TECHNICAL NOTES

Literature Review on Hybrid Fire Suppression Systems

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About the Fire Protection Research Foundation

The Fire Protection Research Foundation plans, manages, and communicates research on a broad range of fire safety issues in collaboration with scientists and laboratories around the world. The Foundation is an affiliate of NFPA.

About the National Fire Protection Association (NFPA)

NFPA is a worldwide leader in fire, electrical, building, and life safety. The mission of the international nonprofit organization founded in 1896 is to reduce the worldwide burden of fire and other hazards on the quality of life by providing and advocating consensus codes and standards, research, training, and education. NFPA develops more than 300 codes and standards to minimize the possibility and effects of fire and other hazards. All NFPA codes and standards can be viewed at no cost at www.nfpa.org/freeaccess.

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Executive Summary

Hybrid suppression systems are a new fire suppression technology used to protect a variety of spaces ranging from machinery enclosures to computer server rooms. These new hybrid systems utilize both an inert gas (typically nitrogen) as well as a fine water mist to provide fire suppression and/or extinguishment more efficiently than standalone inert gas or water mist systems.

Recently, the industry has brought hybrid suppression technology to the public, in the form of two commercial fire suppression systems. Despite the growing interest in the hybrid suppression technology, including FM Approval's release of FM Approval Standard 5580 for Hybrid Fire Extinguishing System, there is not an NFPA Standard that governs such a system's installation, inspection, or application. Because hybrid suppression systems resemble water mist or inert gas systems in many aspects, this has posed the question of whether or not a hybrid suppression system can be standardized as a water mist, inert gas, or whether it should be listed as a new system classification. This decision greatly affects the way a hybrid suppression system is installed and used.

The NFPA Fire Protection Research Foundation employed the University of Maryland's Fire Protection Engineering Department to research the existing literature, tests, and approvals from various manufacturers and insurers. Since the technology is new to the market, there is not a lot of information regarding hybrid suppression systems. However, the information found provided some information on how a hybrid suppression system should be classified and whether or not the new technology may deserve its own standard or not.

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Background

While both water mist and inert gas fire suppression systems are common today, hybrid fire extinguishing systems are a new technology that has become an area of interest in the recent years. Motivated primarily by the replacement of Halons as a gaseous fire suppressant after the 1989 Montreal Protocol, the industry has been continually innovating to find effective alternatives for special applications. Hybrid fire extinguishing systems, are a new fire suppression system that uses both water mist and inert gases to extinguish fires, often mixed together at the discharge nozzle. The combination of water and inert gas, working together in an extinguishing system, has made hybrid water mist systems a unique classification of suppression systems. Two hybrid suppression systems have been recently made available to the public and marketed as a unique configuration (Figure 1). These systems abide by the only current standard on hybrid suppression systems by FM Approval's, FM Approval Standard 5580, "Approval Standard for Hybrid (Water and Inert Gas) Fire Extinguishing Systems" [1]. Being the only current standard available, it is being used as the regulation for installation, maintenance, and performance of hybrid suppression systems.

Figure 1: Two examples of hybrid water mist systems currently on the market. (left) Victaulic Vortex system discharging. (right) ANSUL Aquasonic system discharging.

The National Fire Protection Association has recently identified the use of hybrid fire extinguishing systems and their growing popularity for unique applications in the suppression system market. The Fire Protection Research Foundation was asked by NFPA committees to investigate existing literature on these systems because the NFPA is not sure how to address these new systems, such as whether to group the new systems in with current NFPA codes or to create a new code for hybrid suppression systems. Currently, NFPA has two codes in place that cover water mist suppression systems (NFPA 750 [2]) and inert gas suppression systems (NFPA 2001 [3]). Both codes cover each separate component, water and inert gas. Included in hybrid suppression systems, however, the two codes do not provide any regulation when the two components are used together. In order to facilitate an informed decision on whether or not to create a new code or include the hybrid systems into an existing code this report will cover the mechanisms for extinguishments used in current existing systems, the existing codes and standards for the three systems, previous testing performed to evaluate these systems, and specific applications for each system.

Water Mist Fire Suppression Systems

History

Water mist fire suppression systems were first introduced in the 1940's as fire protection systems on passenger ferries and maritime transportation. These systems were primarily used for this application until a new interest in their capabilities was sparked by the replacement of Halon systems following the 1989 Montreal Protocol. Water mist's use of a limited amount of water while still effectively suppressing fires made it attractive to applications where water usage was limited due to property conservation or limited supplies. Their use did not decrease the tenability of the compartment at all and was more environmentally safe than its Halon counterpart [2].

In 1993, demand was strong for a standard regulating Water Mist systems. The technology became a marketable item and manufacturers started to develop Water Mist Systems for sale to the public. As a result, the International Maritime Organization and Underwriter's Laboratories created protocols and standards for fire testing of water mist nozzles; however an installation standard from the NFPA was yet to come about. In 1996, a panel formed by the NFPA made the first edition of NFPA 750 which became the standard on the use and installation of a water mist system [2].

NFPA 750

NFPA 750 is the NFPA standard on Water Mist Fire Protection Systems. NFPA 750 outlines the requirements for water mist systems including: design objectives, fire test protocols, documentation, system acceptance, system maintenance and marine systems. The standard outlines the use of 5 performance objectives. These objectives are: fire extinguishment, fire suppression, fire control, temperature control, and exposure control. Limitations of water mist use to perform these objectives are typically due to the reactive properties of water with certain materials, such as metal alkoxides, metal amides, carbides, halides, hydrides, and oxyhalides or its ability to heat cooled gasses, such as liquid nitrogen.

In NFPA 750, there are three types of water mist systems defined: local-application, total compartment application systems and zoned applications. The applications of these systems are to be designed and installed to meet the objectives of these systems per NFPA 750. Local application is the application of the water mist directly on an object or a hazard. Compartment application is designed to provide complete protection of an enclosed space. Zoned application is designed to protect only a portion of a hazard [2].

The applicability of a specific system in question is based on fire test protocols. The test protocols are designed around the hazard or occupancy of the structure. The tests are then based on a set of application parameters. These parameters are outlined in Section 8.4 of NFPA 750. The parameters are based on: compartment variables and geometry, ventilation (natural or forced), fire hazard classification, combustible loading, fuel type, the classification of the fire, combination fires, fire location, and obstructions and shielding of the system's nozzles. The list of parameters is then used to test the ability of a system against a design fire [2].

Extinguishment

Water is an effective option for suppressing and controlling fire. Water absorbs large amounts of heat due to its high heat capacity and latent heat of vaporization, cooling both gas phase combustion and pyrolyzing fuel surfaces. Water vapor also dilutes the oxygen in the burning environment through the displacement of oxygen. Water mist systems utilize a fine water spray, where 99% of the volume of water dispersed contains water droplets of less than 1000 microns. The water droplets have an increased surface area compared to standard spray sprinkler droplets and are therefore smaller, easily drawn into the fire plume. When drawn into the fire plume, the rapid evaporation of droplets into steam causes both oxygen displacement and heat absorption mentioned earlier. The rapid absorption of heat as part of its phase change process is primarily responsible for the gas-phase extinguishment of flame due to water mist application, with secondary effects of oxygen displacement and pre-wetting contributing to a lesser extent towards fire suppression and extinguishment [4].

Figure 2: Example of Water Mist System Discharge (Marrioff HI-Fog System)

Clean Agent Fire Extinguishing Systems

History

Clean Agent Fire suppression systems were introduced in the 1930's during World War Two. Their uses at the time were concentrated in aviation and maritime applications where man power was limited for fire suppression and clean agents afforded fire extinguishment capabilities with little to no manpower. After it was found that certain agents used were highly toxic, such as methyl bromine and carbon tetrachloride, the United States Army funded research to search for an alternative. The results of this research lead to the successful development of Halon 1301 and Halon 1211 as the new agents used in gaseous suppression systems [5].

These Halon agents provided quick and efficient fire suppression while being less abrasive, toxic and reactive than prior alternatives. The ability of Halon gas to suppress fires without depositing water or other residue on protected areas made Halon popular in applications where conservation of property was of high value, including use in libraries, electronic server rooms and museums, primarily preventing water damage to valuable inventory.

After being in use for more than 30 years, Halon was found to be an Ozone-depleting gas after the Montreal Protocol. The uses of Halon became limited and the race to find an alternative option began. The need for a replacement to Halon systems led to increased research on inert gas and clean agent systems. In 1991, a NFPA committee was made to address the new clean agents that were being used to replace Halon as inert gas systems were becoming marketable to the public to offer a replacement to Halon systems. After researching the topic of gaseous systems and clean agents, the NFPA created NFPA 2001 in 1994. This standard offered explanations for the design, installation, maintenance, and operation of clean agent fire suppression systems [5].

NFPA 2001

NFPA 2001 is the NFPA standard on Clean Agent Fire Extinguishing Systems. NFPA 2001 outlines the requirements for a clean agent system, such as design requirements, local application systems, inspection, testing and marine systems. Clean agent systems are normally pre-engineered systems that are installed within the limitations established by each system's listing. These listings can either be formed by using pre-tested limitations by a testing laboratory or the standards set forth in NFPA 2001 [3].

Restrictions on the use of clean agent systems are due to the gasses reactivity to certain chemicals as well as associated health risks. Clean agent systems are not to be used with certain chemicals or mixtures that react with the specific agent being used. These include reactive metals, metal hydrides and autothermal decomposing chemicals. There are also safety concerns and hazards outlined in NFPA 2001. Hazards to personnel are taken into consideration due to the health impacts some agents cause. Here, the lowest observable adverse effect level (LOAEL) and no observable adverse effect level (NOAEL) are taken into consideration for the design of systems in given areas. These safety requirements are categorized for halocarbon agents and inert gas agents in the standard [3].

In NFPA 2001, flame extinguishment is further outline under system design requirements. Minimum design specifications are provided for class A, B and C fires. Associated with these requirements are corresponding safety factors. Concentrations for the classes of fires are also outline in the system design.

Extinguishment

Clean agent systems utilize either reacting or non-reacting gaseous suppressants in order to extinguish fires. Reacting gaseous suppressants, such as halocarbon agents act to chemically interrupt the combustion process in the gas phase with secondary effects of oxygen displacement and cooling also aiding in fire extinguishment. Reacting gaseous clean agents, however are not utilized in hybrid water mist systems on the market today so will not be reviewed further.

Inert gas clean agent systems extinguish fires by decreasing the oxygen level within the space where combustion occurs. Many systems are designed to reduce the oxygen level below 15%, below which fires cannot normally be ignited or sustain ignition. The primary method of extinguishment used in an inert gas system is therefore the displacement of air within the involved compartment, with an inert gas such as argon or nitrogen, decreasing the oxygen level to a percent below the ignition percentage. A secondary and limited means of extinguishment is heat absorption. Depending on the inert gas used in the clean agent system, this value varies and plays a small role in fire extinguishment.

Figure 3: Example of Clean Agent System Discharge (http://www.arafire.com.au/fire-suppression-systems.htm)

Hybrid Water Mist Suppression Systems

History

The combination of water mist and gaseous suppression agents saw an increase in commercial interest around 1996. It was said that both the fuel vapor dilution and oxygen displacement would be increased with the addition of an inert gas to a water mist system. At the same time, the United States Navy was conducting research on the topic. At the conclusion of the research, it was found that the combination of water mist with halocarbon agents was most effective. In this application, water mist cooled the gases before the application of a gaseous suppressant was used to displace the oxygen [6].

In 1996 Zhigang Liu and Andrew K. Kim, while reviewing standalone water mist, investigated a hybrid system, which was classified as "Water Mist with Additives." The authors said that additives to a water mist system, such as an inert gas, may improve the extinguishing efficiency of water mist alone. The authors also stated that, when combing the "twin-fluid" system, it could prevent the re-ignition of combustibles and the presence of the inert gas could reduce acid decomposition products of the fire. However, it was also mentioned that if the water mist was deflected away from the fire, the gaseous suppressant's effectiveness would be hampered [4].

Beyond the noted items above, the amount of literature available on hybrid water mist systems until recent years has been scarce. Recently, however the hybrid water mist system is gaining more interest due to its scalability and functionality. Manufacturers, including both Victaulic and Ansul have combination water mist/ nitrogen gas suppression systems that have been marketed to the general public as hybrid suppression systems. These systems are currently listed under a new standard set forth by FM Approvals, FM Approvals Standard 5580, Approval Standard for Hybrid (Water and Inert Gas) Fire Extinguishing Systems, November, 2012. This is the only standard available for these systems to be listed. Currently, there is no NFPA code or guidance regulating these systems.

FM Approval Standard 5580

FM Approvals Standard 5580 "Approval Standard for Hybrid (Water and Inert Gas) Fire Extinguishing Systems" provides the listing criteria for the use of hybrid systems for fire control and extinguishment by FM Approvals. It involves the implementation of design and performance requirements for a range of 8 different applications for hybrid systems. The reason for the limited number of applications is due to the current state of hybrid system technology. According to FM Approvals, hybrid systems, "are too unique in design and operation and a general approval standard cannot be created yet due to this finding" [1].

Since hybrid systems are unique in nature and differ in listed applications, they are listed by FM Approvals on a case by case basis. This listing limits the applications and protection requirements in Section 1.2.3 of the FM Approvals Standard 5580. Eight applications within FM Approvals Standard 5580 are defined based on the area of the compartment, the material or structure the system is protecting, and the size of the material or structure [1].

FM Approvals Standard 5580 Fire Tests

Depending on the configuration and application, a different fire test is outlined for listing of a hybrid system in FM Approval Standard 5580. In appendix B-I of the approval standard, the fire tests for the listed applications are explained in detail and summarized here. The below approval standards are summarized in Tables 1 and 2. Table 1 outlines the four similar tests between FM Approvals Standard 5580 (hybrid) and 5560 (water mist). While the first three of the four similar scenarios share almost exactly the same test descriptions and performance criteria, the final test (FM Approvals Standard 5580, Appendix H and FM Approvals Standard 5560 Appendix G) differs as the hybrid test refers to computer rooms with raised floors and the water mist test of computer rooms with sub floors, therefore somewhat differing test protocols and performance criteria are outlined in the appendix. A full list of all fire tests provided in both FM Approvals Standards 5580 and 5560 are outlined in Table 2. No similar scenarios were found between FM Approvals Standard 5580 (hybrid) and 5600 (clean agent), therefore they are not listed here.

Table 1: Similarities between FM Approvals Standard 5580 and 5560.

Hybrid (FM 5580)		**Water Mist (FM 5560)**	
Test	**Scenario**	**Test**	**Scenario**
Appendix B	Protection of Combustion Turbine in Enclosures With Volumes not Exceeding 2825 ft^3 (80 m^3)	Appendix A	Protection of Combustion Turbines with Volumes up to, and Including 2825 ft^3 (80 m^3)
Appendix E	Protection of Combustion Turbines Enclosures With Volumes not Exceeding 9175 ft^3 (260 m^3)	Appendix B	Protection of Combustion Turbines with Volumes up to, and Including 9175 ft^3 (260 m^3)
Appendix G	Protection of Combustion Turbines Enclosures With Volumes Exceeding 9175 ft^3 (260 m^3)	Appendix C	Protection of Combustion Turbines with Volumes Exceeding 9175ft^3 (260 m^3)
Appendix H	Protection of Computer Room *Raised* Floors	Appendix G	Protection of Computer Room *Sub* Floors

<u>Section B:</u> Fire Tests for Hybrid Fire Extinguishing Systems for the Protection of Machinery in Enclosures with Volumes not Exceeding 2825 ft^3 (80 m^3)

The fire tests in Section B include the use of hybrid systems for the protection of machinery in enclosures with volumes not exceeding 2825 ft^3 (80 m^3). The fire tests for this application include an unshielded 1 MW diesel spray fire, a shielded 1 MW diesel spray fire, a shielded 10.8 ft^2 diesel pool fire, a shielded 2 MW diesel spray fire under limited natural ventilation, an unshielded 1 MW Heptane spray fire, a shielded 1 MW Heptane spray fire and a shielded 10.8 ft^2 (1 m^2) Heptane pool fire. Specific criteria for each test specification, including the fuel, type of fire spray pattern, spray nozzle, fire location, fire pre burn time, and the test procedure specific to the test being performed is provided in the appendix [1].

Table 2: All tests in FM Approvals Standard 5580 and 5560.

Hybrid (FM 5580)		Water Mist (FM 5560)	
Test	**Scenario**	**Test**	**Scenario**
Appendix A	Hybrid Fire Extinguishing System Classification	Appendix A	Protection of Combustion Turbines with Volumes up to, and Including 2825 ft^3 (80 m^3)
Appendix B	Protection of Combustion Turbine in Enclosures With Volumes not Exceeding 2825ft3 (80 m^3)	Appendix B	Protection of Combustion Turbines with Volumes up to, and Including 9175 ft^3 (260 m^3)
Appendix C	Protection of Machinery in Enclosures With Volumes not Exceeding 2825 ft^3 (80 m^3)	Appendix C	Protection of Combustion Turbines with Volumes Exceeding 9175 ft^3 (260 m^3)
Appendix D	Protection of Machinery in Enclosures With Volumes not Exceeding 9175 ft^3 (260 m^3)	Appendix D	Protection of Wet Benches and Other Similar Processing Equipment
Appendix E	Protection of Combustion Turbines Enclosures With Volumes not Exceeding 9175ft3 (260 m^3)	Appendix E	Protection of Local Applications
Appendix F	Protection of Machinery Enclosures With Volumes Exceeding 9175 ft^3 (260 m^3)	Appendix F	Protection of Industrial Oil Cookers
Appendix G	Protection of Combustion Turbines Enclosures With Volumes Exceeding 9175 ft^3 (260 m^3)	Appendix G	Protection of Computer Room Sub Floors
Appendix H	Protection of Computer Room Raised Floors	Appendix H	N/A
Appendix I	Occupancies which FM Global has an Interest in Protecting with Hybrid Fire Extinguishing Systems	Appendix I	N/A

<u>Section C:</u> Fire Tests for Hybrid Fire Extinguishing Systems for the Protection of Combustion Turbines in Enclosures with Volumes not Exceeding 2825 ft^3 (80 m^3)

The fire tests in Section C include the use of hybrid systems for the protection of turbine enclosures with volumes not exceeding 2825 ft^3 (80 m^3). The fire tests for this application include an unshielded 1 MW diesel spray fire, a shielded 1 MW diesel spray fire, a shielded 10.8 ft^2 (1 m^2)

diesel pool fire, a shielded 2 MW diesel spray fire, system performance tests under limited ventilation, spray cooling with no fire, a spray fire with a saturated insulation mat, and a large saturated insulation mat. The saturated spray fire with a saturated insulation mat and the large saturated insulation mat tests are optional tests per FM Approvals Standard 5580 [1].

Section D: Fire Tests for Hybrid Fire Extinguishing Systems for the Protection of Machinery in Enclosures with Volumes Exceeding 9175 ft^3 (260 m^3)

For the fire tests in Section D, intermediate pendent or upright nozzles that are not ceiling level, or wall mounted nozzles, are not permitted for the machinery spaces. The system being tested must successfully complete all ten fire tests described in Appendix D. The longest extinguishing time for a test in the series is used as a criteria for special protection applications. For the primary protection of machinery enclosures, the hybrid system must have the same requirements of that of an automatic sprinkler protecting the same hazard.

For Appendix D, the ten fire tests are an unshielded 1 MW diesel spray fire, a shielded 1 MW diesel spray fire, a shielded 10.8 ft^2 (1 m^2) diesel pool fire, a shielded 2 MW diesel spray fire, system performance tests under limited natural ventilation, a shielded 2 MW diesel spray fire, system performance tests at smaller enclosure volumes, an unshielded 1 MW heptane spray fire, a shielded 1 MW heptane spray fire, a shielded 10.8 ft ^{2} (1 m^2) Heptane pool fire, a shielded 2 MW Heptane spray fire, system performance tests under limited natural ventilation, a shielded 2 MW Heptane spray fire, and system performance tests at smaller enclosure volumes. A criterion for all tests in Appendix D is that the fire must be extinguished. Failure to do so will result in a failure and no acceptance of the system [1].

Appendix E: Fire Tests for Hybrid Fire Extinguishing Systems for the Protection of Combustion Turbines in Enclosures with Volumes not Exceeding 9175 ft^3 (260 m^3)

For the fire tests in Appendix E, intermediate pendent or upright, ceiling level or wall mounted nozzles are permitted for the protection of combustion turbines. There are five tests in this section which the hybrid system must complete. Along with these five mandatory tests are two optional tests which involve turbine insulation mats. During the tests, the hybrid system cannot cause any damage to critical turbine parts and must prevent said damage. However, the system can cause damage due to direct fire impingement to the hot turbine casing or by the rapid cooling of the turbine casing. As with the other appendices, the longest extinguishment time will be recorded for generating criteria for special protection systems while for primary protection, the agent supply must equal the amount required for an automatic sprinkler protection system for the hazard in question.

The fire tests in Appendix E include the mandatory tests, an unshielded 1 MW diesel spray fire, a shielded 1 MW diesel spray fire, a shielded 10.8 ft^2 (1 m^2) diesel pool fire, a shielded 2 MW diesel spray fire, system performance tests under limited natural ventilation, a shielded 2 MW diesel spray fire, system performance tests at smaller enclosure volumes, and spray cooling with no fire. The optional tests, pertaining to insulation mats, include a saturated insulation mat with a spray fire and a standalone large saturated insulation mat.

The five mandatory tests for Appendix E must completely extinguish the design fire, with the exception of the spray cooling test. The spray cooling test is used to determine whether the system discharge will adversely affect the turbine and its operation. The discharge must not adversely affect the turbine or the test will fail. The two optional fire tests involving insulation mats have different criteria. For the saturated mat and spray fire test, both the spray and insulation mat fires must be extinguished. For the large saturated insulation mat test, the mat fire is to be controlled, where control is defined as the fire only having flamelets remaining at the surface of the mat [1].

Appendix F: Fire Tests for Hybrid Fire Extinguishing Systems for the Protection of Machinery in Enclosures with Volumes Exceeding 9175 ft^3 (260 m^3)

For the fire tests in Appendix E, intermediate pendent or upright nozzles, or wall mounted nozzles are not permitted for the tests. For Appendix F, there are eight mandatory tests that must be completed. Again, the longest extinguishment time will be recorded for the purpose of establishing criteria for special protection systems while for primary protection, the agent supply must equal the amount required for an automatic sprinkler protection system for the hazard in question.

The fire tests for Appendix F include a low pressure, exposed, diesel spray fire, a low pressure, low angled, diesel spray fire, a low pressure, concealed, diesel spray fire, a high pressure, exposed diesel spray fire, low pressure, low flow concealed diesel spray fire and several pool fires including a concealed heptane pool fire, a flowing fire, a wood crib and a heptane pool fire. All the tests in Appendix E involve either extinguishment or suppression of all the fires involved in the test [1].

Appendix G: Fire Tests for Hybrid Fire Extinguishing Systems for the Protection of Combustion Turbines in Enclosure with Volumes Exceeding 9175 ft^3 (260 m^3)

For the fire tests in Appendix G, the hybrid system is permitted to use intermediate pendent or upright nozzles that are not ceiling level, or wall mounted nozzles for the protection of combustion turbines. Similar to other turbine fire tests mentioned earlier, the hybrid system cannot cause any damage to critical turbine parts during its operation. As with previous tests, the fire scenario with the longest extinguishment time will be used as criteria for special protection systems. For primary protection the supply must be equal to the supply required for that of an automatic supplier system.

The tests include eight fire tests, a spray cooling test and two optional tests that involve insulation mats. For this appendix, the insulation mat tests are optional. As with the other tests, the agent supply for the longest extinguishing time is used for the criterion for special protection systems. The agent supply will also have to be equal to the required supply for that of an automatic sprinkler system.

The eleven tests for Appendix G are a low pressure, exposed diesel spray fire, a low pressure angled diesel spray fire, a low pressure concealed diesel spray fire, a high pressure exposed diesel spray fire, a low pressure, low flow concealed diesel spray fire and pool fires including a concealed heptane pool fire, a flowing fire, a wood crib and a heptane pool fire, a spray cooling test with no fire, a test with a saturated insulation mat and a spray fire (an optional test) and a saturated insulation mat fire (an optional test) [1].

Appendix H: Fire Tests for Hybrid Fire Extinguishing Systems for the Protection of Computer Room Raised Floors

For the fire tests in Appendix H, there are a different set of standard requirements than those used in other configurations. The following criteria must be met for the successful completion of the fire tests in Appendix H: systems shall operate with the restrictions imposed by the size of a raised floor test room and an equivalent opening space of the floor area tested, the water supply and inert gas supply shall be capable of supplying 10 minutes of extinguishing agent to all nozzles in the determined design area, the manufacturer's design manual shall describe, in detail, the scaling parameters used for different room configurations, the maximum nozzle spacing shall be used for all tests (this includes using the maximum spacing of nozzles from the walls), the minimum operating nozzle pressure (as specified by the manufacturer) shall successfully complete all fire tests for approval system components, and component locations and operating conditions shall remain unaltered throughout all of the fire tests. The test protocol calls for three sets of tests, including telltale fire tests, a cable fire test and a test verifying the degree of moisture build-up inside a computer cabinet caused by the hybrid fire extinguishing systems discharge [1].

The fire tests for Appendix H include the use of four tests. These tests are a telltale fire test with a singular module, a cable fire test, a moisture concentration test, and a telltale fire test with two modules. All the fire tests, with the exception of the moisture concentration test, have the criteria that final fire extinguishment must be achieved within 5 minutes of system operation. For the moisture concentration test, the test is performed in order to determine the moisture content in the computer cabinet spaces in the upper-floor due to the activation and discharge of the hybrid system [1].

Appendix I: Future Applications

In conclusion of the 7 tests described, there is an eighth test in Appendix I; however it is not based on an actual test. This appendix simply states the interests that FM Global has in future applications. As for the other tests, the applications are specific; each appendix is for a certain set of fire scenarios pertaining to the precise setups mentioned in the 7 test appendices. The required level of protection is also defined by FM Approvals Standard 5580 in section 1.2.4; the system must be equivalent to the requirements for that of an automatic sprinkler protection system for the hazard in question [1].

The FM Approval Class 5580 standard also defines the requirements for special protection systems, where three distinct fire scenarios are listed. Table 1.2.4.2.4 bases the scenarios on extinguishment time, these times being 0-5 minutes, 5-8 minutes and greater than 8 minutes. Based on the extinguishment time, a minimum discharge time is defined for the three areas. For the 0-5 minute and 5-8 minute extinguishment times, a minimum discharge time of 10 minutes is required. For discharge times greater than 8 minutes, a discharge time is not permitted and a hybrid system cannot be used. Also, based on the extinguishing times is the agent quantity safety factor. For the 0-5 minute extinguishment time, an agent quantity safety factor is not required. For a 5-8 minute extinguishment time, an agent quantity safety factor of 20% is required.

FM Approval is then decided upon under an evaluation of the system in question. The evaluation tests the suitability of the product, the performance specified by the manufacturer and required by FM Approvals, practicality of this performance, and the durability and reliability of the product [1]. After the FM Approval testing is completed, continued listing of the system is contingent upon periodic reexamination of the systems and satisfactory field experience.

Hybrid System Extinguishment and Differences

FM Approvals Enclosure Fire Testing

FM Global Research in support of FM Approvals analyzed a series of tests in order to formally make a distinction between hybrid systems and traditional water mist and inert gas systems. As a result of these tests, three system classifications were developed, twin fluid water mist, gaseous and hybrid systems. Both experimental data and numerical modeling of fire extinguishment determined that the dry-based oxygen levels at extinguishment between the systems differed, thus serving as an ideal classification factor. Gaseous systems were defined as those which extinguish fires through inerting a gas to displace oxygen. Hybrid systems were those that extinguish fires with the combination of water and gas, where both are contributing factors and not one of the two fluids can extinguish the fire on their own. A twin fluid water mist system was finally defined as a system that uses water for cooling, vaporization and inerting. The gas in a twin fluid system does not play a role in the extinguishment process and only serves as a medium for the water to atomize in [7].

Before explaining the results of the dry-based oxygen levels and extinguishing times used for determination of the system, the experimental test setup needs explanation. The test enclosure was a 260 m^3 enclosure with a 0.9 m wide by 2.2 m high door opening. Four tests were conducted, including a 1 MW enclosed diesel fire (test D3.2), a 2 MW open diesel fire (test D3.4), a 1 MW enclosed heptane fire (test E3.2) and a 2 MW open heptane fire (test E3.4). The fires were given an average pre-burn time of around 20 seconds. The fire tests utilized the three types of systems to come up with a classifying factor to find a correlation between hybrid water mist, water mist and gaseous systems.

The results of the FM Approvals enclosure fire tests yielded distinct oxygen concentrations observed during water mist, hybrid and gaseous system test extinctions. When testing a traditional water mist system, its dry-based oxygen levels were found to be between 14.9% and 16.2% and the wet-based oxygen levels measured between 12.4% and 12.6%. For testing of the hybrid system, the dry-based oxygen concentrations were in the range of 13.5% to 14.6% and a wet-based oxygen range of 12.2% to 12.3%. The gaseous system testing yielded a dry-based range of 12.3% to 12.6% and a wet-based based range of 12.0%-12.1% [7].

The oxygen levels observed for the specific systems were determined to be an ideal classification factor between the three types of systems. The oxygen level for the water mist system is the highest. This is due to the mechanism of fire extinguishment occurring during water application. Primarily, the water cools the environment and absorbs heat. For inert gaseous systems, the oxygen levels are the lowest. This is due to the primary method of extinguishment being oxygen displacement. These oxygen levels are brought down low enough to prevent combustion in the atmosphere. The hybrid water mist system, as expected, results in oxygen concentrations that fall in-between the oxygen levels found in the inert gaseous and water mist system tests. An explanation for this finding is the combination of the two agents. The water and inert gaseous agent work in tandem to extinguish the fire. The oxygen level is lower than the observed water mist level due to the introduction of the gaseous agent's method of suppression. However, the levels do not reach as low as the inert gaseous system. This is due to the water agent. The oxygen level observed with the hybrid system concludes that the two agents work together. Both agents utilized their specific capabilities in suppressing the test fire. The results of the FM Global enclosure fire tests are summarized in Table 3.

Table 3: *The results of FM Global Research's and FM Approvals analysis and testing. Fire extinguishment times and oxygen levels* [7].

Test	**Reported Fire Extinguish Time (s)**	**Predicted Fire Extinguish Time (s)**	**Measured O_2 Concentration at Fire Extinguishment**	**Predicted O_2 Concentration at Fire Extinguishment (%)**	**Predicted Fire Extinguishment time (s)**	**Predicted O_2 Concentration at fire Extinguishment (%)**	**Predicted Fire Extinguishment Time (s)**	**Predicted Concentration At Fire Extinguishment (%)**
D3.2	125	101	No data	14.6 (dry based) 12.3 (wet based)	113	12.3 (dry based) 12.0 (wet based)	124	16.1 (dry based) 12.5 (wet based)
D3.4	65	73	No data	14.0 (dry based) 12.2 (wet based)	84	12.5 (dry based) 12.0 (wet based)	88	14.9 (dry based) 12.4 (wet based)
E3.2	173	100	14.4 (dry based)	14.6 (dry based) 12.3 (wet based)	112	12.4 (dry based) 12.0 (wet based)	122	16.2 (dry based) 12.6 (wet based)
E3.4	86	72	13.5 (dry based)	14.1 (dry based) 12.3 (wet based)	83	12.6 (dry based) 12.1 (wet based)	87	14.9 (dry based) 12.4 (wet based)

System Classification

As oxygen concentrations observed at extinguishment were seen to clearly distinguish the three systems, it was determined that this was ideal to determine the classification of the system. An inert gaseous extinguishing system was classified as a system that reduces the dry-based oxygen concentration to less than 12.5 percent for 1 MW and 2 MW spray fires. A twin-fluid system one that reduces the dry-based oxygen concentration to greater than 16 percent for 1 MW and 2 MW spray fires. A hybrid system is a system that reduces the oxygen concentration to within the range of 12.5 to 16 percent.

Once a system is determined to be a hybrid system, the system must meet the system requirements set forth by FM Approvals Standard 5580, rather than traditional water mist or inert gas standards. The minimal discharge duration for a hybrid system was set to be a 10 minute minimum with a safety factor added to systems that have an extinguishment time of greater than 5 minutes for all of the required tests. The extinguishment time also cannot exceed 8 minutes for any fire test for listing by FM Approvals Standard 5580.

System Design

In comparison with gaseous and water mist systems, the hybrid system was noted to be different in terms of the suggested agent safety factor, extinguishing time, and discharge time. For gaseous systems, the required extinguishment time is 60 seconds with agent safety factors of 20 percent for CO_2 and 20 to 30 percent for inert gases and a discharge time of 10 minutes. For water mist systems there is no required extinguishment time or agent safety factor. The discharge time for water mist is two times that of the extinguishing time or 10 minutes. The agent safety factors and discharge times associated with gaseous systems are similar to the hybrid system's requirements; however they differ greatly from the water mist system requirements, which do not require an agent safety factor due to the nature of the system. The discharge time for the water mist is also two times the extinguishment time or 10 minutes if the extinguishing time is less than 10 minutes. These results can be seen for comparison in Table 4.

Table 4: *The results of FM Global Research's analysis including comparison of extinguishment time, agent safety factor and hold times from* [7] *utilized in FM Approvals Standard 5580* [1].

Agent	**Extinguishment Time**	**Agent Safety Factor**	**Discharge/Hold Time**
CO_2	60 seconds	20%	10 minutes
Inert Gas	60 seconds	20-30%	10 minutes
Water Mist	No requirement	No requirement	2X extinguishment time or 10 minutes
Hybrid Water Mist	0 to 5 minutes	Not required	10 minutes
	5 to 8 minutes	20 %	10 minutes
	Greater than 8 minutes	Not permitted	

Hybrid System Scalability

Hybrid systems have the unique feature of scalability. Depending on the application, a hybrid system in theory has the ability to be utilized as either a local application or total flooding application system. This is both an important feature and a potential ambiguity that needs to be carefully researched prior to the listing of a hybrid system, as currently-available data [1, 7] only reveal hybrid water mist's ability to replace a system similar to a total flooding application.

In the total flooding application, a hybrid system acts as defined by the FM Approvals Enclosure Fire Tests [7]. The inert gaseous and liquid suppressants are dependent on each other to extinguish the fire and work together. Of the two suppressants, neither one nor the other can extinguish the fire alone. For local application, the hybrid system acts more like a water mist system. Depending on the scenario, the water mist and gas ratio changes which means that the components of the hybrid system may no longer work in tandem to extinguish the fire. The system designed for a specific location may therefore depend on one component more than the other. If such a system is more dependent on the water mist or inert gas agent to extinguish the fire it begins to operate more like a distinct water mist or clean agent system, deviating from the hybrid system identification. This type of operation can be determined in specific scenarios by measurement of oxygen concentrations at extinguishment [7], however it is important to note that no local application scenarios are known to have been tested or listed yet. Even if a system uses both liquid and inert gas agents in its operation, the operational use of the agents may not make the system hybrid in nature.

The current hybrid systems listed under FM Approvals Standard 5580 are combinations of inert gas and water mist systems. The components of hybrid systems are therefore different from both clean agent and water mist systems. For example, only about 1.5 gallons of water is advertised to be used in some configurations of the Victaulic Vortex system, where water and gas suppressants ideally work in tandem [8]. The systems may be scalable and adjustable for different suppression volumes, where nitrogen acts as the primary suppressant in smaller systems reducing the oxygen concentration in the combustion atmosphere while the water mist cools the fire plume. In larger fires, the water mist acts as the primary suppressant by absorbing heat and displacing the oxygen in the combustion compartment. Some hybrid systems also create droplets on the order of 10 microns that are smaller than traditional water mist droplets, whose diameters average 100 microns. Hybrid droplets, having a larger surface area to absorb heat than water mist droplets may also be more effective in gas-phase cooling [8].

Recommendations and Conclusions

As a result of experimental classification work, primarily conducted by FM Global Research and FM Approvals, hybrid water mist systems have now been shown to differentiate themselves from traditional water mist or inert gas systems in the combined gas-phase cooling and inerting capabilities of the twin fluids used in the system. While the system still shares many similarities with traditional water mist and inert gas systems described in NFPA 750 [2] and NFPA 2001 [3], there are clearly differences that must be considered in the installation, inspection and application of hybrid suppression systems.

As a result of the literature survey, FM Global Research and FM Approvals has shared their test results which both distinguishes hybrid suppression systems as a unique design and certifies them for use in specific applications, similar to total-flooding scenarios [7, 9]. The known testing as-is only covers 8 specific configurations as listed in FM Approvals Standard 5580. For any scenario beyond these configurations, such as local application scenarios, test results in the public domain are necessary before inclusion in a code or standard.

There are two potential avenues for the classification of hybrid water mist systems. The first scenario involves addition of the hybrid system technology to the existing standard in either NFPA 2001: Standard on Clean Agent Fire Extinguishing Systems or NFPA 750 Standard on Water Mist Fire Protection Systems, while the second scenario is to create a new standalone standard for hybrid water mist systems. While hybrid suppression systems share similarities with both clean agent (NFPA 2001) and water mist (NFPA 750) systems, the current scope of each Standard limits its potential addition to the technical committee's purview without expanding the scope of the Standard. For instance, NFPA 2001 specifically excludes systems that use water as the primary extinguishing media, which could be interpreted as excluding hybrid water mist systems. However, the technical expertise for installation, operation and maintenance requirements exists on the Technical Committee for NFPA 750 as some commercial twin-fluid water mist systems may be designed to operate as either water mist or hybrid water mist. Still, safety considerations such as the need for an agent safety factor, personal life safety for occupied enclosures and pressure venting are not currently addressed in the technical makeup of the NFPA 750 technical committee but are in the NFPA 2001 Committee.

Whether hybrid water mist systems are to be included within NFPA 2001, NFPA 750 or a standalone standard, the technical makeup of the responsible committee must be expanded or newly formed. To be added to NFPA 2001, the committee's technical expertise will need to include a portion where water is a contributing extinguishment mechanism along with associated experts on installation, operation and maintenance. To be added to NFPA 750, the committee's technical expertise will need to include a portion where gaseous agents are a contributing extinguishment mechanism, including expertise on agent safety factors that differs from current clean agent standards. These objectives must be addressed regardless of where hybrid suppression systems are placed. The conclusion of the report is that there is a significant need for a standard that covers hybrid suppression systems and the choice of incorporating it into an existing standard or forming a new one should not affect the outcome.

Whether a new standard is developed or is just an addition to current standards, it must include separate chapters on system definitions, system design and system inspection, testing, maintenance and training. Currently, these criteria rest only on the manufacturer's specifications, as the only available criteria is FM Approvals Standard 5580, which is a listing standard only. A means to standardize existing manufacturer specifications is needed by creating a subsection of an existing standard or a new independent standard. Even though hybrid suppression systems have an inert gas component, which acts as one of the extinguishing agents, the NFPA 2001 or NFPA 750 standards will not sufficiently provide requirements for a hybrid suppression system without the addition of dedicated subsections or chapters of the existing standard, shown in [7].

References

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