Safe Design and Operation of Hyperbaric Chambers

Reviewed by: UHMS Hyperbaric Oxygen Safety Committee

Summary

The safety of hyperbaric chambers relies on three critical elements: appropriate pressure vessel engineering, appropriate fire safety engineering, and appropriate operating practices. National statutory and regulatory documents commonly control the operation of pressure vessels for human occupancy, the operation of potentially dangerous machinery, and occupational health and safety. At the time of this writing, numerous such documents exist throughout the world (some are listed below for reference). However, many countries do not provide any form of safety standard for hyperbaric chambers. If a standard exists, then local, regional, or national jurisdiction takes precedence. Where a standard does not provide adequate guidance or does not exist, the hyperbaric chamber user must seek appropriate guidelines to ensure safe working practice. Hyperbaric chamber mishaps throughout the world have highlighted the need for better guidance and education in hyperbaric chamber safety.

Pressure Vessel Design

The failure of a hyperbaric chamber can cause injury to occupants and others outside the chamber. In 2004 a home-made chamber ruptured, causing damage to the adjacent building and killing both the occupant and an outside observer. This chamber was made from an air receiver that had been modified by adding an entry hatch. Analysis of the mishap concluded the failure occurred at the modified hatch weld. In another mishap in 1995, two patients and one outside observer were injured when a hyperbaric chamber door fractured during a patient treatment. This sprayed door fragments into the room and caused rapid decompression of the chamber. The chamber was also propelled into a nearby wall. The original metal door of the chamber had been replaced with an acrylic door. A pressure vessel standard was not used in either of these two cases.

In order to build or modify hyperbaric chambers safely, guidance on design criteria, suitable materials, and fabrication and testing technique is necessary. This information can be found in the *International Boiler and Pressure Vessel Code*, Section VIII (American Society of Mechanical Engineers) for general pressure vessel construction and in *ASME PVHO-1: Safety Standard for Pressure Vessels for Human Occupancy* (American Society of Mechanical Engineers), which supplements the content of Section VIII specifically for human occupancy and acrylic viewport design. The current clinical and diving pressure vessel standards for acrylic viewports in the United States, Europe, Australia, South America, South Africa and Asia all now refer directly to the ASME PVHO Standard. This standard represents the most comprehensive data source available.

Fire Safety Design

Within the last 40 years, there has been an average of one clinical hyperbaric chamber fire every two years around the world. On average, two people have died in each fire. Many of these fires were caused by electrical design problems - one of the most recent occurred in 2009. It is important to note that in the USA, specifically where *NFPA 99: Health Care Facilities Code* (National Fire Protection Association) has been adopted, there has been not a single fatality in a clinical hyperbaric facility until May of 2009. This standard is internationally recognized to have an effective and lasting safety record and represents the most comprehensive fire prevention standard.

Operational Safety

Even safely designed hyperbaric chambers are subject to misuse and poor maintenance. In two hyperbaric chamber fire mishaps, poor maintenance was clearly a contributor to the tragic outcomes. In 1998, the fire started inside a recently maintained oxygen supply line. The most likely cause was improperly installed or improperly cleaned piping. The fire spread to the inside of the chamber, killing three occupants. A fire suppression system was available, but it was not used due to poor training of the chamber operator. In another mishap in 1997, the cause of the fire was a liquid fuel warmer in a patient's pocket. The chamber operator activated the fire suppression system, but it did not work. It had been disabled during previous maintenance work. Eleven occupants were killed.

Although maintenance is an important safety element, the most common cause of clinical hyperbaric chamber fires is the ignition mechanism taken into the chamber by an occupant. In addition to guidance on safe design of hyperbaric chambers, *NFPA 99* includes extensive guidance on maintenance and operational safety.

Fatalities in hyperbaric chambers are not limited to fire and pressure vessel failure. Failure to use appropriate decompression procedures like the United States Navy decompression tables (found in *US Navy Diving Manual*) has led to decompression sickness related deaths and injuries in hyperbaric chambers.

In almost all hyperbaric mishaps, either inadequate training or an inadequate safety program is cited as a contributing factor. This emphasizes the need for safety training. Staffing and training recommendations can be found in *UHMS Guidelines for Hyperbaric Facility Operations* (Undersea and Hyperbaric Medical Society).

Pressure Vessel Standards (USA)

Title: International Boiler and Pressure Vessel Code (ANSI ASME BPVC), Section VIII, 2010

Publisher: American Society of Mechanical Engineers, New York

Title: Safety Standard for Pressure Vessels for Human Occupancy (ANSI/ASME PVHO-1: 2007)

Publisher: American Society of Mechanical Engineers, New York

Title: Safety Standard for Pressure Vessels for Human Occupancy: In-service Guidelines for PVHO Acrylic Windows (ANSI/ASME PVHO-2: 2003)

Publisher: American Society of Mechanical Engineers, New York

Fire Safety Standards (USA)

Title: Health Care Facilities (NFPA 99). Chapter 14: Hyperbaric Facilities. 2012

Publisher: National Fire Protection Association, Quincy, Massachusetts

Title: Inspection, Testing, and Maintenance of Water-Based Fire Suppression Systems (NFPA 25)

Publisher: National Fire Protection Association, Quincy, Massachusetts

Title: National Electrical Code (NFPA 70 1999)

Publisher: National Fire Protection Association, Quincy, Massachusetts

Title: Fire Hazards in Oxygen-Enriched Atmospheres (NFPA 53 1994)

Publisher: National Fire Protection Association, Quincy, Massachusetts

Title: Recommended Practice on Materials, Equipment and Systems Used in Oxygen-Enriched Atmospheres, NFPA 53 1994)

Publisher: National Fire Protection Association, Quincy, Massachusetts

Title: Schramm PJ, Early MW. “Electrical Installations in Hazardous Locations.”

Publisher: National Fire Protection Association, Quincy, Massachusetts, 1994

Operational Safety Guidance (USA)

Title: Cleaning Equipment for Oxygen Service (G-41)

Publisher: Compressed Gas Association (CGA), Chantilly, Virginia (1996)

Title: 8. Standard Practice for Cleaning Methods and Cleanliness Levels for Materials and Equipment Used in Oxygen Enriched Environments, G-93: 1996

Publisher: American Society for Testing and Materials, West Conshohochen

Title: Handbook of Compressed Gases

Publisher: Compressed Gas Association (CGA), Chantilly, Virginia (1999)

Title: Rules for Building and Classing Underwater Vehicles, Systems and Hyperbaric Facilities

Publisher: American Bureau for Shipping (ABS), Houston, Texas (2002)

Title: UHMS Guidelines for Hyperbaric Facility Operations

Publisher: Undersea and Hyperbaric Medical Society, Dunkirk, Maryland (2004)

Title: US Navy Diving Manual

Publisher: US Government Printing Office, Washington, D.C. (2008)

International Safety Guidance

Title: A European Code of Good Practice for Hyperbaric Oxygen Therapy

Publisher: European Science Foundation, Mannheim, Germany (2004)

Title: ECHM Educational and Training Standards for the Staff of Hyperbaric Medical Centres

Publisher: European Committee for Hyperbaric Medicine, Lille, France (1997)

Title: ECHM Recommendations for Safety in Multiplace Medical Hyperbaric Chambers

Publisher: European Committee for Hyperbaric Medicine, Lille, France (1998)

Title: Guide to Electrical Safety Standards for Hyperbaric Treatment Centres

Publisher: British Hyperbaric Association, Aberdeen, UK (1996)

Title: Guide to Fire Safety Standards for Hyperbaric Treatment Centres

Publisher: British Hyperbaric Association, Aberdeen, UK (1996)

Title: Health and Safety for Therapeutic Hyperbaric Facilities: A Code of Practice

Publisher: British Hyperbaric Association, Norwich, UK (2000)

Title: Hyperbaric Facilities, Occupational Health and Safety (CSA Z275.1-05)

Publisher: Canadian Standards Association, Toronto, Canada (2005)

Title: Occupational Diving Operations (AS/NZS 2299.1.2007)

Publisher: Standards Australia, Sydney, Australia (2007)

Title: Pressure Vessels for Human Occupancy (PVHO). Multiplace Pressure Chamber Systems for Hyperbaric Therapy. Performance, Safety Requirements and Testing. EN 14931:2006

Publisher: CEN European Committee for Standardization (CEN), Brussels

Title: Pressure Vessels for Human Occupancy, Part 1: Hyperbaric Chambers (therapeutic) (SABS 0377-1)

Publisher: South Africa Bureau of Standards, Pretoria (2002)

Title: Risk Assessment Guide for installation and operation of clinical hyperbaric facilities

Publisher: International ATMO, San Antonio, Texas (2010)

Title: DNV-OS-E402. Offshore Standard for Diving Systems

Publisher: Det Norske Veritas (DNV), Hovik, Norway (2010)

Title: GL-2009, Part 5, Section 1: Classification & Certification of Diving Systems & Diving Simulators Publisher: Germanischer Lloyd (GL), Hamburg, Germany (2009)

Title: Rules and Regulations for the Construction and Classification of Submersibles and Diving Systems

Publisher: Lloyd’s Register of Shipping (LR), London (1989)

Title: Safety Supervision of Multiseat Hyperbaric Chambers in a Clinic Environment (ISPESL/C.I. Document)

Publisher: ISPESL, Rome (1999)

Title: Work in Compressed Air and Hyperbaric Facilities: Part 2: Hyperbaric Oxygen Facilities (AS 4774.2-2002)

Publisher: Standards Australia, Sydney, Australia (2002)

Title: Hyperbaric chambers – Specific requirements for fire extinguishing systems – Performance, installation and testing. (EN 16081: 2011)

Publisher: European Committee for Standardization (CEN), Belgium,