COMPOSITE PROPANE CYLINDERS

An Overview of Fire Safety Risks for Emergency Responders and Fire Marshals

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INTRODUCTION

The objective of this paper is to introduce emergency responders and fire marshals to the new types of composite cylinders that are entering the marketplace and to provide an overview of the fire safety risks they may present in a fire emergency scenario. The paper also summarizes the results of recent live fire testing of various types of composite cylinders currently being manufactured and distributed in the United States for outdoor use and examines how these cylinders may be used for future indoor use with cabinet heaters.

Hildebrand and Noll Associates, Inc. developed this paper under an agreement with the Propane Education & Research Council (PERC). [2]

OVERVIEW OF COMPOSITE MATERIALS

Composite materials are not new and have been used for many years in the automotive, marine, and aerospace industries. More recently, composites have been used to manufacture a variety of cylinders and containers for transportation and storage of regulated materials. [3]

Composites are highly engineered materials designed for very specific applications. They are made from two or more different materials to form one single structure with an identifiable interface. The properties of the new structure are dependent upon the overall properties of the constituent materials as well as the properties of the interface. Composite materials typically form molecular bonds in which the original materials retain their identity and mechanical properties. [4]

Reinforced concrete serves as a good example of a simple composite structure. Concrete is poured over steel rebar to make up a single structural component, but the concrete and steel still retain their individual identities. The steel bars carry the tension loads and the concrete carries the compression loads. [5]

Figure 1 Composite materials are incorporated into automobiles, boats, and aircraft.

HYBRID COMPOSITES

Composite products are usually hybrids manufactured for specific purposes. They are made by adding some complementary material such as fiberglass or Kevlar® fiber to a basic carbon fiber/epoxy matrix. The addition of carbon/epoxy to the fiberglass structure is used to provide additional stiffness. The specific materials selected by the manufacturer are designed to obtain characteristics required by the end user such as greater fracture toughness and impact resistance.

Composites have many advantages over metals. Some of the primary advantages include:

- Composites are stronger and stiffer than metals on a density basis. This characteristic is important when high performance of the material is required but weight is a factor. For example, strength being equal, composites are lighter than steel and aluminum. [6] Some composite cylinders are 30% to 40% lighter than steel. [7]
- Composites are highly corrosion resistant. Most are inert even in the most corrosive environments.
- Composites can be formed into complex shapes during the fabrication process and can be made from fewer parts. This reduces manufacturing and assembly time and costs.
- Composites can be made so they are translucent, which allows the user to view the level of product inside, or they can be blended with colors.

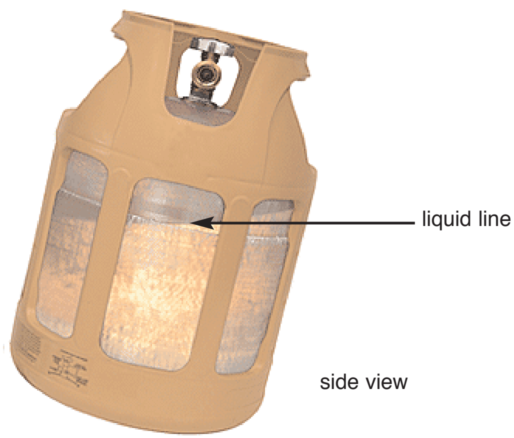

Figure 2 Composite materials can be made translucent so internal liquid levels can be safely viewed.

PROPANE CYLINDERS MADE FROM COMPOSITES

Propane cylinders made from composite materials are relatively new inside the United States, but they are very common and have been used for many years in other countries. These cylinders are currently being legally manufactured, transported, and distributed in the United States. [8] The most common cylinders being manufactured are the 20-pound cylinder for barbeque grills and outdoor heaters, and the 33-pound cylinder for forklifts. [9]

Figure 3 The most common composite cylinders are the 20 lb. BBQ and 33 lb. Fork Lift types.

The propane industry has proposed code changes that will permit composite cylinders inside buildings, especially in residential occupancies in combination with cabinet heaters. [10,11]

The composite cylinders currently being manufactured are a polymer wrapped in fiberglass. An outer casing protects the cylinder. Construction materials include poly-acrylonitrile butadiene styrene (ABS), high-density polyethylene (HDPE), and polyethyleneterephthalate (PET).

COMPOSITE CYLINDER CONSTRUCTION FEATURES

Composite cylinders are constructed in accordance with U.S. Department of Transportation (DOT) special permits. The special permits are based upon the DOT Standard FRP-1, the European Standard EN 12245, and the ISO 11119-3 standard. [12] Cylinders under DOT special permits can be found in two basic designs approved by the DOT. [13] These include one-piece and two-piece construction. Both types of cylinders include the same type of approved valves, pressure relief devices, and overfill prevention device as found on metal propane cylinders. [14]

ONE-PIECE CONSTRUCTION

The one-piece composite cylinder is currently manufactured by two different companies: Ragasco and Kompozit-Praha. Both companies manufacturer a one-piece composite cylinder with a blow molded PET liner and HDPE jacket. [15,16] The Ragasco cylinder has a DOT special permit for use in the United States, and the Kompozit-Praha cylinder is currently in the special permit process.

Figure 4 One-piece construction composite cylinders.

For the one-piece fully wrapped fiberglass and resin composite cylinder, the blow-molded high density polyethylene (HDPE) liner provides the inner gas barrier. The composite layer is made from a tough polymeric material that is chemical resistant. It is applied in a filament winding process. An advanced curing process ensures the translucent see-through feature. The cylinder has a permanently attached outer casing made with injection-molded HDPE. The outer casing provides protection for the pressure vessel as well as for the valve. It has ergonomic handles for easy lifting and stacking. [17]

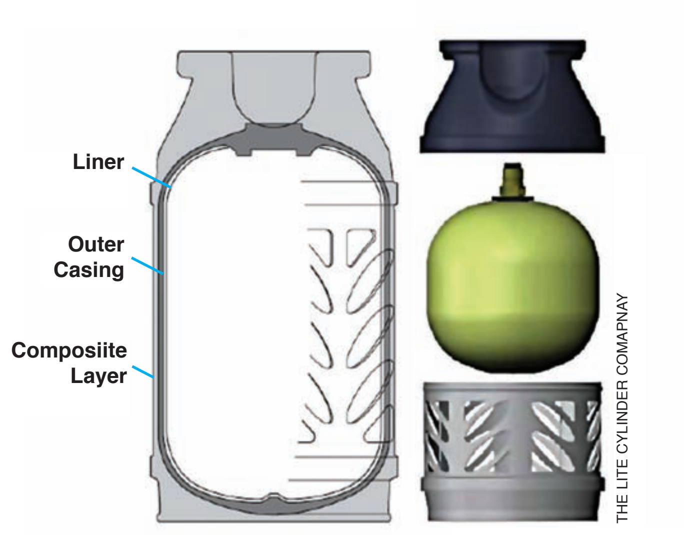

Figure 5 One-piece construction composite cylinders.

TWO-PIECE CONSTRUCTION

The two-piece composite cylinder is currently manufactured by The Lite Cylinder Company as a linerless two piece (top and bottom fitted together) with an ABS jacket. [18] The two halves of each cylinder are wound with fiberglass around a mandrel and then injected with plastic resin under high pressure in a hermetic process. After hardening, the two halves are taken out of the molds and are adhesively joined together. Holes are drilled in one half for the valve and the two halves are bonded together to create the completed cylinder. A thermoplastic outer casing is attached to the cylinder to provide additional protection. [19]

Figure 6 Two-piece construction composite cylinders.

REGULATIONS AND STANDARDS

In 2002 the propane industry began an effort to develop an interest in new products that would potentially expand the use of propane by U.S. consumers through the use of indoor cabinet heaters using the features of composite cylinders. [20] The problem the propane industry faced was that the Department of Transportation regulations did not specifically cover composite cylinders for transportation of propane and the National LP Gas Code prohibited the use of both composite cylinders and cabinet heaters indoors. [21] As a result the U.S. propane industry, under the leadership of the Propane Education & Research Council (PERC), funded the following projects:

1. Program to develop a template for the DOT exemption process. The template was developed through an industry-wide working group of over 40 members. The intent was to establish a guide for assisting potential cylinder manufacturers through the exemption process. [22]
2. Research program to assist the National Propane Gas Association (NPGA) in the development of a proposal to the National Fire Protection Association 58 Technical Committee for the accepted indoor use of composite propane cylinders. [23] PERC engaged Battelle, Columbus, Ohio to conduct the research. The project was divided into two phases. [24]

   Phase 1—Investigated the market viability for indoor composite propane cylinders and reviewed previous work performed by NPGA to gain approval for indoor use, reviewed international experience with indoor propane cylinders, and met with firefighters and fire safety experts to identify potential concerns regarding indoor use. [25]

   Phase 2—Develop testing protocols and performed fire testing of composite propane cylinders for use with portable heating appliances. [26]

U.S. DEPARTMENT OF TRANSPORTATION

The U.S. Department of Transportation (DOT) currently allows composite cylinders for transportation by motor vehicle, rail freight, cargo vessel, and cargo aircraft under a special permit.

Both the Lite Cylinder Company and Ragasco versions of the cylinders are authorized for transportation by DOT special permits. [27] These permits authorize the manufacture, sale, and use of composite cylinders for the following hazardous materials:

- Compressed gas, flammable, n.o.s. (Division 2.1), UN1954
- Compressed gas, non-flammable, n.o.s. (Division 2.2), UN1956
- Liquefied gas, flammable, n.o.s. (Division 2.1), UN3161
- Liquefied gas, n.o.s. (Division 2.2), UN3163
- Liquefied gases, non-flammable charged with nitrogen, carbon dioxide or air, (Division 2.2), UN1058
- Petroleum gases, liquefied, (Division 2.1), UN1075

The safety and control measures required by DOT under these special permits are very specific. Requirements include manufacturing in accordance with American Society for Testing and Materials (ASTM) standards. DOT also requires production testing, random lot inspections, and other testing criteria which were extracted from existing standards including:

- British Standards Institution—EN 12245, Transportable Gas Cylinders—Fully Wrapped Composite Cylinders (2002).
- International Standards Organization—ISO 11119-3, Gas Cylinders of Composite Construction (2002).

- US DOT FRP-1, Basic Requirements for Fiber reinforced Plastic (FRP) Type 3Fc Composite Cylinders.

The primary testing requirements extracted from these standards cover:

- High temperature creep test maintaining test pressure for 1,000 hours
- Leak test under pressure
- Permeability test
- Flawed cylinder test
- Drop test
- Torque test on the cylinder neck boss with a fitted valve
- Water boil test—the cylinder is subjected to boiling water for 100 hours.

DOT also requires composite cylinders to be equipped with pressure relief devices in accordance with 49 CFR Section 173.301 (f). Composite cylinders are limited to a 15 year life cycle and require requalification by visual inspection and proof pressure tests every 5 years.

While DOT's special permit testing requirements are rigorous, it is important to note that DOT testing requirements are designed only for the safety analysis of the hazards and risks associated with transportation in commerce. In other words, DOT's safety analysis of composite cylinders did not consider the hazards and risks associated with consumer safety, which is outside the scope of the DOT's authority. DOT also does not approve steel or aluminum cylinders for consumer safety. DOT does specify that any composite cylinder that has been subjected to fire may not be returned to service.

NATIONAL LIQUEFIED PETROLEUM GAS CODE

The current edition of Liquefied Petroleum Gas Code (NFPA 58) 2004 does not specifically prohibit composite cylinders. [28]

In 2005 the propane industry proposed revisions to NFPA 58 that would allow composite cylinders to be used indoors in conjunction with portable unvented cabinet heaters having a maximum output rating of 10,000 btu/hr. This proposal is scheduled for a vote by members at the NFPA's World Safety Conference, June 6-7, 2007, Boston, Massachusetts. [29]

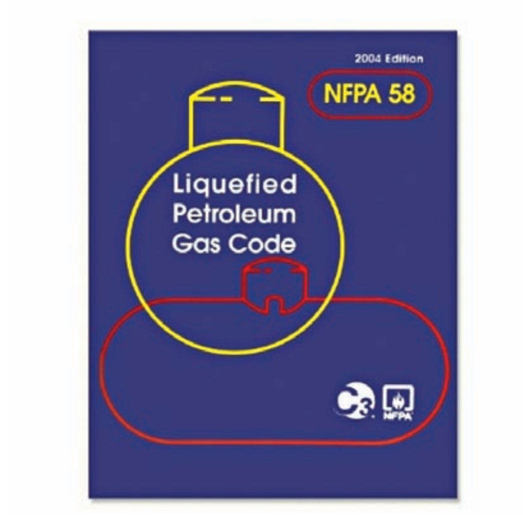

Figure 7 National LP Gas Code.

The following key points summarize the proposed changes to NFPA 58 concerning composite cylinders and cabinet heaters for indoor use. [30 31]

- Composite cylinders that are contained within and connected to listed cabinet heaters shall be permitted to be used indoors only in one and two family dwellings and in businesses.
- Only composite cylinders will be permitted for indoor use, and those cylinders must be Listed.
- Cabinet heaters shall be Listed. The intent of this section is to ensure that manufacturers meet fire safety requirements established by a third party listing agency. The American National Standards Institute (ANSI) is presently developing a new standard on cabinet heaters (ANSI

Z1.11.3) which is expected to be released in 2007.

- Cabinet heaters shall have a maximum rating of 10,000 btu/hr.
- Composite cylinders are required to have pressure relief valves and are prohibited from being equipped with a fusible plug.
- Composite cylinders used with cabinet heaters shall have a maximum capacity of 16 pounds (7.3 kg) of propane (nominal 41 lb or 19 kg water capacity). The intent of this section is to reduce fire loading inside structures and to reduce the possibility that a standard 20 lb metal cylinder will be illegally adapted to a cabinet heater.
- Composite cylinders are required to have an overfill prevention device installed for use with cabinet heaters and shall be equipped with a CGA793 connection. The CGA793 connection is unique and designed for use only with the approved 16 lb composite cylinder. The intent of this requirement is to ensure that the appliance side of the connection for use with cabinet heaters indoors cannot fit standard 20 lb metal cylinders approved for outdoor use.
- The maximum filling limit by weight of propane in a composite cylinder in non-engine fuel applications shall be 39.5 percent of the water capacity in pounds of the cylinder.
- Modification of the cabinet heater CGA connection or the use of an adapter that allows an alternate fuel source or cylinder to supply the cabinet heater shall be prohibited.
- The composite cylinder shall be located in a separate compartment from the heating element.
- Cabinet heaters shall utilize a two stage regulator that shall not be equipped with a pressure relief valve in either stage.

FIRE TESTING OF COMPOSITE CYLINDERS

THE BATTELLE FIRE TESTS

In 2005 Battelle and ThermDyne performed fire testing of six conventional steel cylinders, 18 two-piece, linerless composite cylinders, and 11 one-piece composite, lined cylinders with various fire exposure conditions, orientations (vertical and horizontal), and fill levels. [32]

Based on input from the Advisory Panel on Composite Propane Cylinder Testing, three fire conditions were selected for preliminary tests. [33] These included:

1. Fire A—This test subjected the edge of the cylinder to a lazy, very luminous flame. Three burners were placed 7 inches from the side, 6.5 inches up from the cylinder bottom with a burner fuel pressure of < 1 psig.
2. Fire B—The test subjected the cylinder to a slightly more intense jetting flame. Three burners were set 7 inches from the cylinder's side, 6.5 inches up from the cylinder bottom with a burner fuel pressure of 2 to 3 psig.
3. Fire C—This test was even more intense than test A & B. A jetting flame was arranged with three burners 16 inches from the side, 6.5 inches up, with a burner fuel pressure of 5 psig.

Figure 8 Preliminary fire tests conducted by Battelle.

In the preliminary testing the cylinders were either oriented vertically or horizontally. In the horizontal position the flame was directed at the side, at the valve, or at the base. [34]

The following summarizes the key findings of the Propane Education & Research Council funded fire tests conducted by Battelle:

- **Steel Cylinders—**None of the steel cylinders ruptured. All of the six steel cylinders tested emptied before the cylinder walls softened and thinned enough to rupture. One cylinder showed a bulge. All of the relief valves opened at 375 to 400 psig. Some pressure relief valves reclosed above 300 psig while others did not reclose until 100 psig.
- **Composite Two-Piece Cylinders—**When tested in the vertical position with a fill level of 75%, none of the linerless composite two-piece cylinders failed. During the tests propane began to leak around the valve to cylinder connection and diffused through the cylinder walls after reaching peak pressures between 98 and 118 psig. The outer protective jacket was consumed on all composite cylinder tests. One of the cylinders tested in the vertical position filled to a level just below the first joint on the two-piece cylinder failed at the joint.

  Nine of the two-piece cylinders tested were equipped with pressure relief valves. Only one of these PRV's opened. This test was designed to create direct flame impingement on the PRV with the cylinder in the horizontal position. [35]

  When the two-piece cylinder was tested in the horizontal position at the medium flame setting, the cylinder ruptured and separated into two pieces. Similar results were obtained in additional tests. It is important to note that these failures were not violent ruptures. The fire rapidly increased in intensity but there was no fragmentation typical of a Boiling Liquid Expanding Vapor Explosion (BLEVE).
- **Composite One-Piece Cylinders—**The one-piece cylinders did not rupture when subjected to similar tests. All of the cylinders were equipped with pressure relief valves. All of the cylinders were also equipped with fusible plugs rated at (266ºF) 130ºC and opened if the flame impacted the valve area. [36]

NASSAU COUNTY FIRE TESTS

In 2005 the Nassau County (New York) Fire Academy conducted live fire tests on composite Liquefied Petroleum Gas (LPG) cylinders. [37] Two separate tests were conducted using two-piece 20 lb composite cylinders filled to 80% capacity with propane.

1. **Burning Pool Fire—**The test was set up as a pool fire using burning fuel oil. The cylinder was placed vertically on a metal grate approximately 5 inches above the liquid. At three minutes the outer protective casing burned away and the pressure relief valve functioned in 3 minutes and 25 seconds. Because the resulting jet was very low velocity, it is likely that the valve seals failed due to the heat rather than the valve opening due to pressure. At four minutes the cylinder vented at the neck of the cylinder, and the tank shell breached at four minutes and

Figure 9 Burning pool fire test of two-piece composite cylinder conducted by Nassau County, NY.

25 seconds, resulting in a complete burn off of the propane. There was no BLEVE and the cylinder remained upright during the entire test.

2. **Pressure-fed Propane Fire—**The test was designed to create a pressure-fed propane fire with direct flame impingement onto the cylinder. At less than one minute the outer protective casing burned away. The pressure relief valve functioned at two minutes and continued venting for three minutes. There was no breach of the cylinder shell. The cylinder burned off completely in 14 minutes.

The Nassau County Fire Academy made the following observations from their fire tests:

- The composite cylinder's potential to BLEVE is remote. The cylinder wall can be breached by fire without catastrophic destruction of the cylinder.
- A large plume of fire can be vented through the breach in the tank shell when the composite material burns through the shell.
- The pressure relief valve on the composite cylinders tested was the same as found on metal cylinders. When sufficient heat was applied to the area of the cylinder's neck the composite shell opened and the fire vented from around the attachment point where the valve is screwed into the cylinder. The valve remained in place but the fire vented around the attachment point.

FIRE TESTING OF CABINET HEATERS WITH COMPOSITE CYLINDERS

In 2005 Underwriters Laboratories, Inc. (UL) investigated the fire performance of composite propane gas cylinders with cabinet heaters in a room.[38] [39] UL designed and conducted five different tests. Both one and two-piece designs were tested. These included the one-piece cylinder with a non-load bearing liner, and a two-piece unlined cylinder. The test designs and results are summarized below.

1. **Empty Cylinder Fire—**Empty one and two-piece composite cylinders were burned to determine their heat and smoke release rates as well as melting and dripping characteristics. Cylinders were placed vertically and exposed to a standard test igniter.[40]

Key Findings:

- The maximum heat release rates from ignition and burning of the empty cylinders were approximately 110 to 120 kW.
- Both the jacket and resin material contributed to the fire. Flames attached to the jacket of the one-piece cylinder in 20 seconds, and to the two-piece cylinder in 30 seconds.
- There was pooling and burning of the melted resin. The size of the pool was 3 ft^2 for the one-piece cylinder and 1 ft^2 for the two-piece cylinder.

2. **Cabinet Heater with Composite Cylinder Fire Inside a Room—**A cabinet heater was tested in an NFPA 286 configuration room with the cylinder exposed to a standard igniter.[41] The room was lined with gypsum wallboard. The cabinet heater was located in the corner of the room facing the open doorway. In one test, an additional spare cylinder was positioned next to the heater and was also exposed to the igniter. During the test, temperature increases and heat flux were measured inside the test room, as well as the gas cylinder.

Key Findings:

- In each of these fire tests the ignited composite cylinder in the cabinet heater assembly released gas resulting in flashover conditions in the room.
- Once the cylinder started to leak, the release of gas continued during the test. A full cylinder was emptied in approxi-

mately 10 to 15 minutes after the maximum pressure was reached.

- Cylinder design may play a role in its fire performance. The two-piece composite cylinder ruptured when partially filled and was oriented horizontally. The one-piece composite cylinder did not rupture in any of the tests conducted.

3. **Cabinet Heater with Composite Cylinder Fire Inside a Room with Flashover**—In this test the room was lined with medium density fiberboard. The cabinet heater and propane filled composite cylinder were placed against the wall facing the open doorway. A propane burner located in the corner of the room was used to ignite the fiberboard and allowed to burn to flashover conditions inside the room. [42] The increase in temperatures from the fire growth were measured and the performance of the cabinet heater were evaluated.

Key Findings:

- In a growing room fire that goes to flashover, the composite cylinder breached and ignited after the flashover occurred. Typically, there was a 3 to 5 minute lag between room flashover and breach of the cylinder. The leaking gas cylinder involving the one-piece cylinder did not rupture.

4. **Cabinet Heater with Composite Cylinder and Additional Spare Cylinder with Fire In a Corner**—In this test the room was lined with gypsum wallboard. The cabinet heater was placed opposite the open doorway with a full spare cylinder next to it. A steady

Figure 10 Cabinet heater with composite cylinder fire inside a room.

Figure 11 One-piece construction composite cylinders fire test.

300 kW fire was set in one corner of the room. The pressure inside the cylinder was measured and the cylinder was observed to determine if the composite material ignited.

Key Findings:

- The spare cylinder's pressure increased from 106 psig to a maximum of 231 psig after 30 minutes of exposure to fire in the room. The pressure in the cylinder inside the cabinet heater remained fairly constant with a maximum of 123 psig.
- The cylinders did not ignite and did not leak.

5. **Burning Cylinder Filled With Water**—A one-piece cylinder was filled to half of its rated capacity with water and then pressurized with nitrogen following a pre-determined pressure—time curve. Two test sample igniters were used (See footnote #41). When the cylinder reached 220 psig, six minutes into the test, it was impacted with a hose stream. [43]

Key Findings:

- A breach occurred in the cylinder at 4 minutes and 12 seconds after ignition before water from the hose stream was applied.
- The burning one-piece composite cylinder pressurized with nitrogen did not breach violently or rupture when impacted with a hose stream.

VIEWPOINTS ON FIRE SAFETY

While propane composite cylinders have widespread use and acceptance outside the U.S., their use within the U.S. is relatively new. Consequently, other than the testing described in this paper, there is little practical field experience in the U.S. concerning their fire safety.

As with any new products, there are both supporting and opposing viewpoints concerning safety. The following key points summarize the findings of the authors based on discussions with members of industry and the fire service as well as the results from feedback obtained through the Advisory Panel on Composite Propane Cylinder Fire Testing and NFPA Regional meetings as reported by Battelle. [44] [45]

SUPPORTING VIEWPOINTS

- Composites have been used for many years in various structural components where safety is an issue. Examples include the marine, automotive, and aircraft industries. Composite cylinders for propane service have advantages over other materials such as metals including: strength, corrosion resistance, light weight, and the ability to actually see the level of propane inside the cylinder.
- Proposed code changes to NFPA 58 concerning propane cabinet heaters and composite cylinders are adequate to provide for safe use indoors. The 16 pound composite cylinder and connection are uniquely designed for connection to cabinet heaters, thereby eliminating the possibility that a larger composite or metal cylinder can be adapted and connected to the heater, and the heater is limited to 10,000 BTU/Hr.
- Composite propane cylinders exposed to indirect or direct flame impingement on the cylinder will not produce a Boiling Liquid Expanding Vapor Explosion (BLEVE). From a firefighter safety perspective, this is good news. Not every metal cylinder subjected to direct flame impingement results in container failure by BLEVE. Some cylinders simply burn off the propane through the pressure relief valve, while other cylinders may open up and vent through a split in the tank shell. Firefighters have been killed or seriously injured from metal propane cylinder failures by BLEVE. [46] Composite cylinders may have safety advantages as compared to metal cylinders. [47]
- If approved by the National LP Gas Code (NFPA 58) as currently proposed, properly designed propane unvented cabinet heaters, when combined with composite cylinders, may present some safety advantages over other types of space heaters already approved for indoor use in occupied buildings; e.g., kerosene heaters. This may be especially true when issues such carbon monoxide or accidental or intentional cross fueling is considered; e.g. pouring gasoline into a kerosene space heater. Propane is a clean burning non-toxic flammable gas.
- The availability to consumers of listed cabinet heaters may reduce the possibility that appliances approved for outdoor use will not be brought indoors. Experience from long term power outages has shown that some residents bring outdoor appliances like propane gas grills indoors for space heating or cooking food. [48] The availability of propane cabinet heaters approved for indoor use may reduce fatalities resulting from carbon monoxide during natural disasters such as hurricanes and winter storms.

OPPOSING VIEWPOINTS

- Allowing cabinet heaters and propane composite cylinders inside residential occupancies results in increased fire loading in compartmented spaces. Even small composite cylinders in the 16 to 20 pound range can create dangerous conditions for firefighters making interior structural fire attacks if they breach when firefighters share the same space within a room.

- Even with proper design and safety features, allowing unvented cabinet heaters inside residential occupancies, regardless of the type of cylinder (composite or metal), there is an increased safety risk from carbon monoxide exposure. There is concern over maintenance issues associated with **all types** of space heaters, not just propane appliances. Allowing propane heating appliances indoors in occupied spaces simply adds another potential source for carbon monoxide poisoning. [49]
- There currently is no national consensus standard available to guide manufacturers and fire safety enforcement agencies in determining if a cabinet heater entering the U.S. marketplace is safe. The American National Standards Institute (ANSI) is presently developing a new standard on cabinet heaters (ANSI Z21.11.3) which is expected to be released sometime in 2007. Propane cabinet heaters should not be allowed inside occupied buildings until a standard has been issued and an opportunity for public comment has been provided.

SUMMARY

Composite materials are not new and composite cylinders have been in use for several years outside the United States. They have recently been introduced into the U.S. and are approved by the U.S. Department of Transportation for transportation by highway, marine, rail, and cargo aircraft. Composite cylinders are currently allowed under the National LP Gas Code for outdoor use only. As noted above, they are being proposed for indoor use in conjunction with a heating appliance known as a cabinet heater.

Composite cylinders are presently manufactured in a one and two-piece design. They are basically made from a polymer wrapped fiberglass with an outer casing designed to provide additional protection to the tank shell. Construction materials include polyacrylonitrile butadiene styrene (ABS), high-density polyethylene (HDPE), and polyethylene terephthalate (PET). Both the one and two-piece designs are equipped with a Pressure Relief Valve set to function at 375 psig. The most common sizes being manufactured are the 20 pound BBQ cylinder and the 33 pound forklift cylinder. A 16 pound version would be manufactured for use with cabinet heaters if they are approved.

Recent fire tests conducted in 2005–2006 by three different respected organizations indicate that composite cylinders will not BLEVE when exposed to direct flame impingement. Composite cylinders may reduce the risk to firefighters by eliminating the threat from BLEVE, but tests indicate that they will breach in a fire. Essentially, the propane vents and burns and/or diffuses through the cylinder wall. The remaining composite melts and burns until it self extinguishes.

Proposed changes to the National LP Gas Code (NFPA 58) will allow propane cabinet heaters and composite cylinders in occupied buildings. This issue will be considered before the National Fire Protection Association Annual Meeting in Boston, MA on June 6–7, 2007. Emergency responders and fire marshals need to be well informed of the fire safety issues associated with composite cylinders and cabinet heaters. Fire safety professionals will need to determine if they will support suggested changes to the National LP Gas Code and if the code is adequate enough to provide an acceptable level of fire safety for U.S. citizens.

[1] Mike Hildebrand and Greg Noll are emergency response and planning consultants with Hildebrand and Noll Associates, Inc., Port Republic, Maryland. They are the authors of *Propane Emergencies*, 3rd edition (2007) and Chapter 8-7, *Public Fire Protection and HazMat Management*, 20th Edition of the NFPA Fire Protection Handbook (2007). They are both members of the NFPA-472 Committee, *Standard for Professional Competence of Responders to Hazardous Materials Incidents*. Contact the authors at hildebrand@chesapeake.net and ggnoll@earthlink.net.

[2] The Propane Education & Research Council was organized in 1996 through legislation authorizing an assessment of each gallon of propane gas at the point it is odorized or imported to the U.S. This multi-million dollar investment by the propane industry is used to improve consumer safety, fund new research and development of new and more efficient propane equipment, and to expand public awareness of propane. In 1998 PERC funded the development of the *Propane Emergencies* training program, consisting of a textbook, companion Facilitator's Guide and video. The *Propane Emergencies* training program is now in its third edition and has been distributed free of charge to over 30,000 emergency responders. The expanded program is now available for a nominal charge. For more information consult www.propanesafety.com and click on Propane Emergencies.

[3] U.S. Department of Transportation—approved pressure vessels have been manufactured for over 18 years using a variety of composite overwraps in an epoxy resin. These include fiberglass, aramid, and carbon and Kevlar® fiber. Materials typically shipped and used in these types of cylinders include breathing air, normal compressed air, oxygen, hydrogen, and natural gas. For an interesting comparison of the strength of composite materials vs. steel and aluminum consult www.bactechnologies.com and click on Design.

[4] Source: Goodrich www.epp.goodrich.com. The earliest known composite material is a simple adobe brick. Straw (a fibrous material) is mixed with mud (an adhesive with strong compression strength). Another common example is plywood. Today, composite materials are widely used in the automotive industry. For example, the entire body of the Chevrolet Corvette is made from composite materials. The Boeing 777 uses various composite materials in its structure because of their strength and weight saving abilities.

[5] Source: The Aviation History On-Line Museum.

[6] Source: Goodrich www.epp.goodrich.com.

[7] Source: The Lite Cylinder Company www.litecylinder.com.

[8] According to one manufacturer, there are about 240 million high pressure cylinders (both metal and composites) in operation in the world today and about 60 million more are being manufactured annually. There are about 1.5 million composite cylinders in the world market today and the potential market size is estimated at 10 million. Source: Kompozit-Praha Company.
See www.kompozit-praha.cz/en/company.html

[9] Cylinders are marked with the maximum amount of water that can be stored in the cylinder, but are typically referred to by the maximum amount of propane that can be stored in them. For example, a 100-pound propane cylinder can safely store 100 pounds of propane but would be marked with a water capacity (w.c.) of 239 pounds.

[10] Source: *Composite Propane (LP Gas) Cylinders*, November 17, 2005, Minnesota Department of Public Safety, State Fire Marshal.

[11] The National Fire Protection Association *Liquefied Petroleum Gas Code* (NFPA 58) is being revised for release in 2007. The National Propane Gas Association has made several proposals to modify NFPA 58 to allow cabinet heaters with composite cylinders.

[12] EN 12245, Transportable gas cylinders, Fully wrapped composite cylinders, and International Standards Organization (ISO), ISO11119-3–Gas Cylinders of Composite Construction— Specification Test Methods—Fully Wrapped Fiber Reinforced Composite Gas Cylinders with Non-Load Sharing Metallic or Non-Metallic Liners.

[13] Composite cylinders are regulated by DOT under 49 CFR Parts 106, 107, and 171-180. They are exempted from 49 CFR Parts 173.304a (a) (1) and 175.3.

[14] Pressure relief valves in both the one and two-piece cylinders are set to relieve pressure at 375 psig.

[15] Ragasco AS, Postboks 50, Raufoss Industrial Park B306, N-2831 RAUFOSS, Norway. Call +47 61 15 16 00. www.ragasco.com.

[16] Kompozit-Praha, Dysina 298 3300 02 Dysina u Plzne, Czech Republic. Call +420 377 946 091. www.kompozit-praha.cz.

[17] U.S. Department of Transportation, Pipeline and Hazardous Materials Safety Administration, Permit for DOT-SP 12706, issued to Ragasco, AS. Raufoss, Norway on March 16, 2006, Washington, D.C.

[18] The Lite Cylinder Company, 139 Southeast Parkway Court, Franklin, Tennessee 37064. Call 866-842-5483. www.litecylinder.com.

[19] U.S. Department of Transportation, Pipeline and Hazardous Materials Safety Administration, Permit for DOT-SP 13957, issued to T.L.C.C., Inc., Franklin, Tennessee on February 3, 2006, Washington, D.C.

[20] Source: Rodney Osborne, Composite Propane Cylinders Current and Future, Battelle, August 25, 2005.

[21] National Petroleum Gas Code, NFPA 58 (2004), Quincy, MA.

[22] PERC Docket Number 10662—Composite Propane Cylinder Regulatory Approval Request. A copy of the Docket can be viewed at http://www.propanecouncil.org/rd/cylinder.html

[23] PERC Docket Number 11328—Code Approval of Composite Propane Cylinders for Indoor Use.

[24] Code Approval of Composite Cylinders for Indoor Use—Phase-2, Docket 11643, Testing Report submitted by Stephanie Flamberg, Rodney Osborne, and Susan Rose, Battelle, Columbus, Ohio. April 2006.

[25] In 2005 Battelle attended NFPA Regional Fire Code meetings in Nevada, Maryland, Colorado, and Georgia to obtain feedback on the proposed fire testing program.

[26] Battelle contracted with National Fire Protection Research Foundation to establish a committee of fire protection officials to aid in the development of a detailed fire testing protocol. The technical Advisory Panel for this project included key representatives of the NFPA 58 committee, the International Association of State Fire Marshals (NASFM), and other technical specialists. The panel consisted of 8 people who were involved in reviewing the test plans, witnessing the fire testing and guiding the project. Battelle and ThermDyne performed preliminary fire testing for the project from February 17 to March 3, 2005 at the Mining Resource Engineering Limited test site north of Kingston, Ontario, Canada. Following these tests, Battelle contracted with Underwriters Laboratories (UL) to conduct live fire testing of composite propane cylinders in conjunction with the heating appliance in an NFPA 286 configuration test room. This research was completed by UL in November 2005.

[27] For more information on DOT special permits go to the Hazardous Materials Homepage at http://hazmat.dot.gov/sp_app/special_permits/spec_prem_index.htm. Click on Special Permits and Approvals.

[28] National Petroleum Gas Code, NFPA 58 (2004). National Fire Protection Association, Quincy, MA. See www.nfpa.org.

[29] Report of the Motions Committee on Certified Amending Motions for the Fall 2006 Cycle Documents, November 15, 2006, National Fire Protection Association, Quincy, MA.

[30] Under the proposed NFPA 58 (2007) Section 3.3.11, a cabinet heater is defined as a portable unvented type heater with a self-contained LP-Gas supply.

[31] Under the proposed NFPA 58 (2007) Section 3.3.17.1, a composite cylinder is defined as a cylinder constructed with fully wrapped fiber reinforced material, or a two part adhesively bonded non-metallic cylinder.

[32] Material in this section is based on tests funded by the Propane Education & Research Council (PERC) under Docket 11643. The tests were completed by Battelle from February 17 to March 3,

2005 at the Mining Resource Engineering Limited's test site north of Kingston, Ontario, Canada.

[33] The Advisory Panel was made up from members of the fire protection community. Representatives included the National Association of State Fire Marshals, National Fire Protection Association, International Association of Fire Chiefs, International Fire Marshals Association, Fire Protection Research Foundation, Underwriters Laboratories, North Carolina Department of Agriculture, Phoenix Fire Department, and the National Propane Gas Association.

[34] Code Approval of Composite Propane Cylinders for Indoor Use, Testing Report, Docket 11643, by Stephanie Flamberg, Rodney Osborne, and Susan Rose. April 2006, Battelle, Columbus, Ohio. Table 2 on Page 6 provides a detailed breakdown of each cylinder, its configuration during the fire test and if it was equipped with a PRV or fusible plug.

[35] The results of the preliminary fire tests of the composite cylinders showed that there was no significant difference in performance between two-piece cylinders equipped with pressure relief valves and those that did not.

[36] The fire tests included fusible plugs to evaluate their performance under live fire conditions. The proposed changes to the 2007 edition of NFPA require composite cylinders intended for use with indoor cabinet heaters to have a pressure relief valve, but they will be prohibited from having a fusible plug.

[37] Composite LPG Cylinder Test Burns: No BLEVE, by Assistant Chief Dennis Murphy and Deputy Chief Gene Pietzak, Firehouse.com, November 20, 2006. For a copy of this article follow the link to: http://cms.firehouse.com/content/article/article.jsp?id=52063&sectionId=18.

[38] Material discussed in this section is based on work funded by the Propane Education & Research Council under contract with Battelle. All tests were completed by Underwriters Laboratories, Inc. See Research Investigation on the Fire Performance of Composite Propane Gas Cylinders: Final Report, November 22, 2005, Project 05CA34146 by Maria Hjohlman, Underwriters Laboratories, Inc., Northbrook, IL.

[39] The cabinet heater used in the UL fire tests was designed and manufactured in Europe and rated at 20,000 btu/hr (5.9 kW). The outer dimensions of the heater were 16-1/2 inches by 17-1/2 inches by 27-1/2 inches high. The heater included a rubber hose and a hose clamp for connection to a regulator that incorporated a cylinder valve connection. A two-stage regulator meeting UL 144 was connected to the cylinder using a QCC1 fitting meeting CGA 791 standards. This system incorporated excess flow and thermal shutoff protection. In one test the CGA E-1 025 connected to the regulator without the other fittings. The heater was left in the ON position in some tests and OFF in other tests.

[40] The standard test igniter consisted of a 3 inch diameter by 6 inch long cellulosic roll placed in a plastic bag filled with 8 fluid ounces of gasoline to soak the cellulosic roll.

[41] Standard Methods of Fire Tests for Evaluating Contribution of Wall and Ceiling Interior Finish to Room Fire Growth, NFPA 286, 2006, National Fire Protection Association, Quincy, MA.

[42] UL used a 300 kW or a 40-60 kW propane burner to ignite the fiberboard.

[43] The hose stream was a 1-1/2 inch rubber hose equipped with an Elkhart SLO/0 adjustable nozzle. The nozzle was set at a maximum flow using straight stream at 100 psig. The stream was aimed directly at the cylinder from a distance of 18 feet.

[44] The authors have taken a neutral position on either the advantages or disadvantages of propane composite cylinders or cabinet heaters. The observations in this section, pro or con, do not necessarily reflect the view of the authors.

[45] Code Approval of Composite Cylinders for Indoor Use—Phase-2, Docket 11643, Testing Report, Pages 2-3, as submitted by Stephanie Flamberg, Rodney Osborne, and Susan Rose, Battelle, Columbus, Ohio. April 2006.

[46] Since 1993 seven firefighters have been killed in three separate BLEVE incidents in the U.S. and Canada involving non-stationary metal LPG tanks. Source: *Propane Emergencies*, 3rd, by Michael Hildebrand and Gregory Noll, page 159, Red Hat Publishing (2007).

[47] In December 2006 one of the worst winter storms to hit the northwest U.S. in over a decade knocked out power to more than 1.5 million homes and businesses. There were 6 fatalities and 100 injuries from carbon monoxide poisoning in separate incidents in Washington and Oregon. These accidents were caused when people brought unapproved appliances such as BBQ grills, charcoal grills, space heaters, and generators indoors to heat their homes and cook. At least 55 of these people required advanced medical treatment in hyperbaric chambers where pressure was used to force oxygen into their blood. Multiple Sources: December 17–18, 2006—Seattle Times, CNN, USA Today, and Firehouse .com.

[48] In the aftermath of Hurricane Katrina (2005) there were 51 cases of carbon monoxide poisoning requiring treatment at hyperbaric chamber treatment facilities in Alabama, Mississippi, and Louisiana. Between August 29 and September 24 there were 5 fatalities and 46 nonfatal CO poisonings. The majority of these poisonings were caused by bringing a generator into the home to provide electrical supply for lighting and cooking appliances. Source: U.S. Center for Disease Control as reported by N.B. Hampson, MD, Center for Hyperbaric Medicine, Virginia Mason Medical Center, Seattle, Washington. M.W. Lai, MD, American Association of Poison Control Centers. M. McNeil, MD, PhD, P. Byers, MD, Mississippi Department of Health. R. Ratard, MD, Louisiana Office of Public Health. M. Patel, MD, M Belson, MD, A Stock, PhD, J. Ferdinands, PhD, R. Funk, DVM, P. Meyer, PhD, C. Pertowski, MD, National Center for Environmental Health; D. Crocker, MD, EIS officer, CDC.

[49] For a good overview of carbon monoxide and its hazards visit the U.S. Environmental Protection Agency Indoor Air Quality Web site at: http://www.epa.gov/iaq/co.html.