WIRE TOUGH

Cylinders LLC

STEEL WIRE WRAPPED TYPE II-S CYLINDERS

User Manual

FOR CNG STORAGE

A Guide to the Use, Maintenance and Periodic Inspection of On-Board WireTough Cylinders

Table of Contents

1. Introduction

Congratulations on acquiring WireTough's Type II-s cylinder. This cylinder consists of a steel liner wrapped with ultra-high strength and high ductility steel wire making it most durable and considerably lighter than Type 1 cylinders of equivalent water capacity. It meets the needs of many different end-users within CNG storage business. Like all high-pressure equipment and components, these cylinders must be well maintained and used only according to guidelines that meet the conditions for which they have been designed and approved. This guide is intended to assist trained personnel in safely utilizing WireTough cylinders. Users must be familiar with all applicable filling guidelines, regulations, requirements and laws of all appropriate local and/or national authorities and industry organizations.

1.1 Distribution and use of this manual

This document must be provided to all parties involved in distributing, handling, installing, inspecting and using WireTough cylinders. The manual may be reproduced to provide copies for this purpose, but its contents must not be altered in any way. WireTough accepts neither responsibility nor liability for consequences resulting from unauthorized alternations to this manual or for failure to follow the instructions herein.

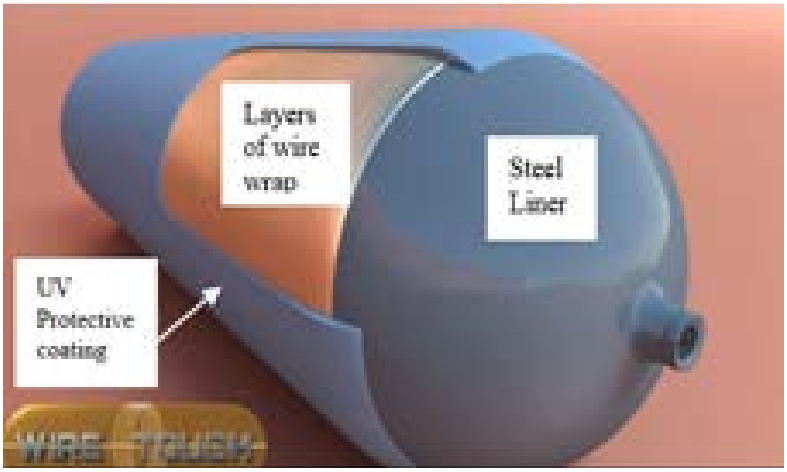
1.2 Application of the manual

This manual applies to cylinders used in the storage of compressed natural gas (CNG) as vehicle fuel only. In other words, WireTough cylinders must only be used as on-board fuel tanks. These cylinders are not meant for use to store CNG or other gases for transport.

WIRE TOUGH
Cylinders LLC
14570 Industrial Park Road, Suite C
Bristol, VA 24202
276-644-9210
www.wiretough.com
sales@wiretough.com

2. Product Description

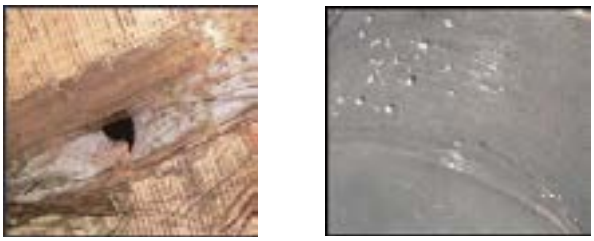
2.1 Unique technology features of WireTough Cylinders



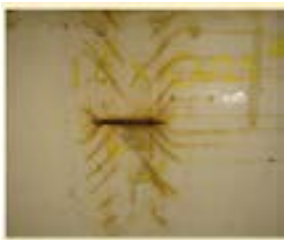
WireTough Cylinders, LLC produces pressure vessels for storing CNG, breathing air, and hydrogen at pressures ranging from 250 to 875 bar (3,600 to 13,000 psi). At these pressures, WireTough's products have distinct advantages because they offer longer service life and higher durability at very competitive prices. WireTough has designated their cylinders as Type II-S to differentiate them from Type II cylinders wrapped with fiberglass or carbon fiber.

WireTough's Type II-S cylinder design uses a commercially available steel liner that is wrapped with several layers of very high strength steel wire filaments, held together by epoxy. WireTough's technology is patented and proprietary. The high ductility of steel wires (>15%) in the wrap allows the cylinders to be pressurized to greater than two-times of their maximum allowable pressure during service. This over-pressurization process is called "autofrettage" and it causes plastic flow in the liner and locks high compressive stresses in the entire cross-section of the liner considerably enhancing the tank's fatigue life during service. Fatigue life is a key issue in storing all gases, particularly corrosive gases like hydrogen.

Steel liners wrapped with carbon or glass fiber are limited in their ability to sustain high autofrettage pressures because the fiber filaments have low ductility (≤ 0.5%). Hence, they do not bring the benefits of long cycle life that WireTough's cylinders offer. Type II-S wire-wound steel cylinders were first introduced in 2011 as onboard CNG storage tanks in vehicles. Extensive testing has been conducted to demonstrate the superior resistance to impact if accidentally dropped, ballistic testing, salt-water corrosion resistance, and fire as seen in the pictures below.



(Left) Picture showing the performance of the WireTough Type II-s tank in a ballistic test involving 50 caliber gun fire. The damage from a 30-caliber test was minimal. (Right) The exterior surface condition of the Type II-S cylinder after a bonfire test showing that the steel wrap was still intact.



Exterior surface of the Type II-S tank after exposure to salt-water for 28 days while being cycled for 3,200 cycles. Note that a crack like notch was machined in the cylinder prior to the exposure to salt-water

2.2 Cylinder identification and label

WIRE TOUGH

CNG ONLY

DO NOT USE AFTER 6/2039

US DOT Type-2 and NGV-2-2007

Serial No.	**WT 341656 A023**
Manufactured	**6/2019**
Service Pressure	**3600 psi (24,800 kPa)** @ 21°C (76°F)
Diameter	**16.5 in. (414mm)**
Volume/(Empty) Weight	**150L / 370Lbs**
Length	**59 in. (1499 mm)**
Thread	**1-1/8"UNF**

Re-inspection Date

Exp. 6/2039

For use only with the container manufacturer approved PRD, Valves and Installation Procedure

This container should be visually inspected for damage or deterioration after an accident, fire, 36 mo. Or 36,000 miles, whichever comes first.

WireTough Cylinders LLC - www.wiretough.com
4570 Industrial Park Road, Bristol, Virginia 24202

Pat.Pend Made in USA
ALL AVAILABLE US COMPONENTS USED

Sample of a cylinder label placed on each WireTough cylinder

Sample of a cylinder serial number on each WireTough cylinder.

If a label is unreadable, an inspector or user can determine the cylinder serial number from the end-plug label or stamping on the liner neck. Contact WireTough Cylinders and provide the serial number to learn the final date of use and to obtain replacement labels. When the service life stated on the label has been reached, the user must remove the cylinders from service. Cylinders removed from service must be disabled or destroyed in accordance with applicable regulations.

3.0 Operating Conditions

Operating conditions for WireTough cylinders include pressure, temperature, gas type and the external environment in which the cylinder is used. WireTough cylinders are designed for storing CNG at operating pressures of 3600 psi, as per the NGV standard. The best source of pressure and temperature limits is the cylinder label for each individual product. See figure below for example. Please refer to those guidelines and contact WireTough Cylinders with any questions.

WARNING: An over-pressure condition can occur as a result of filling to service pressure in cold weather. As temperature increases, the pressure will increase, and the settled condition could exceed the service pressure. Even though this is less of a problem with wire-wound vessels because of the thermally conductive nature of the wire jacket, temperature rise must always be considered and compensated for during filling.

3.1 Gas Chemistry

WireTough cylinders are designed and approved for storage of natural gas used as a motor vehicle fuel. The natural gas used must comply with: Recommended Practice for Compressed Natural Gas Vehicle Fuel, SAE J1616; Canadian General Standards Board Standard for Natural Gas for Vehicles, CGSB 3.513; or an equivalent national standard; and/or as shown below.

Dry Gas - Water vapor would normally be limited to less than 32 mg/m3 (2 lbs./ MMSCF), a pressure dewpoint of -9ºC (16ºF) at 20 700 kPa (3,000 psi). There would be no maximum constituent limits for dry gas, except for:

1. Hydrogen Sulfide	23 mg/m^3
2. Oxygen	1.0 percent by volume
3. Hydrogen	2.0 percent by volume

Wet Gas - Gas that contains 32 mg/m3 (2 lbs./MMSCF) of water or more normally meets the following maximum constituent limits:

1. H_2S and other soluble sulfides	23 mg/m^3 (1 gr/100 SCF)
2. Total Sulfur	115 mg/m^3 (5 gr/MMSCF)
3. Oxygen	1 percent by volume
4. CO_2	3 percent by volume
5. Hydrogen	0.1 percent by volume

Under wet gas conditions, a minimum of 1 mg of compressor oil per kilogram of gas (0.007 grains of compressor oil per pound of gas) is necessary to protect metallic containers, liners and bosses.

WARNING: NEVER use a cylinder past the “Do not use after” date. Personal injury or death may result.

3.2 Service life

If a label is unreadable, an inspector or user can determine the cylinder serial number from the end-plug label or stamping on the liner neck. Contact WireTough Cylinders and provide the serial number to learn the final date of use and to obtain replacement labels. When the service life stated on the label has been reached, the user must remove the cylinders from service. Cylinders removed from service must be disabled or destroyed in accordance with appliable regulations.

4.0 Cylinder Handling, Storage and Installation Instructions

Use the following guidelines to install WireTough cylinders into vehicles.

4.1 Handling

To prevent cylinder damage, WireTough recommends the following:

- Only handle CNG cylinders with appropriate lifting devices and equipment that will not cause damage.
- Do not walk on cylinders! Walking on cylinders can cause damage
- Do not handle cylinders with internal pressure above 3 bar (40 psi)
- Do not drag, drop or handle cylinders roughly
- Protect cylinder labels to ensure legibility
- When transporting a cylinders with valves mounted, protect the valve and properly secure the cylinder. Never handle cylinders by their fittings, valves, pressure relief devices or piping.

4.2 Storage

WireTough cylinders must be stored in a dry environment away from direct sunlight (UV radiation), chemicals, heat sources and corrosive environments. Prevent cylinders and/or assemblies from rolling or moving. Protect cylinders from any contaminants and damage. WireTough recommends storing cylinders in their original shipping packaging.
Cylinders should not be stored completely unpressurized. If a cylinder is stored unpressurized at very low temperatures, moisture condensation and contamination could damage the cylinder. Install plugs and/or valves and O-rings intended for use according to the valve manufacturer’s recommendations. Store cylinders with a small positive pressure (not less than 25 psi and not more than 40 psi) of a dry inert gas or natural gas.

4.3 Preliminary inspection

Prior to installation, visually inspect the cylinder for any damage caused during shipping and handling. If no damage is found, proceed with installation. If damage is found or suspected, complete a thorough visual inspection (see Section 6) before installing the cylinder.

4.4 Installation

4.4.1 Cylinder installation and protection

When the cylinder is installed on a vehicle, use shielding to protect the cylinder from damage caused by road debris and contact with vehicle components and cargo. The preferred shielding is open mesh, which not only protects the cylinder, but also permits easy reading of cylinder labels.
To prevent cylinder damage:

- Avoid direct contact between the shielding and the cylinder
- Avoid trapping solid debris or liquids between the shielding and the cylinder
- Avoid cylinder contact with vehicle components (e.g., brake lines, etc.)
- Avoid exposure to vehicle heat
- Avoid exposure to harmful liquids and gases
- Avoid prolonged exposure to sunlight

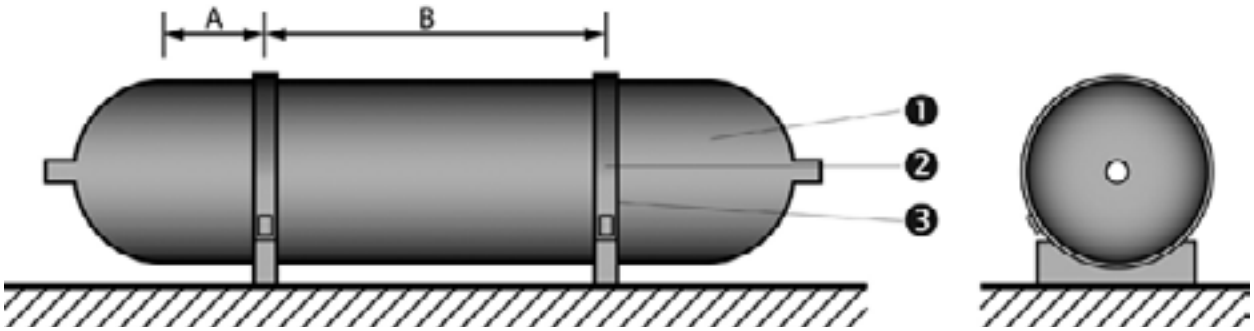
4.4.2 Mounting cylinders

Various mounting methods may be used with WireTough cylinders. The mounting method and appropriate mounting hardware are often specified by the system manufacturer. Refer to applicable instructions and specifications provided by the system manufacturer before attempting to mount cylinders. Cylinders used to store natural gas as vehicle fuel and bearing NGV2 or FMVSS304 markings should be installed in accordance with NFPA 52 requirements.

When installing a cylinder in an underbody configuration, proper consideration must be given to avoid potential damage from impact with large objects. Cylinders should be shielded not only from road debris, but also from impact with curbs, high traffic bumps, deep potholes, pavement protrusions and large objects in the road that can damage cylinders and cause hazardous situations.

CAUTION: During pressurizing and de-pressurizing of a composite cylinder, it is normal for the cylinder to expand and contract. The chosen mounting system must allow for this expansion and contraction; otherwise, damage to the cylinder and fuel storage system may occur.

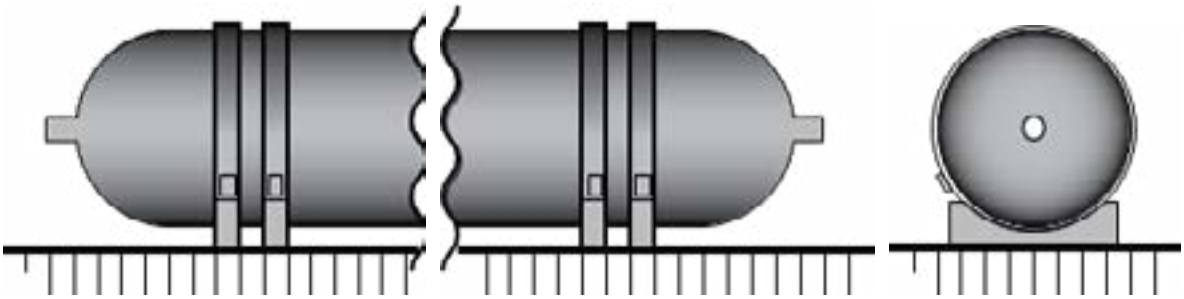
4.4.3 *Strap or band for "belly" mounting*



Minimum dimensions: A = 25mm (0.984"), B = 1/3 of cylinder length

PARTS LIST	
Item	*Description*
1	Composite cylinder
2	Belly mounting strap
3	Rubber strip

If the cylinder is long or heavy to require more than two brackets for installation, follow the bracket manufacturer's installation guidelines. Brackets should be installed 6 to 8 inches apart near the cylinder ends as shown in the figure below. Do not use one bracket in the center and one on each end; this may lead to damage of brackets and/or the cylinder.



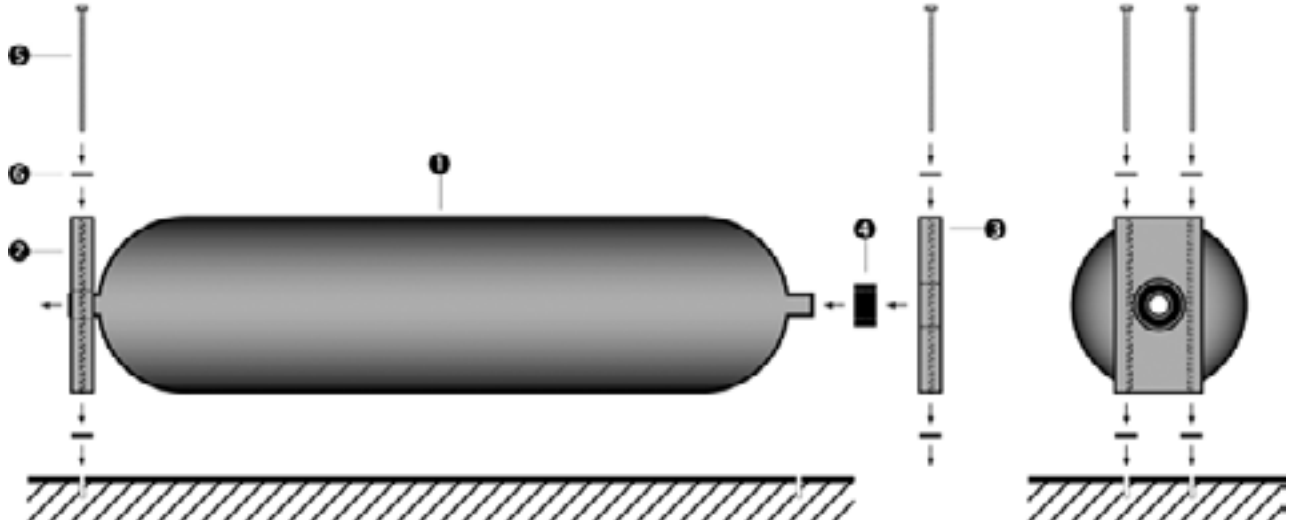
Vertical mounting of a cylinder with straps is not permitted. The cylinder may slide out of the straps due to gravity and vibration and cause damage to the fuel system components and/or the cylinder, which could cause personal injury or death.

Any straps or bands used to secure a cylinder must not induce a pressure on the outer surface of the cylinder greater than 3.45 MPa (500 psi) at any cylinder fill pressure.

CAUTION: When using the strap or "belly" mounting method, a strip of rubber must be installed between the cylinder and metal straps to protect the cylinder exterior coat and paint. The mounting should also be sufficiently flexible to allow for longitudinal cylinder expansion and contraction.

4.4.4 *Neck mounting*

The figure below shows the configuration below for neck mounting



PARTS LIST	
Item	*Description*
1	Composite cylinder
2	Fixed neck block
3	Sliding neck block
4	Bearing
5	Bolt
6	Washer(s)

Visually inspect end-mounting blocks regularly for signs of corrosion and premature wear. Replace the mounts and blocks if they are corroded. Vertical mounting of WireTough cylinders is not authorized.

4.5 Valve and pressure-relief device (PRD) installation and removal

Use only approved valves and pressure-relief devices that comply with applicable standards and regulations (e.g., NGV 3.1 and PRD-1).

WARNING: Do not use valves or pressure-relief devices that have not been tested and approved by WireTough.

4.5.1 Valve and/or plug installation

Inspect the valve in accordance with the valve manufacturer's recommendations prior to installation. Do not install any valve that has not passed such an inspection.

Valve threads must be free from damage. Visually inspect threads to ensure that the mating surface of the valve is smooth and free from damage.

Not all O-ring materials are compatible with all gases. To ensure that the O-ring material being used is suitable for natural gas service, follow the recommendations of the valve manufacturer or use an O-ring supplied by the manufacturer. The natural gas industry generally recognizes Nitrile (also called Buna N), with a 70 – 90 Durometer hardness, as the standard O-ring material. If you have questions, please contact the system manufacturer or the valve manufacturer.

Check to make sure that the O-ring groove and threads in the cylinder are clean and free from debris and damage. Install a new O-ring on the valve or plug in accordance with the valve or plug manufacturer's recommendations.

4.5.2 Valve and/or plug removal

Follow the system manufacturer's guidelines for depressurizing the system. Following the recommendations of the system manufacturer or valve manufacturer, ensure that the cylinder is completely empty before attempting to remove the valve and/or plug. WireTough recommends removal of the valve before attempting removal of any plugs. Removal of a plug while under pressure can lead to serious injury or death.

WARNING: If the valve is hard to remove, STOP! If you suspect for any reason that a valve may be defective, do not attempt to remove the valve because a damaged or not properly functioning valve may cause you to erroneously think that the cylinder is empty when you do not hear gas being released. Handle all cylinders with valves mounted, including those that you think are empty, as if they were under pressure. To check whether a hard-to-remove valve is functioning properly, add to the cylinder a small amount of the gas specified on the cylinder label to prove that gas goes in and out of the valve. If the valve works properly during this check, fully depressurize the cylinder and then carefully remove the valve. If you have questions about valve function or require further instructions, contact the valve manufacturer.

Once the valve and/or plug is removed, inspect it thoroughly if it will be reused in the installation or another installation. Check valve and/or plug threads for damage and inspect cylinder threads to verify that they are clean-cut and undamaged. Clean and inspect the cylinder O-ring gland (groove) to verify that there is no damage.

REJECT cylinders with damaged threads.
REJECT cylinders with O-ring gland damage that prevents an effective, safe seal.

4.5.3 Pressure-relief device (PRD)

Use only approved pressure-relief devices that comply with applicable standards and regulations (e.g., PRD-1). Contact the system integrator or WireTough for a list of approved PRDs and PRD configurations.

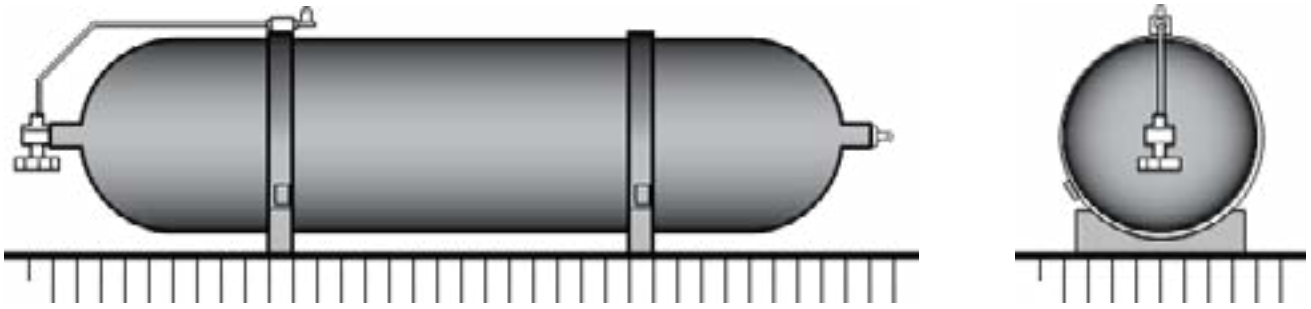
Some PRDs are integrated into the valve, while others must be installed separately. If a vent line is required to vent gas away from the cylinder, take note that no valves or flow restrictions are allowed anywhere in the inlet or outlet flow path of a PRD. Below are sample PRDs installation methods.

Single PRD configuration—Where only a single PRD is required, use one of the following configurations approved by the System Integrator or WireTough for the specific cylinder model being considered:

CNG valve with an integrated PRD Valve with a retrofitted PRD Separate end-plug PRD

Double PRD configuration—There are three possible configurations for double PRDs:
(1) A valve either with an integrated PRD or an installed PRD plus a separate end-plug PRD. (2) A valve with a PRD that has been piped to the center of the cylinder plus a separate end-plug PRD. (3) Two PRDs piped from either the valve or the plug of the cylinder and centrally located along the length of the cylinder.

Multiple (more than two) PRD configuration—Figure (below) is an example of a cylinder configured with three PRDs—one integrated in the valve, a second end-plug PRD in the opposite cylinder end and a third, L-shaped PRD connected with a pipe from the valve to a central position. Additional T-shaped PRDs could also be installed in series along the pipe from the valve.



Shared PRDs - Some fuel systems can have multiple cylinders plumbed to a single PRD or set of PRDs; these are generally plumbed either from end plugs of multiple cylinders or from valves of multiple cylinders. Contact WireTough for more information about approved configurations for shared PRDs.

General guidelines that apply to all PRD installations:

- Ensure that threads are undamaged.
- Clean threads thoroughly.
- Dry threads and ensure that the area is free from debris.
- Select the proper O-ring or copper-crush washer specified by the PRD manufacturer. Do not reuse copper-crush washers or O-rings. Always use a new copper-crush washer or O-ring; failure to do so may cause a leak.
- Remove the used copper-crush washer or O-ring before replacing the PRD. Do not double-stack copper-crush washers or O-rings.
- If recommended by the PRD manufacturer, apply lubricant to the O-ring or copper-crush washer.
- Place the O-ring or copper crush-washer properly on the fitting, being careful not to damage the O-ring or copper crush-washer.
- Thread the fitting into the mating surface.
- Apply the proper installation torque recommended by the PRD manufacturer.

5.0 Fueling (filling) and Defueling (evacuating) Cylinders

The following procedures apply for initial fueling (filling), re-fueling, and defueling (evacuation) of cylinders.

Note: During fueling (filling) and defueling, expansion or contraction of the cylinder sometimes causes snapping or popping noises. This is normal and is not a cause for concern. This is minimal for WireTough's Type II-s cylinders compared to Type III and Type IV cylinders

WARNING: Rapid flow of gas can generate a static electrical charge, which can ignite escaping gas. Therefore, the cylinder, attached components (including the vent pipe used for defueling) and vehicle must be connected to a ground for purging, fueling (filling) and defueling

Prior to filling the cylinder, it is important to understand the characteristics and hazards of natural gas, including explosion, fire and asphyxiation.

Fuel (fill), defuel (evacuate) and purge all systems in a well-ventilated area that is free from possible ignition sources, including (but not limited to) open flames, electric sparks and static electricity.

WARNING: When working with flammable gases in a confined area, it is good practice to always use gas-monitoring equipment.

5.1 Filling

WARNING: Always remove all oxidants (including air) from a cylinder prior to filling the cylinder with flammable gas! Failure to remove oxygen or other oxidants from the cylinder before filling with natural gas can create a combustible mixture that can ignite and cause serious injury or death. Be alert to the fact that air may enter the cylinder whenever the cylinder has been vented or exposed to ambient pressure, including during initial filling, after valve installation or any time the system has been bled to zero pressure.

5.1.1 Initial filling (fueling)

WARNING: Failure to follow the fuel system manufacturer's instructions during filling may lead to serious injury or death!

An "initial fill" is the first pressurization that occurs after the cylinder has been vented or exposed to ambient pressure, including initial filling, after valve installation or any time the system has been bled to zero pressure. Before filling a cylinder with natural gas, the cylinder must be purged of any oxidants. Failure to purge oxidants can create a combustible mixture that can ignite and lead to serious injury or death. Do not perform the purge operation or the initial filling of a WireTough cylinder if the cylinder has been stored in an environment at or below 0F (-18°C). Allow the cylinder to warm up to room temperature, 60°F or greater, before attempting to purge or fill an empty cylinder.

Follow the fuel system manufacturer's guidelines to purge the system before the initial fueling, if required, or use the following procedure to purge any oxidants before filling the cylinder with CNG. The following is a guideline to safely remove or reduce any oxidants (including oxygen from air) in the cylinder.

1. Ensure that the cylinder is grounded and in a well-ventilated area.
2. Pressurize the cylinder or assembly to at least 5 bar (72.5 psi) with dry nitrogen, and bleed the nitrogen from the cylinder.
3. The cylinder or assembly is now ready to be pressurized with CNG.

During the initial filling of a cylinder that has been purged of oxidants, fill with natural gas to a pressure of at least 50 psi. If the cylinder is filled to a pressure less than 50 psi with natural gas, there is still a potential to create a flammable mixture that could ignite.

5.1.2 Standard filling (refueling)

If the residual pressure in the cylinder is less than 300 psi and the cylinder/vehicle has been stored in an environment that is 0°F (-18°C) or lower do not fill the cylinder. Bring the cylinder and/or vehicle inside and allow the cylinder to warm up to 60°F or higher before filling. If the residual pressure is higher than 300 psi, the cylinder may be filled if the temperature is above -40°F (-40°C).

WARNING: Fill the cylinder such that the settled pressure does not exceed the marked service (working) pressure at 21°C (70°F). Never fill the cylinder greater than 1.25 times the marked service pressure immediately after filling, regardless of the temperature.

5.2 Defueling

WARNING: When working with flammable gases in a confined area, always use gas-monitoring equipment and ground (earth) all equipment.

Follow the fuel system manufacturer's guidelines for venting CNG from the system. Otherwise, if possible, the preferred method of de-fueling is to run the engine. Note that some residual pressure will likely remain in cylinders and will need to be vented. During defueling, make sure pressure is sufficiently low that those performing the procedure will not be harmed if gas escapes due to a leak or broken seal. However, defueling pressure must be slightly higher than atmospheric pressure to stop air from entering the cylinder if a seal is broken. Vent gas properly through a flue or flare stack to prevent contaminating the environment and to avoid a potentially hazardous gas accumulation. Always make sure that all equipment is properly grounded. Use caution and avoid any uncontrolled ignition sources during any defueling operation.

6.0 Inspection

It is suggested that general inspection be performed on a scheduled basis and at any time following an incident that could potentially compromise the integrity of the cylinder or any attached components. Prior to a general, routine inspection, make sure that all surfaces are appropriately cleaned and cleared of any residual debris, using non-abrasive solutions such as a mild detergent.

6.1 Mounting inspection

Ensure that you have secured and have become familiar with your fuel system installer's (manufacturer's) manual regarding mounting brackets and associated components, regarding proper assembly and maintenance of that system's support structure. If any irregularity is discovered, it is the responsibility of the user to suspend use and immediately notify the fuel system manufacture for service

6.2 Fuel System Inspection

As stated in section 6.1, it is suggested that the user be familiar with the system supplier's instructions pertaining to inspection and maintenance of all components used in the fuel delivery system. If irregularities or malfunction of the system occurs, immediately suspend use and notify system manufacturer for service.

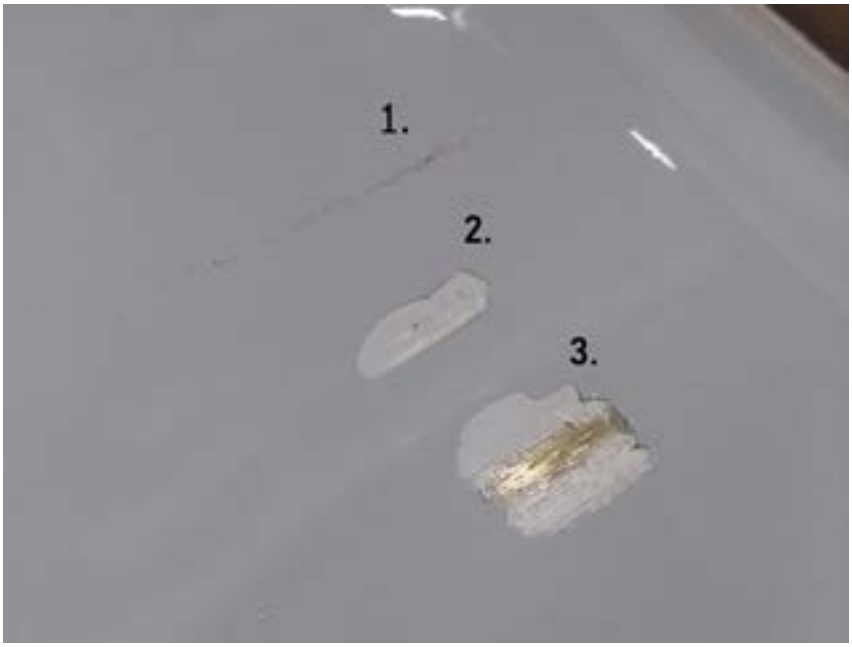
6.3 Cylinder Inspection

General inspection of WireTough Cylinders products should be performed periodically for the following:

- Surface inconsistencies, such as cuts, gouges or any impact damage due to collision, etc.
- Any indication of fire or heat damage
- Environmental effects

Note: WTC cylinders are wire wrapped and impregnated in industrial grade epoxy. The "Outer Skin" consists of a two-part industrial grade, polymer laminate. Neither of these constituents are provided in a structural capacity and they serve as protection against environmental effects for the core and wire reinforcements. If the wire reinforcement is compromised, it is strongly suggested that it be immediately taken out of service and replaced. If damage is superficial, contact WireTough Cylinders, LLC for kits and instructions for corrective measures.

The polymer skin coat is primarily used for UV protection. However, exposure to direct sunlight over time, can adversely affect the integrity of the laminate. It is suggested that the container be housed in an enclosure to further protect from environmental effects. If over exposure occurs, contact WireTough Cylinders, LLC for options for resurfacing the product.



Cylinder surface is comprised of an under layer of epoxy and an outer layer of polymer.

Examples, 1 and two illustrate "superficial" damage, that can be repaired, using commercial grade fillers and laminates. Example 3 illustrates "**infiltration**" of the steel wire reinforcement. If this occurs, the user **should immediately remove from service and replace.**

Appendix A: CNG Sample Label

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US DOT Type-2 and NGV-2-2007

Serial No.	**WT 341656 A023**
Manufactured	**6/2019**
Service Pressure	**3600 psi (24,800 kPa)** @ 21°C (76°F)
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Volume/(Empty) Weight	**150L / 370Lbs**
Length	**59 in. (1499 mm)**
Thread	**1-1/8"UNF**

Re-inspection Date

Exp. 6/2039

For use only with the container manufacturer approved PRD, Valves and Installation Procedure

This container should be visually inspected for damage or deterioration after an accident, fire, 36 mo. Or 36,000 miles, whichever comes first.

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Pat.Pend Made in USA
ALL AVAILABLE US COMPONENTS USED

A guide to the safe use, maintenance and periodic inspection of WireTough cylinders