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CATASTROPHIC FIRE SUPPRESSION AND SAFE EVACUATION IN HIGH - RISE BUILDINGS USING BREATHABLE FIRE - SUPPRESSIVE ATMOSPHERE

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Abstract

Active and passive fire protection systems are a significant part of any current building design. However, the current fire-preventive and fire-suppressive methods in high-rise are insufficient to combat a large or catastrophic fire resulting from an intentional act of terrorism or accidental airplane impact.

This paper describes fire prevention and suppression system which can suppress large and catastrophic fire then enable occupants in high-rise buildings to evacuate safely.

The system can be engineered for preventive or suppressive mode or combination of both and applicable to new buildings and for retrofitting of existing ones. The technology allows construction of high and large buildings with the highest level of fire safety.

Keywords: Fire suppression, Fire prevention, High-rise buildings, Breathable fire-suppressive atmosphere, Safe escape, Total flooding system.

1. Introduction

The cost of fire and fire protection, combined with spending to prevent or mitigate losses in life and property within industrial countries, constitutes a large percentage of gross domestic product. The total cost of fire in the USA is particularly high, estimated at $100 to $200 billion a year, or over 2% of the gross domestic product (Ahrens 2001).

During the last years, the United States, as well as other countries, has awakened to the reality of a terrorist act involving powerful explosive materials. Ineffectual fire preventive and suppressive means characterized the mass destruction and devastation caused by terror attacks such as the Oklahoma City bombing or that of September 11, 2001. Large and catastrophic fires resulting from terrorist attacks pose an unprecedented challenge with no adequate technology existing today to combat this hazard.

The events of September 11 have issued a wake-up call to the world community, providing a unique opportunity to architects and civil engineers to take a leadership role in responding to the need to radically improve fire safety of high-rise buildings. Active and passive fire protection systems are a significant part of any current building design.

However, the current fire-preventive and fire-suppressive methods in high-rise buildings are insufficient to combat a large or catastrophic fire resulting from an intentional act of terrorism or accidental airplane impact.

Numerous systems, either installed or contemplated (aside from their effectiveness during a medium size fire) show little capability of satisfactory operation during a catastrophic fire emergency. These methods include fire extinguishers, stand pipes, and sprinklers, with their ancillary systems of water supply. The safety-support systems (communication, ventilation, lighting, and escape) support the safe evacuation of occupants during medium size fires, but their functions during catastrophic events are not effective enough.

In the aftermath of Sept.11 tragedy architects and structural engineers have sought new approaches to provide robustness and integrity of structural elements in large and catastrophic fires. Among solutions proposed are: concrete-encased steel columns, bombproof elevator shafts, pressurized stairwells, smoke and fire-protected "areas of refuge" and sophisticated water-mist sprinkler systems.

However, automatic fire suppression systems based on water mist can retard development of a small fire, but will be of little benefit in preventing structural damage to a high-rise building and will not be effective in reducing loss of life in the event of a catastrophic fire. The fire will most likely fully develop before the suppression system is even activated. The initial explosion can damage the water standpipes before sufficient pressure for sprinklers is created. Additionally, the time lag between fire ignition and the activation of any water suppression system will also lead to significant damage and can increase the number of fatalities.

Available statistical data indicates that currently nowhere in the world an adequate and reliable fire-preventive and fire-suppressive technology for mitigating large fires in high-rise buildings exists. Moreover, we must admit that this problem hardly has a viable solution in the framework of the existing fire-safety paradigm, based on water sprinklers. To solve the problem of fire safety in high-rise buildings, a radically new approach was found and is described in this paper.

2. Development of a Fire Prevention and Suppression System

The recently developed fire-safety technology, FIREPASS (Fire Prevention And Suppression System) can help to resolve the complicated problem of fire safety in high-rise buildings and minimize structural damage and fatalities caused by catastrophic fires. The principles upon which the system were developed is describe below.

It works by creating a safe human-breathable atmosphere in which nothing can be ignited or burn. This technology employs a new agent produced on-site by hypoxic generators. This agent used is breathable hypoxic (means low-oxygen) air with a precisely controlled oxygen/nitrogen proportion that differs for prevention and suppression purposes.

Fire prevention and control has long dealt with the familiar fire triangle consisting of ignition, fuel, and oxygen, all three of which are required to initiate and support combustion. In this case the use of nitrogen gas for fire suppression is based on reducing the volumetric concentration of oxygen below a maximum level that will not sustain combustion under a given barometric pressure. Such studies have been conducted in the U.S. since the 1950's with the purpose of inerting aircraft compartments and fuel tanks. Results show that various experimental data support different optimal nitrogen/oxygen ratios to provide inerting environments for different flammable materials and amount of ignition energy.

Previous research by the Federal Aviation Administration on tests to evaluate fuel tank inerting requirements for ground-based fires (Fuel Tank Inerting, Final Report, July 1998) reported a range of fire protection from 9% up to 18% oxygen concentrations. One of the most recent studies proved that 12.5% oxygen in $O_2 - N_2$ gas mixture is sufficient for complete inerting of fuel tanks at 150°F at sea level barometric pressure (Summer, 2000). However, inerting was never considered to be applicable to normally occupied facilities.

The strategy of maintaining a gaseous environment in human-occupied confinements is based mainly on the common sense presumption that an artificial breathing mixture should simulate the Earth's atmosphere as closely as possible. It is commonly believed that any significant change in the proportion of constituent gases would be potentially hazardous for humans.

Meanwhile, an alternative approach is also possible, asking: what benefits would a normobaric hypoxic gaseous environment provide? In 1996, this question was addressed during the development of the first Hypoxic Room System, designed for athletic and fitness training and to stimulate of adaptation to hypoxia. The numerous advantages of adaptation to hypoxia are broadly recognized today in the field of sport and fitness training, and find growing applications in preventive and curative medicine (Bailey et al. 2000; Mortimer et al. 1977).

Some ignition suppression and flame extinction experiments were conducted in the laboratory of Hypoxico Inc. in the normobaric environment of hypoxic, breathable air at room temperature. The results correspond to the data obtained by military research (Summer, 2000). It was found that when oxygen concentration fell lower than 16.8% at standard climatic conditions, no ignition of common combustible materials was possible. Below this oxygen content, commonly occurring diffuse flames of different tested materials were gradually extinguished.

The observed *Hypoxic Threshold of Ignition Suppression* (at 16.8% O_2) and observed *Hypoxic Threshold of Diffuse Flame Extinction* (at 16.2 %O_2) in normobaric human-breathable air correspond to Flammability Limits for a non-premixed flame in ambient air. The studies, as well as available research publications (Gusstaffson et al. 1997) demonstrate the possibility of creating a controlled normobaric hypoxic environment comfortable for humans, which is completely safe from any fire hazard, regardless of its origin.

Based on the phenomenon of Hypoxic Flame Extinction, the fire safety system FIREPASS was invented, developed and patented (US Patents. No. 6,314,754; 6,334,315; 6, 401,487; 6,418,752; 6,502,421 and multiple international patents pending).

In order to understand better the functional difference between the two amazing oxygen-dependent systems, the flame and the human body, a schematic diagram (Fig.1) is provided.

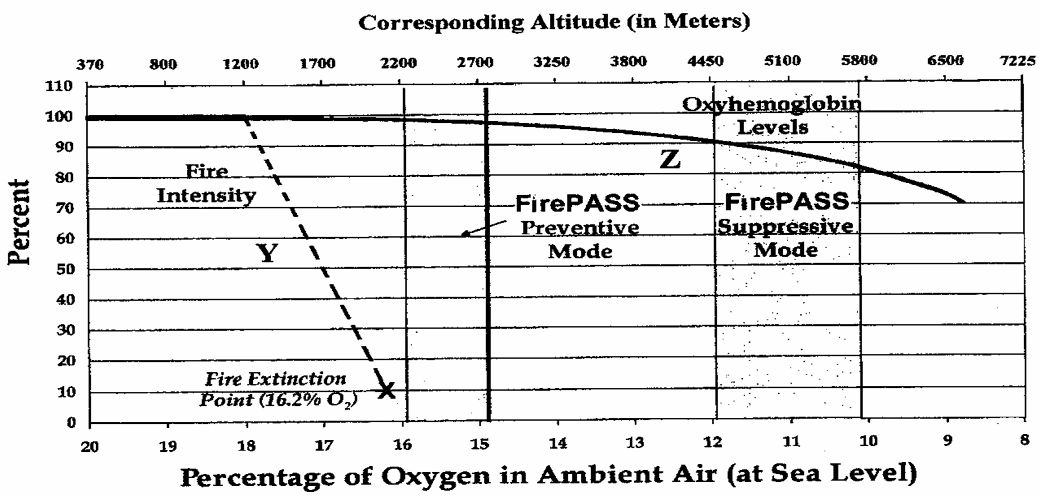

Fig. 1 Influence of Oxygen Concentration on Flame Intensity and Oxyhemoglobin Level

The curve Y represents decline in combustion intensity, which corresponds to the height of a stable diffusion flame, dependent on the oxygen content in a normobaric environment. One hundred percent corresponds to the maximal height of the flame at ambient atmospheric oxygen content of 20.94%. Below 18% of O2 there is a continuing decline in height of the flame, which at 16.2 % results in complete flame extinction.

The curve Z shows the dependence of oxyhemoglobin saturation from the partial pressure of inspired oxygen. The binding and dissociation of oxygen to hemoglobin is a typical reversible reaction. At equilibrium, molecules of oxygen are binding to heme (the active, oxygen-carrying part of hemoglobin molecule) at the same rate as other oxygen molecules are being released. Under pO2 increase more oxygen gets bound to hemoglobin and under the decrease of pO2 more oxygen is released.

As evident, a sufficient oxygen transport will continue despite a significant decrease in the oxygen content of alveolar air down to 10% providing adequate oxyhemoglobin saturation above 75% during even extended exposure to such hypoxic conditions.

Nitrogen concentration has no influence on these physiological processes at sea level conditions. In contrast, reactivity of oxygen in the combustion process depends significantly on the molecular concentration of nitrogen in the hypoxic air. The affinity of O2 to hemoglobin depends only on its partial pressure, while the kinetic of combustion depends on the proportion of oxygen in the oxygen-nitrogen gas mixture.

According to the National Fire Protection Association (NFPA) Standard 2001, "Clean Agent Fire Extinguishing Systems" p.28. Table A-1-6.1.3 "Physiological Effects for Inert Gas Agents", 12-percent minimum oxygen corresponds to No Observable Adverse Effect Level (NOAEL) and 10-percent minimum oxygen for the Low Observable Adverse Effect Level (LOAEL). At 16% oxygen concentration (corresponds to 7200 feet, or 2200 m) no significant impairment of physiological function was shown.

The difference between inerting (which is incompatible with occupied facilities) and using breathable hypoxic agent for ventilation of occupied facilities is that the latter provides a controllable, precisely designed gaseous environment, which completely suppresses ignition and combustion, is not only safe, but in fact, healthier for the human body than normal ambient air. Safety of such an environment is unquestionable in light of data, obtained during decades of scientific studies (Bailey et al. 2000; Hochachka et al.1998).

In the medical field, there is the saying "*a grain of prevention is worth more than a pound of treatment.*" FIREPASS' fire-preventative and suppressive normobaric hypoxic environments provide the ultimate solution for the fire safety problem in high-rise buildings.

Moreover, with FIREPASS architects have opportunities to get away from design restrictions dictated by fire safety codes and regulations based on current ineffective fire suppression technologies.

3. MODES OF APPLICATIONS

3.1 Description

FIREPASS can be engineered for preventive or suppressive applications, as well as a combination of both. Both agents, FirePASS – PA (preventative agent) and FirePASS – SA (suppressive agent), fully comply with the requirements of the National Fire Protection Association (NFPA) Standard 2001, "Clean Agent Fire Extinguishing Systems".

3.2 Prevention Mode

FIREPASS in prevention mode provides a breathable, fire-extinguishing atmosphere for any normally occupied facility. This eliminates the hazard of ignition of all common inflammable materials. FIREPASS hypoxic generators maintain this atmosphere by constantly ventilating an enclosed space with fresh hypoxic air, which has 16% of oxygen by volume.

Hypoxic generators installed in a building or located outside can provide sufficient flow of hypoxic air to maintain the fire-preventive atmosphere inside. Hypoxic generators constantly maintain a slightly positive pressure inside the building and can be equipped with special air intake filters that guarantee a significant degree of protection against pollution, as well as biological or chemical weapons, including radioactive contaminants. Such a building or an underground facility (e.g. subway tunnels in cities) can therefore also be used as an emergency shelter (Kotliar 2002).

3.3 Suppression Mode

FIREPASS in suppression mode requires a sufficient amount of the agent stored in pressurized containers in order to provide the initial knockdown of fire. Rapid discharge of the breathable agent FirePASS-SA (containing 10-12% of oxygen) would eliminate fire of any origin and size in seconds, simultaneously evacuating toxic combustion gases and providing people with fresh breathable hypoxic air.

A quantity of the fire-extinguishing hypoxic agent to totally flood the affected floor can be delivered directly to the fire site via preinstalled piping or a gas delivery system. On-site hypoxic generators will continue to produce the suppressive agent from ambient air after the initial rapid discharge, and supply it to the fire zone, thereby keeping a fire-extinguishing atmosphere for as long as needed. Subsequently, the high-pressure containers can be refilled with the breathable fire-suppressive agent using these same hypoxic generators.

In the suppression mode, FIREPASS is an engineered total flood system with an agent distribution network that fully complies with the NFPA Standard 2001, "Clean Agent Fire Extinguishing Systems". FIREPASS can prevent and/or extinguish fires in Class A, B, and C hazards. The system can be activated by detection and control equipment for automatic system operation or by local and remote manual operation as needed.

Hypoxic agent can be stored at a minor pressure in a specially engineered staircase shaft equipped with airlock-type doors (Fig.2). When fire is detected on the affected floor, the suppression system is activated, releasing hypoxic agent that floods the space. Hypoxic fire extinguishing composition replaces the atmospheric air on the floor, which together with the combustion products is forced outside through the overpressure relief vents. At this time all other ventilation equipment in the building must be shut down.

The volume of the hypoxic composition released into the floor affected by fire should be enough for its total flooding and instant fire extinguishing. Any fire would be extinguished immediately and the hypoxic fire-suppressive atmosphere would be maintained at a positive pressure for as long as needed by the hypoxic generator station that continuously produces the breathable agent.

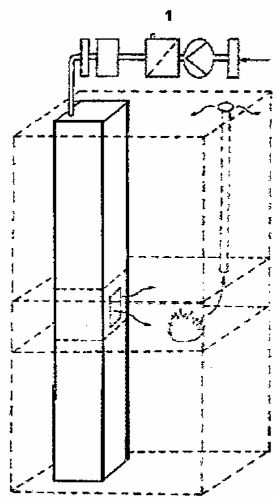

Fig. 2 Release of the agent stored in staircase

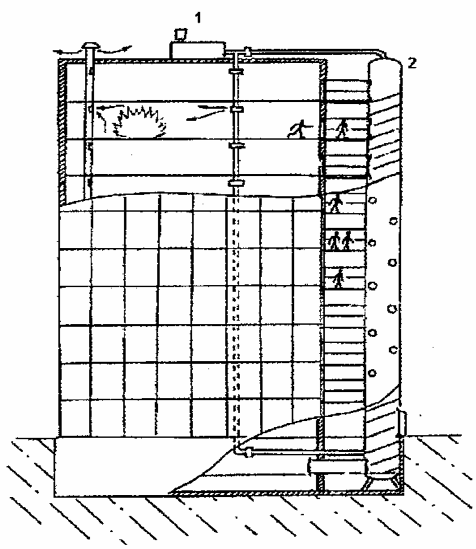

Fig. 3 Fire Suppression and Safe Escape

Simultaneously with the fire-suppressive flooding of the affected floor, its occupants will be evacuated, using escape ways and emergency elevators. Such fire-escape staircases and elevator shafts can be structurally integrated with a pressurized vessel containing fire-suppressive agent, using the vessel (Fig. 3) as a vertical self-carrying element. The pressurized vessel (2) with an external or internal emergency staircase shown in Fig. 2 can at a low pressure (5^{th} bar) contain a volume of hypoxic agent sufficient to completely exchange atmosphere in several floors of the building.

The system is capable to extinguish any fire within 60 seconds, which actually eliminates the necessity of the total evacuation and can reduce number of the space consuming multiple staircases required by current standards. The system can be designed to release the agent continuously within 2-3 hours – the time sufficient to find and eliminate the ignition source. Alternatively, the hypoxic generator (1) installed for refilling the system can maintain the fire-suppressive atmosphere for as long as needed by days or weeks.

3.3 Dual Mode

FIREPASS installed in the dual mode can prevent most important buildings from a disaster similar to the tragedy of September 11th. Such a building with FIREPASS installed constantly maintains the hypoxic fire-preventive atmosphere inside at a slightly positive pressure. This fire-retardant atmosphere containing 16% of oxygen is proved to be even healthier than ambient air for anyone (Bailey et al. 2000; Hochachka et al.1998).

Structural damage (e.g. from an airplane impact) would be immediately detected by common pressure transducers and would lead to activation of the suppression system. Breathable suppression agent containing 10% O_2 would be gradually released into damaged floors in order to suppress fire and to prevent the outside air from entering by maintaining a slightly positive pressure inside for at least an hour. Hypoxic generators that supply the whole building with hypoxic air for ventilation would redirect most of the flow into affected floors as well, helping to suppress the fire even for a longer period of time.

More suppression agent can be delivered by FIREPASS mobile units described below. Most important is that the aviation fuel injected into the building and collected in the lower levels will not ignite in the constant fire-preventive atmosphere that can sustain for days even in case of a major power failure or destruction of the FIREPASS equipment.

In case, if FIREPASS had been used at the Twin Towers of the World Trade Center, the catastrophic fire would have been prevented without imposing additional structural damage, buildings would not have collapsed and the lives of thousands would have been saved. Property and equipment on floors unaffected by a direct hit would have remained intact, and surrounding buildings and underground communications would not have collapsed or suffered structural damage at all.

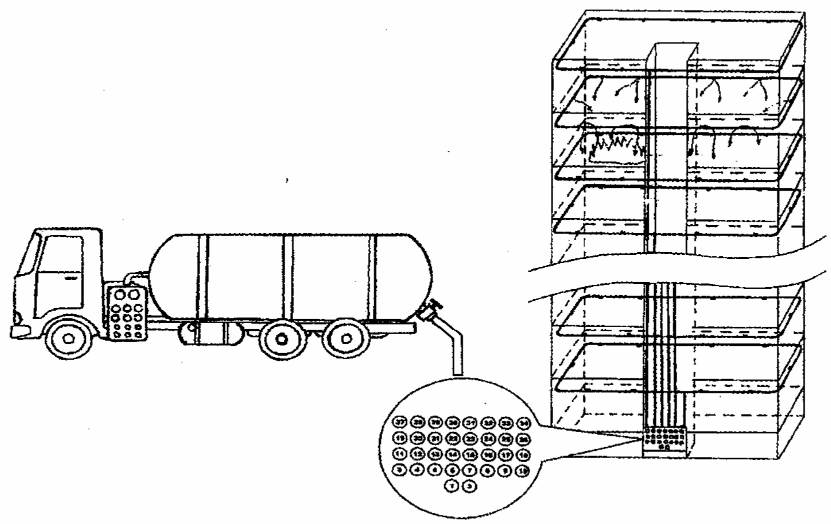

Fig.4 Standpipes for Floor-targeted delivery of the agent, supplied by Mobile Unit

A further cost-efficient solution is to install inside or outside the building the standpipes for the floor-targeted delivery of the agent, supplied by a mobile unit (Fig.4). This solution is recommended in retrofitting of existing buildings, but can also be implemented in new projects. All standpipes should be connected with floor-numbered manifolds, located in the lobby or on the outside wall at the ground level of a building. In case of a fire a mobile FIREPASS unit will arrive and provide the initial effluent discharge of the breathable fire-suppressive agent, followed by continuous delivery of instantly produced agent for as long as needed.

An important feature of FIREPASS is its ability to provide adequate protection against aerosolized biological and chemical warfare agents that can be filtered out by special air intake filters of the FIREPASS hypoxic generators that supply hypoxic air for ventilation in prevention mode.

In the application with the pressurized staircase environment, the complete safety against a fire, smoke, biological and chemical contaminants is provided because:

- nothing can be ignited inside thus making combustion impossible
- smoke from a floor fire cannot get in due to a constant pressure difference
- biological and chemical agents are filtered out by an air intake filter
- staircase can be used as a shelter, safe evacuation assured.

Even in suppression mode, FIREPASS can instantly convert the whole building into a protected zone by simply releasing the agent inside in case of a chemical or biological attack. This will provide a safe positive pressure inside the building that will be maintained by the hypoxic generator station. All external ventilation is shut down in this case and internal atmosphere is recycled in a closed loop.

4. Discussion

The building-specific configuration of FIREPASS provides high reliability and efficiency that is not affected by electrical power supply failure as it relies on a self-propelled agent. FIREPASS is also resistant to structural damage. Even in case of a major explosion causing some damage to the agent delivery pipe, the system will still operate and deliver the self-propelling fire-suppressive agent to the affected area. Additionally, FIREPASS can provide reliable protection for the building's underground facilities and infrastructure (Kotliar 2002).

FIREPASS satisfies all critically important properties required for building fire suppression, such as: fire suppression efficiency, evacuation of smoke, safety for occupants, electrical conductivity, corrosivity to metals, polymeric materials compatibility, stability under long-term storage and speed of dispersion. Contrary to all existing inert gas fire-suppressive systems the FIREPASS fire-preventative and suppressive agents can be produced on site by hypoxic generators that consume nothing but electric energy. No transportation and refilling problems, low maintenance costs, simple integration in the existing structural configurations are all advantages of FIREPASS technology that allow for reliable and cost-effective fire protection.

Implementation of FIREPASS in preventive mode does not require significant re-engineering of the protected space to achieve a drastic improvement in the current level of fire safety. On the other hand, if needed, the technology allows combining various fire-suppressive approaches, which can give a significant synergistic effect.

The FIREPASS equipment can be custom made and installed in specified applications both for retrofitting of existing and newly planned high-rise buildings. The cost of system design, manufacturing, installation and maintenance is comparable to the cost of far inferior traditional means and is significantly less than the expected costs of damage and liability resulting from a catastrophic fire.

Summary

I. FIREPASS (Fire Prevention and Suppression System) helps to resolve the complicated problem of fire safety and emergency escape in high-rise buildings and to minimize structural damage and fatalities in terrorist attacks.

II. Today, no physiological, environmental, technical or financial obstacles exist for broad implementation of FIREPASS technology for protection of high-rise buildings.

III. The system can be applied both for new buildings and for retrofitting of existing ones.

IV. FIREPASS technology allows constructing higher and larger buildings with the highest level of fire safety.

V. FIREPASS can provide adequate protection for the building's underground facilities and infrastructure.

Footnote: "FIREPASS" is used here solely as abbreviation of Fire Prevention And Suppression System, developed by FirePASS Corporation.

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