Oxygen Reduction

An Introduction and Case Study

By Adam Barowy and Scott Creighton, F(PE)

FOR APPROXIMATELY 20 YEARS, OXYGEN REDUCTION FIRE PROTECTION SYSTEMS HAVE BEEN DEVELOPING as a new approach to providing a primary means of fire protection for enclosed spaces. The design concept of these systems is to reduce the oxygen concentration within a space (by constant inerting with nitrogen) sufficiently to prevent ordinarily combustible materials from igniting in the presence of a typical ignition source. Oxygen reduction systems should not be confused with gaseous extinguishing systems, which discharge extinguishing agents after a fire starts in response to detection. Oxygen reduction systems provide constant control over the gaseous makeup of the enclosure while online.

As of 2014, more than 700 installations have been constructed outside of North America by just one manufacturer.[1] Common applications for oxygen reduction systems include data centers, cold storage, museum storage areas and archives, and electrical rooms. Few installations currently exist in North America. However, two notable examples are a system that protects the Betsy Ross American Flag at the Smithsonian National Museum of American History,[2] and a system in Richland, Washington that protects the largest cold storage warehouse in North America (as of September 2015).[3]

What is an Oxygen Reduction Fire Protection System?

Nitrogen producing equipment is the backbone of any oxygen reduction fire protection system. The nitrogen supply is produced onsite from ambient air. The systems employ technology originally developed in the 1980's for the industrial gas industry in a process known as "air separation."[4] The development of air separation equipment for use in fire protection applications began approximately 20 years ago,[1] though this is not to suggest that controlling the gaseous environment within an enclosure is a new concept. The first published research into the feasibility of mitigating fire hazards by continuous inerting an enclosed space was conducted by the U.S. Navy in the late 1960s,[5] and continued with research into the medical hazards of flame-suppressing atmospheres in 1990s.[6] Oxygen reduction systems referred to as On Board Inert Gas Generating Systems (OBIGGS) have been deployed for explosion prevention in the fuel tank ullage spaces of military aircraft for approximately 30 years.[7]

Manufacturers of oxygen reduction systems use three different air separation technologies to produce nitrogen: selectively permeable gas membranes, pressure swing adsorption (PSA), and vacuum pressure swing adsorption (VPSA). The membrane systems work much like a filter: as compressed air flows through a membrane, smaller oxygen molecules pass through the porous membrane walls. This allows oxygen and nitrogen to be collected into separate pipework. The PSA and VPSA systems work similar to each other, by passing compressed air through pressure vessels containing a carbon material that selectively adsorbs oxygen and allows nitrogen to pass through. Flow through a vessel is discontinued when the carbon material becomes saturated, and nitrogen flow is continued from another vessel. A saturated vessel "regenerates" when it is depressurized back towards atmospheric pressure. A continuous effluent of nitrogen is typically produced using two vessels.[8]

Figure 1 demonstrates the basic operation of an oxygen reduction fire protection system. Membrane, PSA or VPSA, air separation technologies are represented in the box labeled "air separation."

The potential for ignition and fire growth within the enclosed space(s) is reduced because of two basic phenomena: 1) less oxygen is available for combustion and 2) a greater amount of thermal energy is lost during combustion due to the additional nitrogen. The oxygen concentration required to establish fire protection is primarily determined by the flammability characteristics of the materials to be stored within the enclosed space, but also depends on ambient temperature and pressure. Figure 2 shows how temperature, pressure, and the addition of nitrogen affect the gaseous composition of a fixed volume of air. The atmospheres illustrated in Figure 2 provide insight into

Fire Protection 101

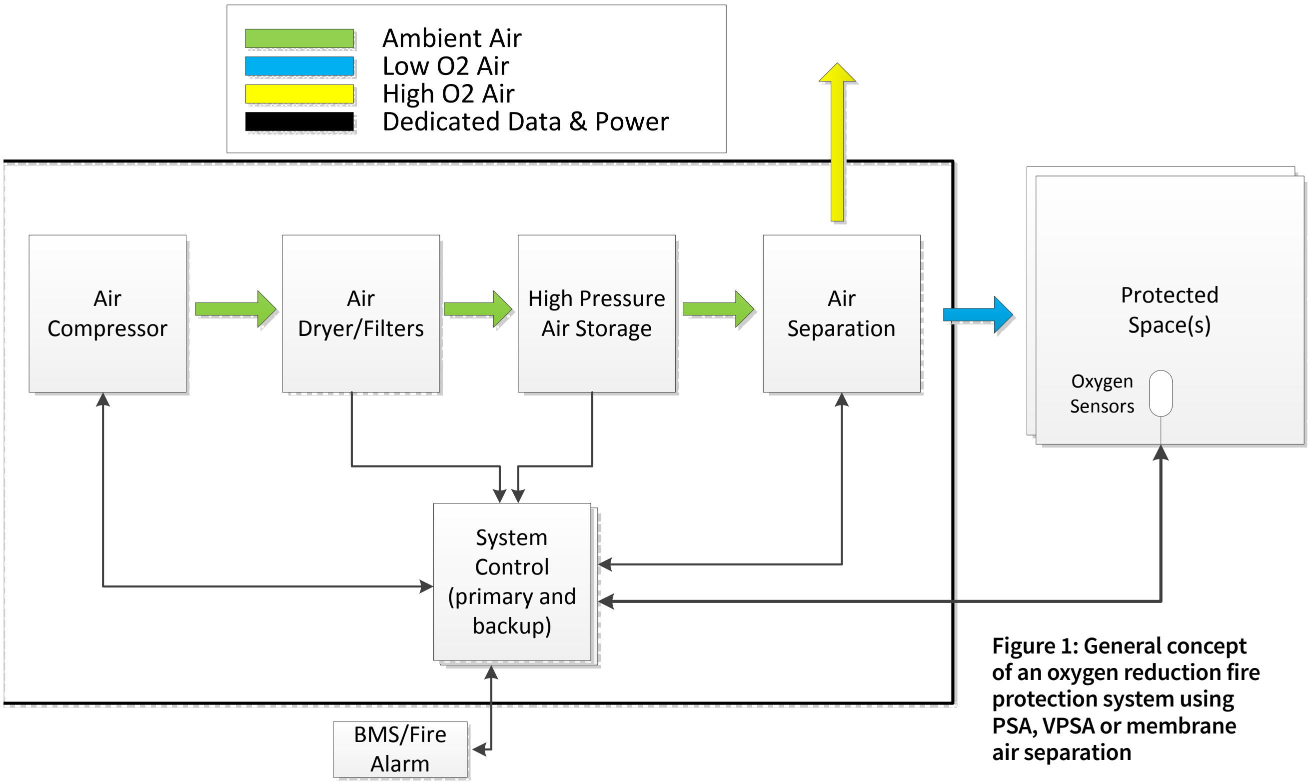

Figure 1: General concept of an oxygen reduction fire protection system using PSA, VPSA or membrane air separation

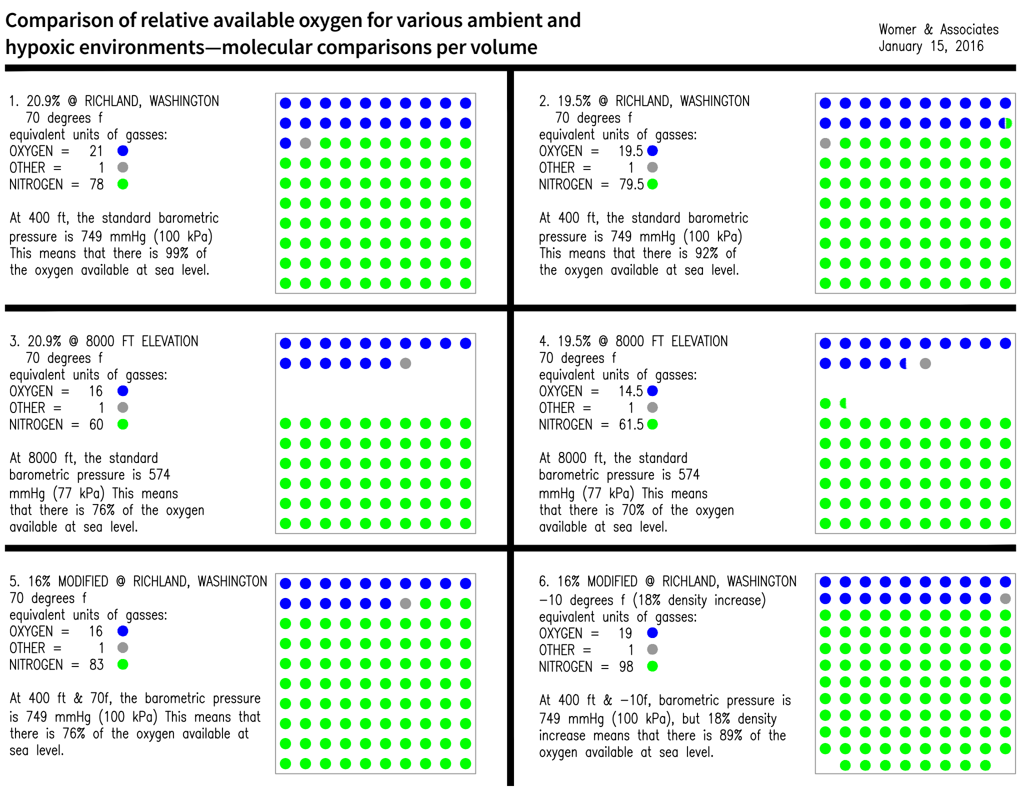

Figure 2: Gaseous composition of the atmosphere under different conditions of temperature, pressure, and oxygen reduction. © Womer & Associates.

the variables considered at the installation described in this article's case study.

The reduced oxygen concentration referred to as the "ignition threshold" by guideline documents that restrict burning, must be empirically determined for all materials stored within the space protected by the system. The design oxygen concentration that any system maintains is principally determined by the stored material with the lowest ignition threshold oxygen concentration. By the test methods currently used in European oxygen reduction system guidelines, ignition thresholds for common plastics and cellulosics typically fall within 14 to 17 percent, and within 11 to 16 percent for solvents.[9, 10] When determining a design oxygen concentration, European guidelines recommend reducing the lowest ignition threshold by 1 percent (volume concentration) as a safety margin.[9] It is anticipated that the first European installation standard, due to be published in 2016, will require a safety margin of 0.75 percent with a further allotment based on the precision of the oxygen sensing equipment.[11]

CASE STUDY Richland, Washington

In July 2015, construction of the largest public refrigerated warehouse in North America was completed in Richland, Wash. An oxygen reduction system is the primary means of fire protection for this facility. The warehouse employs an automated storage and retrieval system (ASRS) and has three common wall freezer spaces that are each 475 ft (145 m) long by 225 ft (69 m) wide by 116 ft (35 m) tall. Each freezer encloses approximately 12,000,000 ft^3 (340,000 m^3) and has a capacity of approximately 115,000 pallet stalls for 9 ft (2.8 m) high pallet loads. The racking has eleven 9.5 ft (2.9 m) tier levels for a total storage height of 106 ft (32 m). Further details of the building construction are available in the January 2015 issue of *Construction Today*.[12]

The fire protection engineer for this project provided the stakeholders with a complete array of prescriptive and performance-based options for this complex and unusual facility. The performance objectives established for the fire protection system in this facility included:

- Provide a system that is least likely to result in the contamination of the stored commodity.
- Provide redundancies of equipment to assure that a single point equipment failure cannot cause loss of protection.
- Provide a system that reduces risk to emergency responders (reduce fire frequency or severity).
- Provide a system that does not require water or chemical (e.g., antifreeze) cleanup.

The stakeholders were most concerned with smoke contamination that can result in a complete loss of the food product. Because fire sprinkler activation is dependent on the heat generated from a fire, the stakeholders chose to pursue an oxygen reduction system using a performance-based approach.

There was an early consensus that oxygen reduction would be a reasonable substitute for fire sprinklers. The stakeholders were already familiar with the oxygen reduction system equipment used in controlled atmosphere food preservation.

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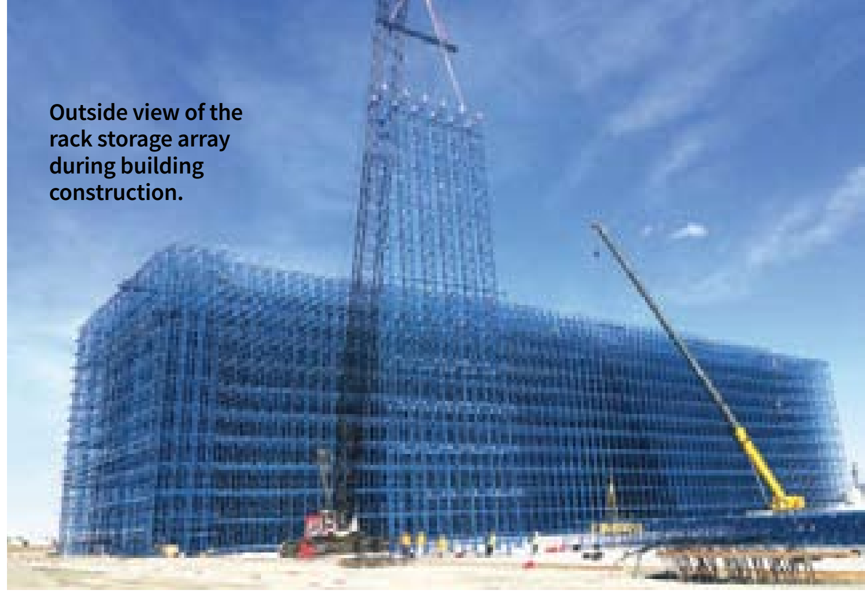
Figure 3: Outside view of the automated cold storage warehouse in Richland, Wash. © WAGNER Group.

The view down an aisle of the Richland warehouse.

Oxygen reduction systems (that maintain ≤ 3 percent O_2)[13] are frequently deployed in apple storage warehouses within the geographical area surrounding Richland.

The proposed design of the oxygen reduction system for this application needed to meet the safety criteria of Verband Der Schadenversicherer (VdS), a German testing, inspection and certification company, as well as the Fire Engineer of Record and the local building and fire department criteria. VdS has developed design and installation guidelines as well as a certification program for oxygen reduction systems. In addition to the details required in the guideline document VdS 3527en,[14] VdS conducted fire testing on the commodity anticipated to provide the greatest challenge to the oxygen reduction system and concluded that an oxygen concentration of 17.4 percent provided the necessary "ignition threshold." The final design oxygen percentage of 16.1 percent was derived by applying a 1 percent safety margin recommended by VdS and a 0.3 percent safety margin recommended by the oxygen reduction system manufacturer.

In the United States, the Occupational Safety and Health



Outside view of the rack storage array during building construction.

Administration (OSHA) regulations require employees to wear self-contained (or supplemental) breathing apparatus to enter and work in the freezer spaces because the oxygen concentration is less than 19.5 percent.[15] Entry points are monitored with position switches and display notifications of the reduced oxygen hazard within the freezer space.

After system installation, equipment was individually tested for function and performance. With the system operational, the oxygen concentration was reduced by approximately 0.25 percent per day. Reducing the oxygen concentration to 16.1 percent required three weeks. The system control panel indicates operational status locally as well as remotely to the building control room and to the manufacturer.

These systems, as with other fire protection systems, require ongoing inspection, testing, and maintenance to ensure reliability of operation.

Advantages, Limitations and Challenges

Oxygen reduction fire protection systems have advantages and limitations. As a new fire protection approach, oxygen reduction faces several implementation challenges, particularly within the United States. Table 1 summarizes the advantages, limitations, and challenges facing oxygen reduction systems.

TABLE 1

Summary of advantages, limitations, and challenges for oxygen reduction systems

Advantages	Limitations	Challenges
Prevention of ignition for materials that have an ignition threshold above the design oxygen concentration of a system.	A risk of fire spread still exists if the oxygen concentration is above the ignition threshold.[11,16]	The current lack of consensus-based design and installation standards
Activation is not necessary because the reduced oxygen atmosphere is constantly maintained.[16]	Not intended for use in explosion suppression or prevention.[11]	Limited data available for ignition thresholds of materials[16]
Oxygen concentration can be adjusted to accommodate changes in stored materials, within limits of system design.[1]	Cannot prevent fire hazards from materials that can provide their oxygen.	Limited research on smoldering in reduced oxygen environments[16]
No damage from an extinguishment agent.[1]	Not intended to provide protection during hot work.[11]	Reconciliation needed between oxygen reduction systems and health and safety regulations
	Intended only to protect an enclosed space (i.e., nothing outdoors).[11]	Better understanding of system reliability[16]

It is important to understand the advantages and limitations of any means of fire protection, but the growth potential for oxygen reduction system deployment within the United States lies in addressing the challenges identified in Table 1.

Regulations

The greatest challenge for oxygen reduction systems is that there is currently no installation standard in the United States. Fire protection engineers pursuing oxygen reduction fire protection will need to rely on either VdS guidelines or the EN installation standard until a U.S. installation standard is developed. Development of an installation standard in the United States is not yet underway.

UL issued a product safety certification document in January 2016 for oxygen reduction systems titled as, UL 67377, Outline of Investigation for Oxygen Reduction Fire Protection System Units.[17] The UL certification document evaluates the capability of a system to develop and maintain a reduced oxygen atmosphere within an enclosure. The document includes requirements for fire, electrical, and mechanical safety of oxygen reduction system equipment, and uses a functional safety approach to evaluating the reliability of the system control hardware and software.

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Limited data is available for the ignition thresholds of materials.[16] In practice, this is not a significant challenge, as existing installation standards for oxygen reduction systems require that material test data form the basis for determination of the design oxygen concentration. This is similar to the practice of commodity classification testing. However, Nilsson and van Hees suggest further developments to the test method currently used in Europe should be based on research into the dependency of ignition threshold oxygen concentration on material orientation and reradiation.[16] Research data is also limited to the effect of reduced oxygen concentrations on smoldering behavior and the production rates of pyrolyzates and other gasses.[16]

Internationally, occupational safety and health regulations establish required oxygen concentrations within working environments. These regulations determine whether an AHJ will permit employees to work within a reduced oxygen space. Regulations may require employees to wear supplemental breathing apparatus or to take mandatory breaks within a normoxic environment. Regulations are based upon an occupational safety regulator's interpretation of health risks at sub-atmospheric levels of oxygen and differ internationally.

For example, Germany has established four risk classes for reduced oxygen atmospheres. Each class requires employee awareness training. As oxygen concentration decreases, each increase in risk class requires reduced exposure durations. Below 13 percent O_2, supplemental breathing apparatus are required.

In the United States, OSHA maintains that an oxygen deficient atmosphere contains less than 19.5 percent O_2. In practice and for the indefinite future, installations in U.S. are likely to be limited to normally unoccupied spaces that require breathing apparatus for entry, similar to the warehouse in Richland.


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