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New Very High-Pressure Oxygen Cylinders for Use in Closed-Circuit Self-Contained Self-Rescuers (SCSRs)

Summary

New materials have allowed for a reduced size and weight of compressed gas cylinders that store pure oxygen at high pressures, giving manufacturers of closed-circuit self-contained self-rescuers (SCSRs) improved options for meeting the new standard for oxygen consumption requirements set forth in 42 CFR Part 84 Subpart O. These newly designed very high-pressure cylinders —currently Department of Transportation (DOT)-certified for oxygen duty to 3,000 psi and now available in two sizes—will enable manufacturers to reduce the overall size and weight of future SCSR units by incorporating these cylinders in their designs. Using this new cylinder technology at 3,000 psi represents a significant advancement, affording greater SCSR design flexibility by allowing manufacturers to choose between cylinders with two length dimensions, using them singularly or in combination, which will enable different capacities and therefore different operational durations for SCSR designs. Moreover, the new cylinder technology was designed to be capable of meeting DOT certification for 5,000 psi oxygen duty. Therefore, SCSR manufacturers can pursue DOT certification for use at 5,000 psi to further reduce the size and weight of their devices beyond what is already achievable at 3,000 psi.

By Rohan Fernando

Need for Improved Breathing Air Supply (BAS) Technologies

The Mine Improvement and New Emergency Response Act of 2006 demonstrated a need to move SCSR technology to a next-generation status. In response to this need, NIOSH established a Breathing Air Supplies (BAS) program to develop components that could be used in next-generation SCSR devices by:

- allowing users to change between breathing apparatus using docking/switch-over valves without exposure to a non-respirable atmosphere
- enabling verbal communications through the use of hoods and/or masks
- addressing performance efficiency improvements in SCSRs by focusing on specific design areas
- providing more ergonomic SCSR designs to improve the user experience
- exploring alternative solutions to SCSR caches along the escape route

Very High-Pressure Oxygen Cylinders

SCSRs used in mines for self-escape post-disaster store and generate oxygen in one of two ways, leading to two design types: chemical oxygen-generating types using potassium superoxide (KO_2) and types using gaseous oxygen stored in a compressed form in high-pressure cylinders. Current high-pressure oxygen cylinders used in NIOSH/MSHA-approved "one-hour" SCSRs store oxygen at 3,000 psi (206 bar) and are manufactured out of aluminum or composite materials. Stainless steel cylinders used in NIOSH/MSHA-approved "10-minute" SCSRs store oxygen at 3,850 psi (265 bar). With advances in materials science, two important opportunities exist: (1) to notably reduce the size and weight of cylinders filled to 3,000 psi, and (2) to significantly improve cylinder capacity by increasing cylinder fill pressure.

Figure 1: *Two new manufactured cylinders that meet DOT requirements for use in SCSRs.*

New Cylinder Designs

Two sizes of carbon composite cylinders with aluminum liners were manufactured (see **Figure 1**) to meet all relevant U.S. Department of Transportation (DOT) regulations. The capacity (or useable oxygen volume) to be contained in the cylinders was determined by considering two relevant standards:

- the oxygen consumption stated in the capacity and performance tables in 42 CFR Part 84 Subpart O—i.e., three capacity ratings defined in relation to volume of oxygen (in liters) available in the device as Cap 1 ($20 \leq L \leq 59$), Cap 2 ($60 \leq L \leq 79$), and Cap 3 ($L \geq 80$);

- the one-hour duration required by 30 CFR Part 75 for self-rescue devices used in mine escape applications.

To allow smaller cylinders to be used in an SCSR with a nominal duration of one hour or one-half hour while meeting the oxygen consumption requirements in 42 CFR Part 84 Subpart O, the design criterion for maximum service pressure was set at 5,000 psi (345 bar). Two cylinder sizes were selected to contain oxygen with expanded volumes (at 1 atmosphere) of 140 liters and 98 liters, respectively, at this pressure. **Table 1** lists the oxygen capacities at different pressures for the two newly manufactured cylinders—the Luxfer L3B and Luxfer L3C.

Table 1. Cylinder oxygen capacities at different pressures

Cylinder	Nominal water volume (cubic inches)	Length (inches)	Diameter (inches)	Oxygen volume (liters) at service pressure (psi)
Luxfer L3B	19.7	6.5	2.7	98 L at 5,000 psi 70 L at 3,000 psi
Luxfer L3C	28.1	8.5	2.7	140 L at 5,000 psi 101 L at 3,000 psi

For fill capacities of both 3,000 and 5,000 psi, the cylinders also provide a significant reduction in size and weight from that which is currently available on the market. The new cylinders described in this document represent a significant opportunity for SCSR manufacturers to address the size and weight concern in new SCSR designs. As an example, when considering only the 3,000 psi fill capacity, one could now develop a smaller and lighter Cap 3 device by using the L3C cylinder filled only to 3,000 psi. Moreover, as manufacturers design their SCSRs to meet the new standard, the need for a different layout/shape or longer-duration (140 L) Cap 3 SCSR may be desirable. In this instance, a manufacturer has the option of using two L3B cylinders in combination, each filled at 3,000 psi. In addition to the size and weight improvements discussed above when the cylinders are filled to only 3,000 psi, additional improvements will also be achievable if a manufacturer pursues DOT certification for filling to 5,000 psi. For this same example cited above, the L3C cylinder can be replaced with the L3B cylinder when pressurized to 5,000 psi, thus making the SCSR still smaller due to the reduced cylinder size for the same duration. The 5,000 psi (345 bar) service pressure rating allows the required quantity of oxygen to be stored in a cylinder that could be used in a person-wearable one-hour SCSR despite the degrading effects of the compressibility factor of oxygen at that pressure. This pressure is within the capability of current oxygen-filling equipment, such as booster pumps.

New Cylinder Specifications

The new cylinders are fully wrapped filament-wound composite pressure vessels designed for a maximum service pressure of 5,000 psi (345 bar) and an operating service life of 15 years. They are constructed of a carbon fiber/epoxy resin composite overwrap of a 6061-T6 aluminum alloy liner. The outermost wrap of the cylinders consists of an S2-glass fiber/epoxy resin composite for abrasion protection.

The cylinders have one port with an internal neck thread with an O-ring seal to accept a shut-off valve and/or pressure regulator. Both cylinders were manufactured to the following specifications: maximum service pressure of 3,000 psi (206 bar) for containing oxygen; maximum service pressure of 5,000 psi (345 bar) for containing air, argon, carbon dioxide, helium, hydrogen, methane, nitrogen, and nitrous oxide; test pressure of 8,333 psi (575 bar); approval by DOT SP-10915; qualification tests according to DOT-CFFC; thread form of 0.625-18 UNF-2B.

The following additional specifications apply to the Luxfer L3B cylinder: nominal diameter of 2.7 in (68.6 mm); nominal length of 6.5 in (164 mm); water volume of 19.7 cu. in (0.32 liters); maximum weight (empty) of 1.1 lb (0.50 kg).

The following additional specifications apply to the Luxfer L3C cylinder: nominal diameter of 2.7 in (68.6 mm); nominal length of 8.5 in (216 mm); water volume of 28.1 cu. in (0.46 liters); maximum weight (empty) of 1.3 lb (0.58 kg).

The material used in cylinder manufacture is oxygen compatible; however, cylinders must be internally cleaned for oxygen service according to MIL1330 or an equivalent standard before being integrated into a breathing apparatus.

Certification Testing

As part of the qualification process, the cylinders underwent a series of tests according to DOT-CFFC procedures. These were the hydrostatic test, hydraulic burst test, drop test, cycling test at ambient temperature, environmental cycle test, thermal cycle test, gunfire test, and bonfire test. The cylinders were tested at a DOT testing facility. Design approval certificates were issued for both cylinder types per DOT-SP10915, allowing the cylinders to be filled with compressed gas to 3,000 psi (206 bar).

Limitations/Restrictions

The current DOT approval for these newly developed cylinders allows a maximum service pressure of 3,000 psi (206 bar) for containing pure oxygen, which is the gas used in closed-circuit SCSR designs. The 5,000 psi (345 bar) pressure rating is for containing air and other gases. DOT approval for the 5,000 psi (345 bar) oxygen rating is being pursued by NIOSH, but until such approval is granted, these cylinders should be limited to a service pressure of 3,000 psi (206 bar).

Breathing Air Supplies Program Statement

As NIOSH continues to implement its Breathing Air Supplies program, we will continue to work with any interested manufacturers to help them produce compliant products to meet NIOSH and DOT standards.

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