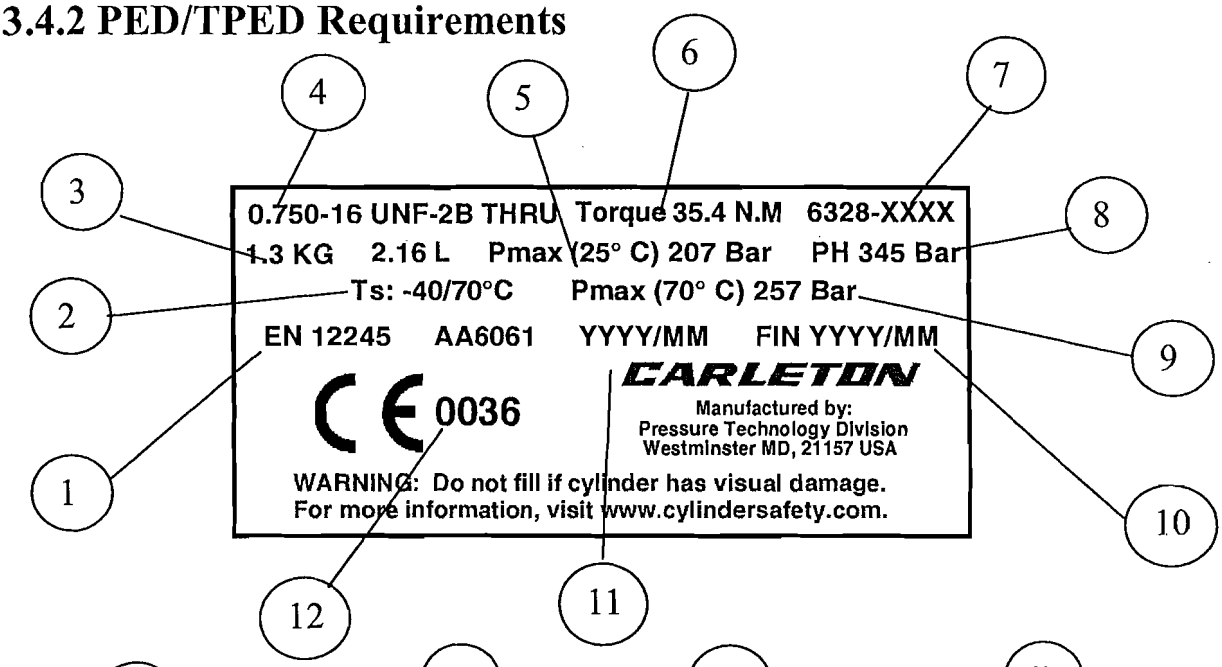


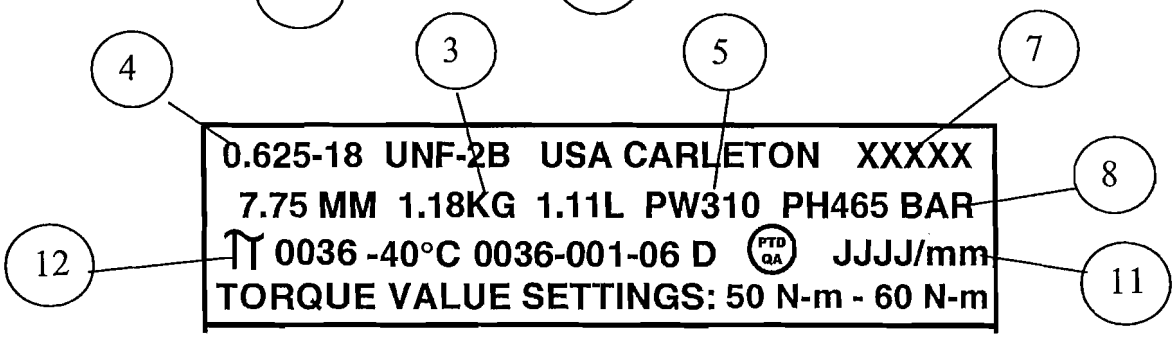
1-DOT exemption number. This number is issued to CARLETON PTD by the DOT

2-Operating pressures. Maximum pressure the cylinder can be pressurized.

3-Manufacturers identification number for CARLETON PTD.
4-TC Permit Number. Issued to CARLETON PTD by TC.
5-Date of manufacture (month, third party inspection agency, year). This date marks the start of the design life.
6-Part number and serial number
7-Rejected elastic expansion. Maximum value of elastic expansion allowed during the hydro test. If at any re-test the REE is exceeded the Cylinder must be rejected.

3.4.2 PED/TPED Requirements





1- Specification to which the cylinder compliant.
2- Operating temperature range.
3- Empty weight.
4- Cylinder thread.
5- Maximum fill pressure (operating pressure)
6- Recommended valve installation torque.
7- Part number and serial number.
8- Hydrostatic test pressure.
9- Maximum developed pressure at maximum operating temperature.
10- Cylinder expiration date.
11- Original date of manufacture. (First Hydrotest date)
12- PED/TPED compliance mark and inspecting body identification number.

3.5 Approved Gasses

Your cylinder can only be used to store certain approved gasses. These gasses are defined in the required exemptions for both carbon fiber and fiberglass cylinders.

Your system supplier will establish the gas that is to be stored to the cylinder in compliance with the gasses accepted in the exemptions.

IT IS YOUR RESPONSIBILITY TO STORE ONLY APPROVED GASSES IN YOUR CYLINDER.

Maintenance and Care of your composite Pressure Vessel

4.1 How to Store and Maintain your Pressure Vessel in Optimum Condition

When using you pressure vessel, always try to protect it from damage as much as possible. Structural damage from impacts or abrasions can cause your cylinder to be rejected.

A CYLINDER REJECTED FOR STRUCTURAL DAMAGE IS NOT ALLOWED TO BE PRESSURIZED.

When planning to store your Pressure Vessel make sure it is kept dry and away from heat sources. If the Cylinder is valved and pressurized, relieve the pressure to between 600 to 1000 psi. Clean the outside surface and place in a sealed plastic bag. If the cylinder is open, visually inspect the interior for any foreign particles or contamination and place in a sealed plastic bag.

4.2 Pre-Pressurizing Inspection

It is very important you inspect the exterior surface of your pressure vessel before any pressurization. Make sure that there are no gouges or scrapes in the composite as this can pose a potential initiation site for a possible failure.

Although some degree of damage is repairable, its extent needs to be assessed in order to accept or reject the cylinder accordingly.

Review the surface damage criteria presented in Section 4.3 of this manual in order to become familiar with the structural assessment criteria and have an authorized representative evaluate and repair your cylinder if the part is considered safe to be in service.

A CYLINDER REJECTED FOR STRUCTURAL DAMAGE IS NOT ALLOWED TO BE PRESSURIZED.

During your inspection you may come across some distinct surface traits that are inherent to a composite pressure vessel. Although they do not represent any structural degradation and do not affect performance they could be labeled as damage to the untrained eye.

THESE MARKS ARE NOT A CONCERN. THE STRUCTURAL INTEGRITY OF THE CYLINDER IS INTACT AND CAN REMAIN IN NORMAL OPERATION WITHOUT CONCERN.

Superficial Resin Craze

These are slight "linear indications" –marks- that appear over the surface of the cylinder. They are due to a superficial resin layer that forms close to where the label is embedded. During initial pressurization, this layer might separate and form slightly visible indications. This does not represent any negative effect on the cylinder and does not require repair or re-test.

THESE MARKS ARE NOT A CONCERN. THEY DO NOT REQUIRE REPAIR OR RE-TEST.

Neck Wrap Craze

Slight crazing can also be seen around the neck wrap where the winding meets the head dome of the cylinder. This is due mainly to differences in expansion rates of the individual sections. This particular region of the pressure vessel is very strong. This craze mark is completely non-structural and does not require any repair or re-test.

THESE MARKS ARE NOT A CONCERN. THEY DO NOT REQUIRE REPAIR OR RE-TEST.

Tail Plug Craze

Slight crazing might also be seen around the tail plug on the tail dome of the cylinder. This is due to differences in expansion rate of the plug material and the fiber/resin. Similar to the neck region, this is also one of the strongest areas of the cylinder. These marks are not a structural concern and do not require repair or re-test.

THESE MARKS ARE NOT A CONCERN. THEY DO NOT REQUIRE REPAIR OR RE-TEST.

4.3 Cylinder Surface Damage
Types of Damage and Rejection Criteria

VISUAL INSPECTION CRITERIA DISCUSSED IN THIS SECTION IS ONLY A RECOMMENDATION. AT NO TIME WILL THIS RECOMMENDATION SUPERSEDE ANY REGULATORY AUTHORITY PUBLISHED CRITERIA.

CARLETON composite cylinders are manufactured with an outer layer of glass fiber in order to provide impact and abrasion protection. Damage to this layer is assessed by way of a visual inspection based on published inspection guidelines.
The Compressed Gas Association (CGA) and ISO, have both established a visual criteria on what to consider when assessing the structural integrity of a cylinder with external damage. On both publications –CGA6.2 and ISO 11623, damage is divided into three categories levels, where damage severity is interpreted in an ascending severity order.

Based this visual assessment, the pressure vessel can either be repaired or will have to be rejected and put out of service.

Level 1 Damage

This is the least severe damage level. Level 1 damage can be considered normal "bumps and scrapes" that have no effect on the structural integrity of the cylinder. This type of damage does not need to be repaired and the cylinder can continue in use normally.
Example:

- Scrapes or cuts that do not penetrate the fiber and only affect the clear coat.
- Impacts that do not break or delaminate the resin, exposing fibers.

LEVEL 1 DAMAGE IS TOLERABLE AND THE CYLINDER CAN REMAIN IN OPERATION WITHOUT RE-TEST.

Level 2 Damage

Level 2 damage is somewhat greater than level 1 but the extent of the damage is more noticeable. All level 2 damages can be repaired but the Pressure Vessel needs to be tested before going into operation.
Example:

- Cuts or scrapes that slightly cut and expose top fibers.
- Impacts that expose fibers and cause slight delamination.

Only an authorized representative is allowed to evaluate and repair your Cylinder.

Level 3 Damage

This is the most severe of the damage levels. Any cylinder with level 3 damage is to be removed from service, with out the possibility of being repaired.
Example:

- Deep gauges that cut deep into the composite or exposes carbon fiber.
- Any scrape or impact that exposes carbon fiber or delaminates a big area of the fiber.

NO REPAIR IS ALLOWED ON LEVEL 3 DAMAGE.

These three categories will be used to classify all types of damage. Damage due to abrasion, impact, cuts, delaminations and fire are all encompassed in the published literature.

As a rule, any composite cylinder that has damage that penetrates the protective outer coating or that cuts, unravels, or in any

way exposes the fibers underneath should be taken out of service immediately and inspected at an approved facility.

REFER TO CGA 6.2 AND ISO 11623 FOR MORE DETAILED INFORMATION REGARDING THE CLASSIFICATION OF DAMAGED SURFACES.

You could visit www.cylindersafety.com in order to obtain more information about exterior damage to your pressure vessel.

4.4 Required Periodic Inspections

Re-Test Period

A periodic Hydrotest is required for all pressure vessels. On carbon fiber cylinders it is usually every 5 years. For fiberglass cylinders it is typically every 3 years.

This periodic inspection assesses the integrity of your cylinder in order to verify proper performance after operating in the field. After each successive hydrotest a re-test date will be attached to the side of your cylinder as a record of the vessels current operation life.
This testing is to be performed by an authorized test facility with the required equipment to accurately perform testing.

IT IS YOUR RESPONSIBILITY TO VERIFY AND COMPLY WITH THE PROPER RE-TEST PERIOD PER THE GUIDES OF YOUR LOCAL GOVERNING BODY.

CONTACT INFORMATION

Please contact CARLETON Pressure Technology Division for any questions or technical issues regarding your Pressure Vessel at:

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