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Hypoxic Fire-Prevention Systems

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Why drown your servers in water or damage your disks with an explosive release of fire-suppressing gas[1] when you can prevent a fire in the first place? That is the role of an hypoxic fire-prevention system. These systems maintain an oxygen level in a computer room that is below the level required to sustain a fire but which is at a safe level for humans.

How do these systems work, and are they really safe to the system operators confined to the oxygen-depleted environment? We review these issues in this article.

The Basis for Hypoxic Fire Suppression

Air as we know it is a mixture primarily of two gases – oxygen and nitrogen. Normal air contains 21% oxygen, 78% nitrogen, and 1% of other gases such as carbon dioxide. This combination is kind to both humans and fire. But reducing the oxygen percentage to 16% creates an air mixture that is still kind to humans but is death to most fires. This is the basis of hypoxic fire-prevention systems.

Understanding how hypoxic fire suppression works depends on understanding two physical characteristics of the amount of oxygen in the air we breathe: *partial pressure* and *concentration*.

Partial Pressure

In a mixture of gases such as air, each gas has a *partial pressure*. This is the pressure that the gas would have if it occupied the entire space.

At sea level under standard conditions, air exerts a pressure of 14.7 pounds per square inch (this is the equivalent of 33 feet of water on top of us, as any SCUBA diver knows). Since oxygen is causing 21% of this pressure, oxygen is exerting a pressure on us of 3.1 pounds per square inch – its partial pressure.

As we move higher in altitude, the amount of air above us decreases; and the air pressure goes down. Up to 18,000 feet, the decrease in air pressure is nearly linear. At 9,000 feet, it is 75% of sea level pressure. At 18,000 feet, it is 50% of sea level pressure. However, at any altitude, air is air. It still contains 21% oxygen. Therefore, at 9,000 feet, for instance, oxygen is exerting a pressure on us of 2.3 pounds per square inch. There is 25% less oxygen to breath.

[1] In February, 2010, an accidental release of Inergen gas took down hosting provider WestHost for six days. It turned out that the noise of the gas discharge damaged multiple hard drives. See WestHost Fire Suppression Test Fiasco – An Update, *Availability Digest*; September 2010. Tyco, the company that manufactures the Inergen gas, has indicated that they understand this problem and are working on a solution by developing improvements to the Inergen nozzle.
http://www.availabilitydigest.com/public_articles/0509/westhost_update.pdf

As we all know, if we go high enough, there comes a point where there is not enough oxygen to support life. However, humans are fairly flexible in this regard. Commercial aircraft are pressurized at 8,000 feet. People live comfortably in La Paz, Bolivia, where the altitude ranges from 10,000 to 13,000 feet. A few climbers have successfully scaled 29,000-foot Mt. Everest without oxygen.

Going the other way shows equal flexibility. A scuba diver descending to 110 feet is under a pressure of four atmospheres, or 58.8 pounds per square inch. The fourfold increase in oxygen is of no concern. However, the fourfold increase in nitrogen can cause a painful and sometimes fatal condition called the bends if the diver remains submerged for too long and surfaces too quickly.

Concentration

The *concentration* of a particular gas in a mix of gases is the percent of the gas that it makes up. It is directly proportional to the gas' partial pressure. In standard air, the concentration of oxygen is 21%; and this concentration remains fairly constant at all altitudes.

However, air mixtures with different concentrations find uses in many applications. SCUBA divers often use an air mixture called Nitrox, which contains a higher concentration of oxygen – typically 32% to 36%. The reduced nitrogen content allows them to stay submerged longer without suffering the effects of the bends.

Inergen is a gas used to suppress fires. It is commonly used in data centers and comprises 52% nitrogen, 40% argon, and 8% carbon dioxide. Note – no oxygen. Typically, when a fire is detected, enough Inergen is released to reduce the oxygen concentration in the computer room to about 10% to 12%, which is not enough to support combustion. However, the increased carbon dioxide level in Inergen increases a person's respiration rate (it is carbon dioxide in our blood stream that invokes the breathing response), allowing a person to function in the reduced oxygen level long enough to exit the room.

Combustion

Fire requires oxygen. But how much? As it turns out, it is not the amount of oxygen that supports combustion (oxygen's partial pressure) but rather its concentration.

The fact that the partial pressure of oxygen is not a significant factor in combustion can be observed by the fact that people in La Paz light fires at 13,000 feet. Non-turbocharged cars climb 14,000-foot Pikes Peak. One would expect that climbers could light camp fires at much higher altitudes.

But reducing the concentration of oxygen from 21% to 16% snuffs out most fires. This is equivalent to an altitude of about 9,000 feet. Even if the total pressure of this oxygen-depleted air is increased so that the total amount of oxygen available is equal to that of normal air at sea level, combustion still will not take place.

Hypoxic Air

Oxygen-depleted air is called *hypoxic air*. How does hypoxic air suppress a fire? When a heat source is applied to a combustible material, it causes that material to react with oxygen and release more energy in the form of heat. This chemical reaction is the beginning of a fire, and the increased heat energy causes more combustible material to react with oxygen. The fire spreads.

If there is an abundance of nitrogen in the air compared to normal air, then less heat energy is generated due to the decreased oxygen, and more of what is generated is absorbed by heating the nitrogen. At some point of reduced oxygen concentration, the nitrogen overwhelms the oxygen; and a fire cannot continue. It is extinguished.

A graphic illustration of the effects of hypoxic air is shown in the YouTube video at http://www.youtube.com/watch?v=e3Itn66hs5s

The U.S. Naval Research Laboratory has performed an extensive study of the effects of oxygen concentration on combustibility.[2] It found that many materials that burn in air will not burn at an oxygen concentration of 17%. Highly flammable liquids such as gasoline will not burn below an oxygen concentration of 12%.

But can people survive in an hypoxic air environment? Studies have shown that they can indeed. The U.S. Navy has determined that there are no untoward effects on healthy humans living in an hypoxic environment of 17% oxygen at one atmospheric pressure. Submariners living in such an environment would be as effective as people living in Denver, Colorado, since both have the same partial pressure of oxygen equivalent to an altitude of 5,000 feet.

Hypoxic Fire-Prevention Systems

Fire prevention systems using hypoxic air are available commercially. Examples of such products are:

- Prevenex (www.prevenex.com) of Boulder, Colorado.
- Tore Eide AS of Bergen, Norway (Prevenex) (http://www.toreeide.no/IndexEnglish.html).
- FirePASS (Fire Prevention and Suppression System) from FirePASS Corporation of New York City and Fire PASS AG of Switzerland (www.firepass.com).
- Wagner UK Limited of Cambridge, England (www.wagner-uk.com).

These systems convert the data center's normal incoming airflow to hypoxic air. This is done either by removing some oxygen from the air or by adding nitrogen. Oxygen concentration is typically reduced to about 16%. It has been determined that this concentration level will prevent materials commonly found in data centers from catching fire and burning.

Is Hypoxic Air Safe for Humans?

A 16% concentration of oxygen is equivalent to a 9,000-foot altitude. At first glance, this would seem to be safe for humans. However, it is a different 9,000 feet than that represented by oxygen's partial pressure in normal air. Does the human body notice the difference?

Most Say It's Safe

The general consensus is that hypoxic air at levels required to satisfy data center fire protection are perfectly safe for humans, and many systems currently installed attest to that fact. The U.S. Navy, for instance, has concluded that a 17% oxygen concentration is safe for submariners.

According to information posted by FirePASS and Prevenex,

[2] H. W. Carhart, Impact of O_2 on fires, *Journal of Hazardous Materials*; 1994.

- The National Fire Protection Agency Association (NFPA) Standard 2001, "Clean Agent Fire Extinguishing Systems," rates an hypoxic atmosphere of 12% oxygen as a "No Observable Adverse Effect Level" on humans.

- Hypoxic air meets the EPA's Significant New Alternatives Policy, which states that hypoxic air "does not require further review and can be marketed."

- Hypoxic air meets ANSI requirements for sufficient oxygen.

- The Fire Prevention Association of Great Britain has endorsed the health and safety of hypoxic fire prevention.

OSHA Begs to Differ

One naysayer is OSHA, the U.S. Occupational Safety and Health Administration. In early 2008, it denied a request by FirePASS for a permanent variance of FirePASS's hypoxic air system. OSHA considers an oxygen concentration of less than 19.5% to be hazardous, and it requires people working in such an atmosphere to have supplemental oxygen.

In response to FirePASS's request, OSHA said in part:[3]

> "Human beings . . . begin to suffer adverse health effects when the oxygen level of their breathing air drops below [19.5 percent oxygen] . . . . At concentrations of 16 to 19.5 percent, workers engaged in any form of exertion can rapidly become symptomatic as their tissues fail to obtain the oxygen necessary to function properly . . . . Increased breathing rates, accelerated heartbeats, and impaired thinking or coordination occur more quickly in an oxygen-deficient environment."

Altitude Sickness

Altitude sickness affects every human being.[4] The only difference is at what altitude? Some people feel symptoms if they exert themselves at 8,000 feet. Others can work hard at 15,000 feet. In most cases, people will acclimate over a period of a few days to higher altitudes. Symptoms of altitude sickness include headache, nausea, and fatigue. A skier from New York skiing at Wolf Creek, Colorado – altitude 10,000 to 12,000 feet – will most likely feel poorly the first day or two (the author did).

However, exertion is a major factor. Being sedentary at 8,000 feet affects almost no one, as is evidenced by the fact that we fly commercially in an airplane pressurized at this altitude.

In extreme cases, serious consequences can appear at higher altitudes. They include HAPE (high-altitude pulmonary edema) and HACE (high-altitude cerebral edema), potentially fatal conditions that cause fluid to accumulate in the lungs or brain, respectively. HAPE and HACE generally affect those trying to scale the highest mountains.

Most studies of altitude sickness have concentrated on the partial pressure of oxygen – the decrease of oxygen at higher altitudes. It appears that little research has been done on the effects of oxygen concentration. Are they the same? Is the effect of being at 8,000 feet in normal air different from being in an hypoxic sea-level atmosphere with the amount of oxygen equivalent to 8,000 feet? More research is needed to answer this question.

[3] OSHA letter to Senator John Sununu; May 1, 2008. http://www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=interpretations&p_id=27004
[4] www.altitude.org

Considerations and Compromises

Clearly, the jury is still out when it comes to the human safety of hypoxic atmospheres. Most agencies seem to agree that they are safe. OSHA seems to be the only holdout; but without OSHA certification, many engineers may not be willing or may not be able to recommend an hypoxic fire-prevention system in the U.S. On the other hand, there are hundreds of systems installed worldwide; and no problems have been reported.

If you are interested in hypoxic fire prevention but want to approach it cautiously, consider the following steps.

Segregation

You can segregate the areas that require fire prevention from the areas in which people will normally be operating. For instance, battery rooms and power-transfer rooms could be flooded with hypoxic air since there is no need for permanent personnel in these areas. The equipment rooms in data centers – servers, storage arrays, network devices – can be in a room isolated from the consoles manned by the system operators. Should someone need to enter an hypoxic room, it will only be for a limited amount of time.

Medical Conditions

If there is a concern about an employee's physical ability to handle an hypoxic environment, FirePASS suggests the following cautionary steps:

- People between the ages of 40 and 65 should check their oxyhemoglobin (SPO2) levels by a pulse oximeter before entering the environment and should have a reading of 95% or above.
- Employees in the ages 40-65 should wear a pulse oximeter for the first week to monitor the SPO2.
- Employees must evacuate the environment if their SPO2 levels drop below 87%.
- Employees who suffer from respiratory diseases, such as emphysema or severe asthma, should not enter this environment without getting permission from their doctors or should wear a supplemental oxygen mask provided by the employer.
- If an employee feels shortness of breath or light headedness or any other unusual symptoms, that employee should step out of the environment immediately.

An excellent detailing of health and safety considerations for hypoxic air can be found in the British Standards Institution (BSI) Publicly Available Specification PAS 95:210, entitled "Hypoxic Fire Prevention Systems for Occupiable Spaces."[5]

Supplemental Oxygen

If there is a concern for an employee who may be susceptible to altitude sickness either because of a medical condition or because of having to spend long periods in an hypoxic environment, that person should be equipped with supplemental oxygen. This typically involves strapping on a small oxygen bottle and breathing oxygen either via a face mask or a nasal cannula. A face mask can be restrictive. A cannula


A nasal cannula (Wikipedia)

[5] http://www.bafsa.org.uk/pdfs/snews/00000939.pdf

provides a pair of tubes feeding oxygen directly into the nasal passages and is much less restrictive. Cannulas are typically used by pilots flying in unpressurized aircraft at high altitudes.

Summary

Data center fires don't have to happen. They can be prevented by flooding the data center with hypoxic air. Several companies market hypoxic fire-prevention systems, and successful installations abound.

There continues to be some concern about the safety of these systems so far as humans are concerned. However, the consensus seems to be that they are safe for healthy humans who are not required to perform physically exhausting work in the hypoxic environment. Several recommendations exist to identify those individuals who may be susceptible and actions to take to protect them.

A study by the Institute and Outpatient Clinic for Occupational and Environmental Medicine concludes:[6]

> "Preliminary evidence suggests that working environments with low oxygen concentrations to a minimum of 13% and normal barometric pressure do not impose a health hazard, provided that precautions are observed, comprising medical examinations and limitation of exposure time. However, evidence is limited, particularly with regard to workers performing strenuous tasks or having various diseases. Therefore, close monitoring of the health problems of people working in low-oxygen atmospheres is necessary."

Epilogue

In the Naval Research Laboratory article cited earlier, the author, Homer Carhart, concluded with an interesting observation that we reproduce here:

> "In view of the extreme sensitivity of fires to oxygen concentration, one has to wonder why the Earth's atmosphere has 21% oxygen and was it ever thus? How fortuitous this value is, and what does it mean for the development of humankind and civilization? What if it were something slightly different, such as 23%? Or 19%? Would mankind have evolved to this present state of civilization and culture? Probably not, because man's technological development has been too closely related and dependent on fire; and fire behaviour under these other concentrations of oxygen is sufficiently different to impact markedly on its use and control.
>
> "Also, there is ample evidence that the Earth's early atmosphere was a reducing one, not an oxidizing one as it is now. How and why did it change? Why did it stop at 21%? From man's standpoint, how lucky, because in terms of the Earth's history, Homo Sapiens is such a Johnny-come-ever-so-lately that by the time he/she showed up, the oxygen had long flattened out at 21%; and mankind could evolve in comfort at that value. But, as shown above, Home Sapiens is now sufficiently sapient to take advantage of greater control of at least unwanted fires. And, in view of our still massive fire losses (5,000 deaths/year in the U.S. alone), should be doing more than he/she is."

Acknowledgement

Thanks to our subscriber, Ole Jacob Eide, for pointing us to this technology.

[6] Angerer P, Nowak D., Working in permanent hypoxia for fire protection-impact on health; March 2003. http://www.ncbi.nlm.nih.gov/pubmed/12733081