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WET COLLECTIONS FIRE PROTECTION: AN OVERVIEW

Introduction

Wet collections are natural history specimens immersed in liquid preservative solutions and typically stored or displayed in glass or plastic containers. The preservative solutions are predominantly ethanol, formalin[1] or isopropanol.

The primary purpose of wet collections is for scientific research. In some instances, wet collections may be of species that are rare or extinct. These collections are not only irreplaceable, but they are also inherently hazardous to store and handle without proper precautions.

The liquid mediums used for specimen preservation, in almost all situations, will be ignitable liquids and are classified based on flashpoint. The containers used to store the specimens can range in size from small vials containing ounces of liquid, to large jars, drums or tanks containing gallons of liquid. The most difficult challenge in assessing the severity of wet collection hazards is that the applied practices amongst the different organizations vary to great extents. In addition, the composition of the ignitable liquid solutions can evolve over time as specimens are studied and maintained.

There is little guidance that specifically addresses the fire hazards and protection of wet collection storage. It is a challenge to apply standards written for commercial warehouses and retail occupancies housing ignitable liquids. However, wet collections and the storage of ignitable liquids used for the preservation of specimens meet the descriptions, the typical storage arrangements and the protection schemes covered in **FM Global Property Loss Prevention Data Sheet 7-29 (DS 7-29), Ignitable Liquid Storage in Portable Containers** for *"the storage of chemically stable liquids that can burn (i.e., ignitable liquids) stored in portable, non-pressurized metal, glass, fiberboard, plastic, or composite containers of any size."*

Data Sheets 7-29 generalizes the hazards as follows:

"Ignitable liquids in sealed containers create many different fire scenarios. With metal containers, there is the potential for the violent failure of the container or jetting if it is not adequately cooled.

[1]Formalin is a water-based saturated solution of formaldehyde gas. It contains about 40% formaldehyde gas (by volume) as well as a small amount of stabilizer. The general stabilizer, in this case, is 10-12 percent methanol, which helps to avoid formaldehyde polymerization.

It is nearly impossible to prevent the failure of a plastic container filled with an ignitable liquid, which creates the potential for the development of a large growing pool fire.

Apart from the type of fire hazard that can be created, it does not take a lot of ignitable liquid storage to create an unacceptably large fire in a general-purpose warehouse. Full-scale fire tests have shown that even a relatively small quantity of ignitable liquid can quickly overwhelm a sprinkler system designed for general storage."

Wet Collection Fire (Before and After), Butantan Institute, San Paulo, Brazil, May 2010

FM Global Property Loss Prevention Data Sheet 7-32 (DS 7-32), Ignitable Liquid Operations is helpful in addressing the handling of ignitable liquids. The data sheet provides recommendations for the prevention of and protection against fires and explosions in occupancies handling, processing, or transferring ignitable liquids. DS 7-32 describes the hazards as follows:

"Ignitable liquids burn as vapor. Low flash point liquids can easily ignite at ambient temperatures, while higher flash point liquids require either higher ignition energy or a physical change (i.e., forced to form small droplets) to burn.

Regardless of flash point, as fluids can flow or spread, this creates a significant challenge when using ceiling sprinkler protection alone to control the fire hazard. The fire will go wherever the liquid goes, the fire's heat release rate will increase with the surface area of a liquid pool, and sprinklers will operate well beyond the actual pool fire area. These conditions lead to the need for additional controls in ignitable liquid use occupancies, in addition to sprinkler protection, to limit the overall fire severity. Measures to stop the flow of liquid and to limit the pool size of already released liquids are needed to control sprinkler operating areas and to limit potential thermal damage to equipment and buildings. These measures apply to both high and low flash point liquids even though ceiling sprinklers can extinguish a high flash point (>200°F [93°C]) liquid pool fire."

Both DS 7-29 and DS 7-32 lead the reader to recognize one of the most significant risks associated with the storage and the handling of wet collections: The potential spillage of the ignitable liquid which will lead to a spreading pool, dramatically increasing the liquid's exposed surface area and heat release rate if ignited. A minor accident has the potential of turning into a catastrophic event if the spilled liquid is ignited.

As previously noted, operating procedures for handling wet collections vary amongst organizations. The ventilation of flammable or combustible vapors is not always considered in maintaining wet collections. Wet collection containers need to be periodically "topped-off" due to evaporation of the preservative and some institutions' practice of "topping off" liquid levels can be as simple as removing the tops from the containers holding ignitable liquids and adding additional liquid to the desired level for each container.

Other organizations transfer the containers to carts and top off the liquids under a hood. The routine handling of wet collections introduces the risk of damaging or dropping a container and creating the immediate hazard of an ignitable liquid pool. Once a liquid spill occurs it will spread horizontally on most surfaces. If the liquid is ignited, the fire will also spread horizontally. The larger the "spilled" pool fire area, the greater the heat release rate. Flame height is a function of the heat release rate which could potentially put other wet collection containers at risk of breakage or failure from the heat of the fire. **NFPA 909, *Code for the Protection of Cultural Resource Properties — Museums, Libraries, and Places of Worship, 2021 edition*** provides basic guidelines and safety precautions to be taken when topping off containers in wet collection storage rooms.

Collections are typically stored on shelves, in compact mobile storage units, or stationary racks. NFPA 909 provides some basic guidelines for shelving units used to hold wet collections including:

- Design of the racks and shelves to support the intended loads.
- Securely anchoring the shelving units to prevent an earthquake or other event from toppling one or more shelves.
- The storage units should be designed such that anchors and bracing provide shelving with strength equal to or greater than the building structure.
- All individual shelves should be constructed with raised lips and barriers to prevent containers from falling off the shelves.

Wet Collections in Glass Jars; Metal Shelving with Containment Rails. (Smithsonian Institution)

Material handling accidents do happen. Seismic events also have caused jars to fall from the storage units, and, in some instances, have caused storage units to topple over.

Wet collections displayed publicly in museum settings are typically located in accessible display cases along with dry collections which add Class A combustibles to the mix of fuels along with the Class B fuels.

The NFPA 909 Technical Committee has formed a task group which is in the process of surveying organizations to better define the hazards found in wet collection storage and display areas. Until more definitive direction can be developed, a hazard analysis should be performed for every occurrence of wet collection use and/or display. Successfully protecting these cultural resources from fire and natural disaster will require a broad-spectrum approach that entails procedures used to protect occupants viewing and/or maintaining the specimens, the building (often historical), and the specimens themselves. A vulnerability assessment, as stipulated by NFPA 909, includes the requirement to identify "existing and potential fire hazards." Wet collections' use, display, maintenance, and storage should all be included in the vulnerability assessment.

Ignitable Liquids in Wet Collection Storage

An organization's wet collection may be composed of specimens collected at different times and places, which can lead to having a variety of preservatives within a storage area. The majority of liquid storage media used for wet collections are alcohol-based solutions. Formaldehyde based solutions were once a common practice, but most organizations have migrated away from their use. Older preserved collections are more likely to contain a formalin solution.

Alcohol-based solutions are water miscible, and they will mix with water rather than separate and stratify at the top or bottom of the jar. Each solution has a different flashpoint, energy output, explosive limits, and other properties. The flashpoint is the temperature at which the vapor becomes ignitable. The flash points for alcohol-based liquids range from 53 to 75°F, making them flammable and the most hazardous of storage media. Other storage media are typically combustible, for example 37% Formalin has a flash point of approximately 147°F.

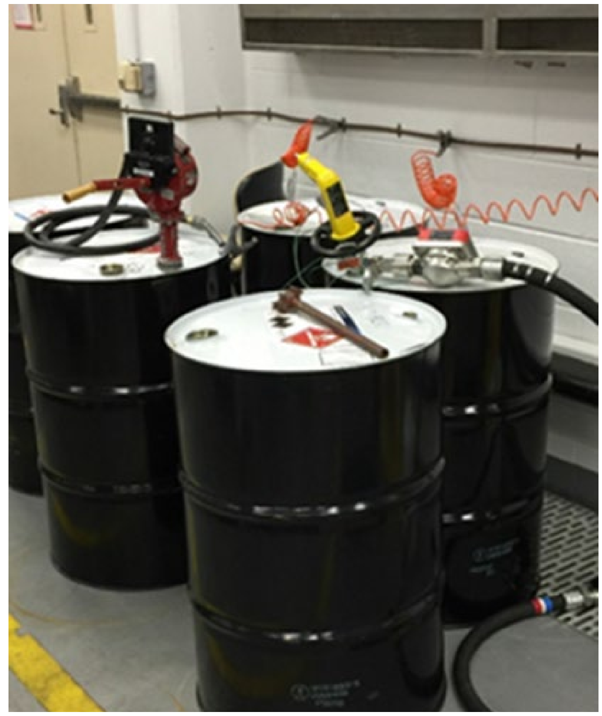
Substance	Flash Point (ºF)	Heat of Comb. (MJ/kg)	Vapor Pres. (mm Hg)	Latent Heat (kJ/kg)	LEL-UEL (%)	Water Miscible?
100% Ethanol	55	26.8	44.0	837	3.3-19.0	Yes
100% Isopropanol	53	30.5	33.0	663	2.0-12.7	Yes
70% Ethanol	72	26.8	24.0	1664	3.3-19.0	Yes
50% Isopropanol	~73	30.5	23.6	1889	2.0-12.7	Yes
37% Formalin	147	18.7	40.0	--	7.0-70.0	Yes

Table 1. Typical Ignitable Liquids used in Wet Collections

As part of a vulnerability assessment all ignitable liquids, mixtures and emulsions should be evaluated.[2] When new collections are added, the hazard could change, thus the vulnerability assessment will need to be updated.

Storage Segregation

Wet collections Ignitable liquids storage hazards should be segregated from other occupancies using outdoor locations, detached buildings, or cutoff rooms. FM DS 7-29 provides valuable detail for the storage arrangements of ignitable liquids provided in portable containers.



Smithsonian Institution's Museum Support Center: Bulk ethanol drums in a separate, 3-hour rated, flammable liquids storage room.

Consider the arrangement of cutoff rooms or detached buildings with the capability of both storing and dispensing in order to minimize the number of hazardous locations containing ignitable liquids.

Partially filled ignitable liquid containers should be handled, stored, and protected as if they are full containers.

A hazard analysis along with a fire safety management plan should include consideration for drainage and/or containment to prevent the flow of ignitable liquid into adjacent areas of the facility that are not protected for an ignitable liquid fire hazard.

NFPA 909 requires that wet collection storage areas of 46.45 m^2 (500 ft^2) or less shall be enclosed with a minimum of 2-hour fire-rated construction. Storage areas greater than 46.45 m^2 (500 ft^2) shall meet the separation requirements of NFPA 30 for liquid warehouses.

Drainage and Containment[3]

As indicated above, ignitable fluids can flow and spread, creating a significant challenge when using ceiling sprinkler protection to control the fire hazard. It is expected that a fire will spread as

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[2] FM Data Sheets DS 7-29 and DS 7-32 evaluate emulsions (mixtures that do not separate) based on the percentage of ignitable liquid in a water base and their flash points. Emulsions with less than 20% ignitable liquid in a water base will not create a pool fire regardless of flash or fire point and are not treated as ignitable liquids. Mixtures of any alcohols and another water miscible liquid should be treated by adding up the percentages and considering the total alcohol percentage as part of the risk assessment.

[3]Drainage and containment discussions are relative to fire protection concerns. There are additional management concerns about the loss of specimens through the drain systems. Trench and drain covers can be used to prevent specimens from going down drains. Also, raised drains, with inlets positioned several inches above the trench floor, can help with containing small spills, and preventing the loss of specimens through the drains.

the ignitable liquid spreads and the fire's heat release rate will increase with the increased surface area of the liquid pool. The increased heat generated could potentially trigger more automatic sprinklers to operate well beyond the actual pool fire area, with more automatic sprinklers operating than included in the original design considerations. Measures to stop the flow of liquid and to limit the pool size of the released liquids are needed to limit sprinkler operating areas and to reduce potential thermal damage to equipment and buildings. It should be noted that if the preservatives used for wet collections are miscible, any spilled liquid will mix with sprinkler water and be diluted.

Along with details for ignitable liquid storage, FM DS 7-29 also provides direction for emergency drainage and/or containment of spilled ignitable liquids. **FM Global Data Sheet 7-83, Drainage and Containment Systems for Ignitable Liquids** provides guidance for emergency drainage and containment systems to prevent the flow of liquid into adjacent areas of the facility.

Where flammable or combustible liquids are present, it should be realized that water discharged from automatic sprinklers or water spray systems must also be controlled or contained (without overflowing) to prevent the spread of fire. In order to avoid spreading fire to other areas, containment trenches should not be sloped.

The control or containment system should utilize one or more of the following:

- Curbing and grading
- Underground or enclosed drains
- Open trenches or ditches
- Diking or impoundment
- Or any combination of the above.

The control or containment system should be designed to accommodate the total combined flow from all of the following:

- All sprinkler and water spray systems intended to operate simultaneously within the fire area
- Supplemental hose streams intended to be used during the fire
- The largest anticipated spill or accidental release of process liquids.

Where the protected hazard involves the possible release of the ignitable liquids, the drainage system shall be designed to safely handle burning liquids.

Ventilation

NFPA 909 provides basic guidelines and precautions when topping off wet collection containers:

- Personnel servicing wet collections in storage should be trained in the use of portable fire extinguishers. Prior to maintenance of wet collections containers in storage personnel should confirm the availability and locations of extinguishers and their ability to operate the extinguishers[4].
- Only one container shall be open at any time.
- The container being topped off or filled shall be placed in a tray or basin to contain spills and to minimize spread of spills.
- Materials for cleaning up spills should be prepared and available for immediate use.
- Containers used for the dispensing ethanol should not exceed a capacity of 5 gallons and shall be approved for the purpose and use. They shall be equipped with a self-closing lid and be designed to safely relieve internal pressure greater than the maximum working pressure of the container.

The actions referenced in the above guidelines help minimize the amount of ignitable vapors being released into a storage room but do not eliminate the release of ignitable vapors. When a container is opened, vapor will be released. Any spill, regardless of how quickly or thoroughly the "clean up" process is completed, releases ignitable vapors into the storage space in a far greater amount than associated with the opening of a container.

Ventilation systems should be provided for all collection storage areas. Continuous ventilation removes flammable vapors before the vapors can collect. A properly designed ventilation system will sufficiently dilute the flammable vapor with air to prevent the concentration from reaching the lower explosive limit. These systems must be properly designed and laid out to ensure all areas of the enclosures are covered by the system. The exhaust ventilation should operate continuously, and the equipment should be monitored to show visual or audible ventilation-failure alarms at supervised locations.

Another component of vapor management is the control of room temperature[5]. Maintaining temperatures below the preservatives' flash point reduces evaporation and thus vapor concentration.

In addition to continuously operating ventilation systems, ignitable gas detection should be provided to notify the appropriate facility management teams of ignitable vapor buildup with an

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[4] Some businesses do not want their personnel to handle fire extinguishers or to be trained in fighting fires with fire extinguishers. Personnel are directed to evacuate their workplace at the first indication of a fire event. This issue should be considered as part of the vulnerability or risk assessment.

[5]For example, some institutions' collection storage areas maintain a temperature of 65ºF or slightly lower for wet collections using a preservative of 70% ethanol.

alarm threshold no greater than 25 percent of the gas LEL/LFL. The gas detection system (along with room lighting and ventilation system) shall be provided with an automatic emergency power system. Electrical equipment, including lighting, should be designed for Class 1, Div 2 locations in accordance with **NFPA 70, National Electric Code.**

FM DS 7-32 notes the following:

"Ventilation systems are designed to confine, dilute, and remove the maximum normal amount of flammable vapor released from equipment and handling of ignitable liquids during normal operations. Adequately designed low-level ventilation will reduce the chances of a flammable vapor-air mixture accumulating in the process area.

Install continuous low-level mechanical exhaust ventilation designed to provide 1 cfm/ft^2 (0.3 m^3/min/m^2) of floor area in rooms or buildings where the following are used:

- *A. Ignitable liquids with flash points below 100°F (38°C)*
- *B. Ignitable liquids with flash points up to 300°F (149°C) that are heated above their flash point*

Design ventilation to confine flammable vapor concentrations exceeding 25% of their lower explosive limit (LEL) to within 2 ft (0.6 m) of points of release (e.g., open mixing or dip tanks, dispensing stations)."

For additional information on FM recommendations for ventilation, see FM DS 7-32.

In general, liquids with a flash point below 100°F (38°C) produce enough vapor at room temperature to require mechanical ventilation, while unheated liquids with flash points above 100°F (38°C) require only natural ventilation.

NFPA 30, *Flammable and Combustible Liquids Code* provides the following information:
"*Generally speaking, 25 percent of the lower flammable limit (LFL) is considered to be the dividing line between a safe condition and one that warrants special attention. For example, in an area where flammable liquids are being used in the open, ventilation would normally be provided to ensure that the concentration of vapor in the adjacent atmosphere is not more than 25 percent of the LFL. A concentration above 25 percent would warrant an alarm condition; a concentration above 50 percent would warrant stopping work.*

Where cutting, welding, or similar hot work is involved, a safe condition is typically defined as a concentration of not more than 10 percent vapor in air."

The ventilation systems should be installed in accordance with NFPA 91.

Areas that handle, dispense or store hydrocarbons (including ethanol, formalin, or isopropanol) are classified as **Class I, Division 1** or **Class I, Division 2** hazardous locations in accordance with **NFPA 70.** It is the responsibility of the user of this document to acquire the appropriate information regarding the processes involved and the types of chemicals being used, and to comply with NFPA 70 for not only areas where handling and storage take place but also the adjacent areas.

Fire Suppression

NFPA 909 addresses the need for fire protection systems in this manner:

"*Without automatic fire protection systems, fire-resistive or noncombustible construction can survive, but combustible contents in the fire compartment will not. Fire protection systems should provide for both detection and extinguishment. While these functions are separate, they can and often should be consolidated into one continuous fire protection system that detects a fire, sounds the alarm, alerts the fire service, and initiates automatic extinguishing devices. Smoke detection systems provide an opportunity for occupant action with portable fire extinguishers before fire development activates the automatic sprinkler or other fire suppression system. Careful planning permits the installation of the necessary equipment with a minimal effect on the appearance or use of the public spaces in the cultural resource facility."*

The standard is clear on the necessity of both fire detection and fire suppression systems. New construction is required to include both detection systems and automatic fire sprinkler systems or alternative suppression systems. Where fire detection systems are required, NFPA 909 advises that smoke detectors be installed where ambient conditions permit. Most wet collection storage areas should be devoid of ordinary combustibles, so the only fuel burning will typically be alcohol-based preservatives. These fires burn so cleanly that smoke detection has been found to be generally ineffective. NFPA 909 does recognize that where ambient conditions will adversely affect the performance, reliability, or normal operation of smoke detectors, other forms of detection technology shall be used.

In *Chapter 9 - New Construction, Addition, Alteration, Renovation, and Modification Projects* of NFPA 909, 2021 edition, alternative fire suppression systems referenced include:

- Foam systems
- Carbon dioxide systems
- Halon 1301 systems
- Water spray fixed systems
- Dry chemical systems
- Wet chemical systems
- Water mist systems
- Clean agent extinguishing systems
- Aerosol extinguishing systems
- Hybrid (water and inert gas) extinguishing systems.

Even though the installations of alternative fire suppression systems are allowed by NFPA 909, the standard states that wet collections must be protected with an automatic water-based fire suppression system and that sprinkler systems must be either wet pipe, single interlock, or non-interlock pre-action sprinkler systems. Smoke and gas detection must be provided in accordance with the requirements of *NFPA 70* for Class I, Division II locations.

Regarding automatic sprinklers, both FM DS 7-29 and DS 7-32 require automatic sprinkler protection. FM DS 7-29 does allow the use of water mist systems as an alternative to automatic sprinklers when certain conditions are met. DS 7-29 permits supplementing sprinklers with an FM approved fixed foam-water sprinkler system or compressed air foam (CAF) system. DS 7-29 also states “do not use gaseous systems in storage occupancies because they have not been shown to be effective against the potential fire scenarios in this type of occupancy.” Note that DS 7-32 allows for Foam-Water, CAF, Total Flooding Water Mist, and Hybrid systems used within the limits of their FM approvals to supplement automatic sprinkler protection and limit fire damage.

Automatic Sprinkler Systems

Water, with its extinguishing or fire control capabilities, has always been the primary tool in the firefighting industry’s arsenal for combating fires. Water is one of the most effective, cost efficient and readily available agents for fighting fires. If an existing sprinkler system is provided in a facility, the most cost-effective means of providing a fire suppression system might be extending or connecting to the existing system. Note, however, that NFPA 909 requires that wet collections be protected with automatic wet pipe, single interlock, or a non-interlock pre-action sprinkler system. Because of the rapid growth of ignitable liquids fires, dry pipe or double interlock type systems should not be considered due to the slower response compared to wet pipe systems. In fact, additional consideration should be given to any type of automatic sprinkler systems’ response times.

Heat detection serves as the basis of sprinkler system response to a fire event and the thermal lag associated with heat detectors should always be addressed when protecting ignitable liquid fire hazards. Quick response sprinklers should be considered in the hazard analysis as an alternative to a standard closed head sprinkler system. Further consideration should be given to an open head water spray (deluge) system[6] paired with a fast response type detection system. If conditions permit, smoke[7] or air sampling smoke detection might be more suitable and quicker in response than heat detection as would optical type flame detection. In storage areas devoid of ordinary combustibles, heat detection or optical flame detection might be required since clean burning alcohol fires are not ready detected by smoke detectors.

It is crucial to exercise caution when employing water to extinguish Class B fires involving flammable and combustible liquids. If the ignitable liquid has a specific gravity less than 1.0, meaning it is lighter than water, the water can sink below the liquid surface, causing the burning liquid to float and potentially spill from its containment and exacerbate the fire's spread.

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[6]The vulnerability assessment should consider the large amount of water discharged from an open head water spray system, along with the associated water damage from the amount of water discharged. A deluge system protecting a large storage area might be prohibitive, but the protection of a small, enclosed area might be an advantage because of the fast speed of fire suppression. Listed open nozzle water mist systems could also be considered.

[7]Most wet collection storage areas should be devoid of ordinary combustibles, so the only fuel burning will typically be alcohol-based preservatives. These fires burn so cleanly that smoke detection has been found to be ineffective.

Most liquid storage media used for wet collections are alcohol-based solutions. Formaldehyde based solutions were once common, but most organizations have migrated away from their use. Older preserved collections are more likely to contain a formalin solution. Alcohol-based solutions and formalin have specific gravities less than 1.0 and are water miscible. They will mix with water and not separate and stratify at the top or bottom of a container.

During the discharge of a sprinkler system, as the water percentage in a pool or contained ignitable liquid increases, the flash point and fire point of the mixture will also increase. The heat of combustion and heat release rate both decrease. At some point, the mixture will cease to have a fire point.

The water discharged from sprinkler or water spray systems must be controlled or contained to prevent the spread of fire where flammable or combustible liquids are present.

As noted above, the control or containment system can utilize curbing and grading, underground or enclosed drains, open trenches, ditches, diking or impoundment. The system must be designed to contain the total combined flow from all water spray systems (intended to operate simultaneously) within the fire area, supplemental hose streams and the largest anticipated spill or accidental release of ignitable liquids. Design should accommodate the total combined flow for the fire's expected duration.

Alternative Fire Extinguishing Systems

There are limitations to all types of fire suppression systems including automatic sprinkler systems. The first and foremost limitation of sprinklers is the need for a water supply adequate to provide properly designed sprinkler protection.

Sprinkler systems are intended to protect personnel and property by controlling and containing a fire but are not necessarily designed to extinguish a fire. In contrast to sprinkler systems, many of the alternative fire suppression systems including carbon dioxide, dry chemical, water mist, halocarbon and inert gas clean agents, and hybrid (water and inert gas) extinguishing systems are all required to extinguish Class B type fuels in order to obtain Underwriters Laboratories listings or Factory Mutual approval.

None of the alternative extinguishing systems have the potential to overwhelm and overflow the containment boundaries with mixtures of ignitable liquids and water as do sprinkler or foam systems. However, the continuing discharge of water that might possibly overwhelm the containment of ignitable liquid is also a reason that some authorities prefer sprinklers. The continuous operation of a sprinkler system can provide a longer duration of fire protection compared to most of the alternative fire extinguishing systems which have limited amounts of agent.

Typically, most non-water based fire suppression systems perform in a similar manner by using early warning fire detection and the total flooding application of the extinguishing agent. Halocarbon and inert gas clean agents, carbon dioxide, dry chemical, water mist, and hybrid (water mist/inert gas) are all well suited for the protection of Class B hazards. Even though a water mist system uses water as the fire extinguishing agent, we include it in this discussion along with non-water based fire suppression systems because the design approach of providing total flooding fire suppression[8] aligns more closely with gaseous suppression system designs than the traditional design approach of automatic sprinkler systems. Water mist fire extinguishing systems provided in accordance with **NFPA 750, *Standard on Water Mist Fire Protection Systems*** are required to be tested for the unique hazards they are designed to protect.

Note: All gaseous fire suppression systems, including clean agent, carbon dioxide and dry chemical fire-extinguishing systems, protecting areas where explosive atmospheres could exist should utilize metal nozzles, and the entire system shall be grounded.

Automatically operated extinguishing systems are controlled by a fire alarm releasing control panel (FACP). Connected to the FACP through various types of circuits are initiating devices (detectors or manual pull stations), notification devices (typically horns and strobes), and actuation devices (electric or manual system actuators) used to initiate the system discharge. The programming of the FACP determines how the panel responds when it receives a signal from one or more detectors. As signals are received from detectors, manual pull stations, or "abort" stations, the panel initiates functions, which can include:

- Initiation of a pre-discharge cycle
- Energizing various notification devices to signal the need for evacuation
- Activation of the building alarm system
- Control of air handling systems
- Power interruption to protected equipment
- Closing of openings (doors and dampers)
- Opening of pressure vents
- Operation of auxiliary relays
- Release of the fire extinguishing agent.

<u>Clean Agent Fire Extinguishing Systems</u>

Clean agents as classified in **NFPA 2001, *Standard on Clean Agent Fire Extinguishing Systems***, are categorized either as a halocarbon compound, an inert gas, or an inert gas mixture. The most commonly used halocarbons today are compounds containing carbon, hydrogen, and fluorine. The inert gases (IG) extinguishing systems are either pure nitrogen (IG-100), argon (IG-01), a blend of the two (IG-55), or a blend of the two with a small amount of CO_2 (IG-541).

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[8]The total flooding application of water mist discharged from an overhead water mist system is deluge type protection with all nozzles in the protected area discharging at the same time. Fire detection and a releasing control panel are required as part of the system. Because of the Class B type hazards presented with wet collections, closed head (automatic) water mist nozzles are not considered suitable.

Halocarbon agents are used at relatively low volumetric concentrations (normally below 10%) to extinguish fires with minimal reduction of the oxygen concentration in an enclosure.

Inert gas agents are used at relatively high concentrations to extinguish fires, typically in the range of 40 to 50 %, or more, in air. At an inert gas agent concentration of 45 %, the residual oxygen concentration is 11.5 % compared with 21 % in normal air.

Clean agent systems are UL and FM listed to extinguish Class A surface fires and Class B and C type fires. The agents absorb heat and cool the flame to the point of extinguishment. "Clean agents" leave no agent residue; thus, no cleanup of the agent itself is required.

Once fire has been detected, it is desirable to extinguish it as soon as practicable to minimize fire damage and accumulation of hazardous combustion products. The clean agents discharge times are prescribed by NFPA 2001 for Class B fire hazards are:

a. Halocarbon agents: the discharge time shall not exceed 10 seconds.

b. Inert gas agents: the discharge time shall not exceed 60 seconds.

The integrity of the enclosure or room must be maintained so that a total flooding clean agent concentration can be held for the required duration. Air circulation systems and forced-air ventilation systems should be shut down or automatically closed if continued operation could adversely affect the performance of the fire suppression system.

Where total flooding gaseous fire extinguishing systems are used, "enclosure integrity" references the ability of a protected enclosure to retain a fire extinguishing atmosphere or "hold" the agent for a required duration of protection. As such, if a protected enclosure is not able to hold the agent long enough to permit the fuel and surrounding materials to cool, there is a real risk that re-ignition might occur. Thus, the enclosure itself is an essential part of a gaseous fire extinguishing system.

Balancing the need for a gas-retentive, or "tight," enclosure with the requirement for adequate vent area to prevent excessively low or high internal pressure during agent discharge presents a challenge. An enclosure must be "leaky" during discharge to regulate pressure within the enclosure but tight after discharge to maintain effectiveness.

The minimum design concentrations (MDCs) of HFC 227ea and FK-5-1-12 required for the various solvents employed in wet collections are noted in Table 2 below.

It should be noted that while "70% ethanol" can be composed solely of 70% ethanol and 30% water, many suppliers' "70% ethanol" product could also contain methanol. The extinguishment of methanol requires a higher MDC compared to ethanol, and hence the protection of "methanol-containing 70% ethanol" should be based on the MDC of methanol.

"50% Isopropanol" typically is composed of only isopropanol and water, and hence the MDC of 50% isopropanol is based on the MDC of isopropanol.

Formalin solutions typically consist of a solution of formaldehyde in water with methanol added as a stabilizer, and hence the MDC of formalin should be based on the MDC of methanol.

Table 2. Minimum Halocarbon Design Concentrations (MDCs) for Wet Collection Solvents

Wet Collection Solvent	HFC 227ea % v/v [a]	FK-5-1-12 MDC % v/v [b]
Ethanol	10.8	7.2
Isopropanol	9.8	6.4
70% Ethanol (methanol-free)	10.8	7.2
70% Ethanol (methanol-containing)	13.5	8.5
50% Isopropanol	9.8	6.4
37% Formalin	13.5	8.5

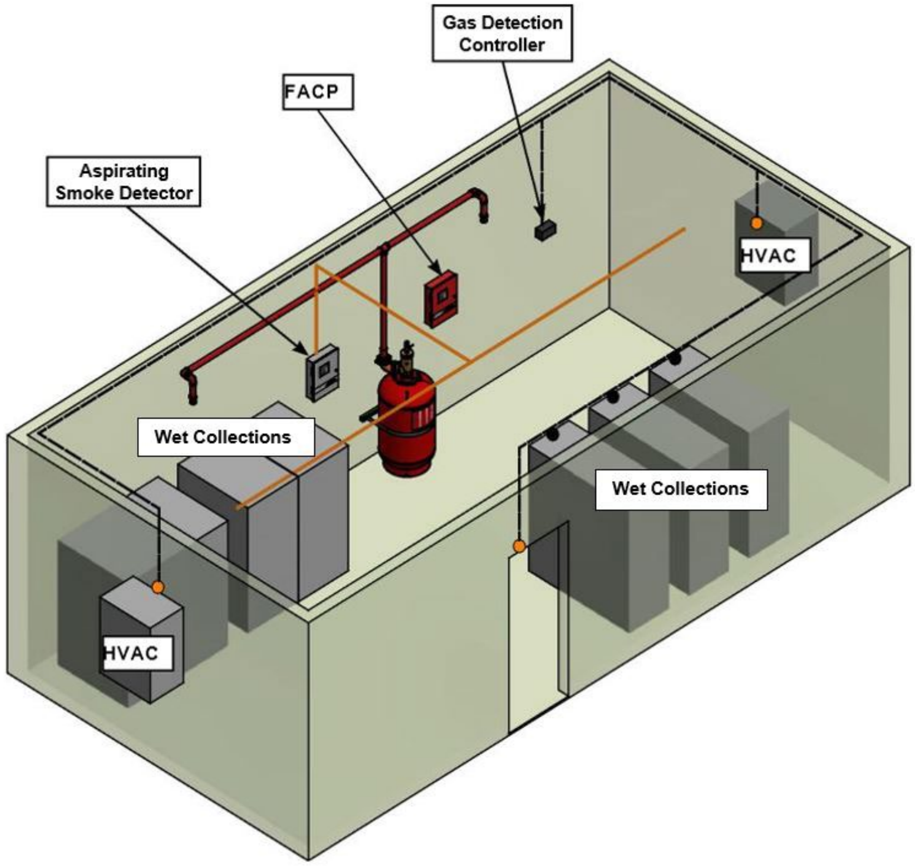
[a] Data from The Chemours Company; [b] Data from 3M Company

The minimum design concentrations (MDCs) of the inert gases or inert gas mixtures required for the various solvents employed in wet collections are noted in Table 3 below.

Table 3. Minimum Inert Gas Design Concentrations (MDCs) for Wet Collection Solvents

Wet Collection Solvent	IG-01 % v/v [c]	IG-100 % v/v [c]	IG-541 % v/v [d]	IG-55 % v/v [d]
Ethanol	68.8	52.7	42	44.9
Isopropanol	63.6	48.7	37.5	40.1
70% Ethanol (methanol-free)	68.8	52.7	42	44.9
70% Ethanol (methanol-containing)	N/A	N/A	N/A	N/A
50% Isopropanol	63.6	48.7	37.5	40.1
37% Formalin	N/A	N/A	N/A	N/A

[c] Data from The Viking Corporation; [d] Data from Fike



Typical Clean Agent Protection of Wet Collections Storage

Dry Chemical Extinguishing Systems

Dry chemical extinguishing systems are noted for their capability to extinguish Class B and Class C type fires. A multipurpose (ABC) dry chemical system is the only dry chemical system capable of extinguishing Class A, B, and C fires. In general, dry chemical agents are noted for their efficiency in extinguishing flammable liquid fires. They can also be used on fires involving some types of electrical equipment. Multipurpose (ABC) dry chemical can extinguish fires in flammable liquids, fires involving energized electrical equipment, and fires in ordinary combustible materials.

When discharged into the fire area, dry chemical causes extinguishment almost at once. Smothering, cooling, and radiation shielding contribute to the extinguishing efficiency of dry chemicals, but studies indicate that the principal cause of extinguishment is the interruption of the chemical chain reaction of flame propagation.

In the past few years there have been significant developments of “engineered” dry chemical systems that make design, installation, and performance of total flooding dry chemical extinguishing systems much more economical and very similar to clean agent systems.

Dry chemicals offer very effective extinguishing alternatives but have associated residual impacts including, but not limited to, significant clean up, and the potential for chemical interaction with and damage to protected materials.

Water Mist Extinguishing Systems

Water Mist may be a suitable option for the protection of wet collections. Water mist discharges a fraction of the water discharged by a standard sprinkler system protecting the same space, hence less potential for water damage or overwhelming control or containment systems.

The total flooding application of water mist discharged from an overhead water mist system is deluge type protection with all nozzles in the protected area discharging at the same time. Open head nozzles are required. Fire detection and a releasing control panel are required as part of the system. Because of the Class B type hazards presented with wet collections, closed head (automatic) water mist nozzles are not considered suitable. Automatic-type closed head water mist nozzles are typically only listed for “Light” or “Ordinary, Group 1” hazards.

Systems have been tested and approved for the total flooding or local application protection of the following:

- Special hazard machinery
- Spaces where equipment is using or handling fuels and/or lubrication fluids with volatilities less than or equal to heptane with incidental use or storage quantities of two 55gal (208 Liter) drums
- Flammable liquid pool fires where the liquid can be confined in diked areas
- Flammable liquid channel fires
- Partially obstructed flammable pool fires
- Spray fires, or combination spray and pool fires where release is confined to a diked area
- Flammable and combustible liquid residues.

The **FM Approval Standard for Water Mist Systems, Class Number 5560** provides fire test protocols for the approval of water mist systems protecting special hazards. Water mist systems use clean, potable quality water, and all piping and fittings downstream of the system strainer are required to have a corrosion resistance equivalent to stainless steel or copper. NFPA 750 does not permit the use of galvanized or black steel pipe, thus there is no chance for internal corrosion associated with steel pipe.

There are multiple suppression mechanisms associated with water mist for the extinguishment of fires. The three primary mechanisms are heat extraction, oxygen displacement and blocking of radiant heat. All three of these mechanisms play some part in the extinguishment of fires but how much involvement of each mechanism depends on the fire dynamics associated with the burning fuel. There are two secondary mechanisms, vapor/air dilution and kinetic effects, involved in extinguishment, but, to date, there has been difficulty in quantifying their importance.

Water mist systems have the capability to extinguish Class A, Class B, and Class C type fires.

Hybrid Fire Extinguishing Systems

Hybrid fire extinguishing systems use a mixture of water and inert gas agents. In the development of hybrid fire extinguishing systems product designers applied *water mist* fire test protocols and *inert gas clean agent* test protocols to develop a combined system that uses the fire suppression qualities of both water and the inert gases. Fire testing has validated that heat extraction, oxygen dilution and the blocking of radiant heat all contribute to the extinguishment of fires by hybrid systems. Hybrid systems are designed to achieve complete extinguishment of the fire.

Water is a physically-acting fire suppressing agent. The specific heat capacity and high latent heat of vaporization (approximately 1000 BTU/lb.) gives water the capability to absorb large amounts of heat from the flames, fuels, and surrounding air. Water is sheared or atomized by the high velocity inert gas. The heat absorbed from the flame front and the fuel reduces the production of flammable vapors needed to sustain combustion and contributes to fire suppression.

In addition to atomizing the water component of the hybrid media, inert gas directly plays a role in extinguishment of the fire. The inert gas reduces the flame temperature by absorbing heat and reducing the oxygen concentration in the combustion zone. The oxygen dilution contributes to fire extinguishment and helps prevent reignition even as sufficient oxygen remains for sustaining human life.

Some systems mix the water and inert gas at the container location and use one piping network to carry the hybrid mixture to the nozzles. Other hybrid systems use separate pipe networks to transport the water and inert gas to the individual nozzles where they are combined.

A total flooding hybrid system is designed to discharge an extinguishant into an enclosure to achieve a uniform distribution of that extinguishant, at or above the design quantity required to extinguish the fires throughout the enclosure. The enclosure allows the hybrid media to be retained and preserves an atmosphere that cannot support combustion, therefore preventing reignition.

The **FM Approval Standard for Hybrid Fire Extinguishing Systems (Water and Inert Gas), Class Number 5580** has fire test protocols for the approval of hybrid systems for protection of special hazards. A key requirement of hybrid systems is the utilization of clean, potable water. Typically, these systems are engineered with water stored in corrosion-resistant pressure vessels and the discharge pipe is dry until the system is activated. This design minimizes, if not eliminates, the risk of leakage from system piping onto high-value assets, preserving their integrity and functionality. NFPA 770 establishes the criteria for the design, installation, acceptance, and maintenance to help assure system effectiveness throughout the system's operational lifespan.

Carbon Dioxide (CO_2) Fire Extinguishing Systems

Carbon dioxide fire extinguishing systems are UL listed and FM approved to extinguish Class A, B, and C fires.

A properly designed CO_2 total flooding system discharges carbon dioxide into an enclosure to provide a uniform extinguishing concentration within the enclosure. Design concentrations have been determined for many applications involving flammable and combustible liquids and gases and can be found in **NFPA 12, *Standard on Carbon Dioxide Extinguishing Systems.***

Table 4. Minimum Carbon Dioxide Design Concentrations for Wet Collection Solvents

Wet Collection Solvent	CO_2 % v/v
Ethanol	43[c]
Isopropanol	TBD[d]
37% Formalin	TBD[d]

[c] Extracted from NFPA 12, ***Standard on Carbon Dioxide Extinguishing Systems***; [d] TBD: To Be Determined.

CO_2 extinguishes fires by removing heat from the flame, reducing the amount of oxygen in the fire zone, and reducing the amount of fuel vapor emanating from the fuel. The minimum design concentration permitted by NFPA 12 is 34% by volume. This concentration is well above the maximum concentration which will sustain human life. Inhalation of atmospheres at CO_2 design concentrations can quickly cause death or severe injury. As efficient as carbon dioxide is as a fire extinguishing agent, it presents a serious hazard to personnel exposed to required CO_2 design concentrations. Personnel safety must be given the utmost attention and consideration during system design, installation, and maintenance of carbon dioxide systems. NFPA 12 details and emphasizes personnel safety at length. CO_2 is not a safe alternative for wet collection storage areas where one or more persons will be present under normal operating conditions (i.e., a **normally occupied space).**

However, if ignitable liquids used in specimens are stored in rooms that are not normally occupied then CO_2 fire protection may be a permissible alternative provided that all the safety requirements set forth in NFPA 12 are provided and all personnel who enter the protected space are properly trained in the hazards of CO_2, system lock out requirements, response to alarms, and other safety considerations covered in NFPA 12.

Fire Detection

Automatic preaction sprinkler and deluge systems, along with the alternative fire extinguishing systems noted above, require a fire detection system to automatically recognize a fire condition and initiate the actions required for the activation of the fire suppression system. The fire suppression system combined with automatic detection is classified as “active” fire protection.

Automatic fire detection devices such as smoke, optical smoke, and heat detectors signal detection of a fire to a fire alarm control panel (FACP). Upon receipt of the signal, the FACP activates various alarms and various “pre-discharge” functions (e.g., air handler shut down, damper closures) and initiates discharge of the suppression system.

Because every fire hazard is unique, the fire protection options vary greatly. The different environmental and process conditions where fire detection systems will be installed and required to function properly must be taken into account. Below are the most common types of initiating devices used to detect fires and cause notification of a fire condition and/or activation of fire extinguishing systems:

- **Photoelectric detectors** sense a change caused by smoke particles in the intensity of scattered light reflected onto a photo receiver in a detection chamber.

- **Ionization detectors** operate on the principle of sensing a change in the flow of ions through the sensor chamber caused by the presence of smoke within chamber.

- **Multi-criteria, Multiple-Sensor detector**: A device that contains multiple sensors that separately respond to physical stimulus such as heat, smoke, or fire gases, or employs more than one sensor to sense the same stimulus.

- **Air sampling smoke detectors** employ an aspirator to draw air from the hazard through a sampling pipe network into a detection chamber where incipient and smoke particles are detected by a variety of means. Air sampling smoke detectors are capable of sensing extremely minute quantities of smoke. Air sampling detectors are commonly known as high sensitivity smoke detectors or very early warning smoke detectors.

- **Flame detectors or radiant energy-sensing fire detectors**, as described in **NFPA 72, *National Fire Alarm and signaling Code,*** are generally considered to have the fastest response time for detection of a flaming fire. These detectors typically respond to Ultraviolet (UV) and/or Infrared (IR) radiant energy given off by a fire.

- **Video Image Detection (VID) is a line-of-sight, visual spectrum detection** method. Cameras are used to capture images and can react to conditions within their line-of-sight. These VID devices do not have a sensing chamber and they do not utilize heat, UV, IR, or obscuration to detect smoke or flames. A Video Image Flame Detector (VIFD) operates on the principle of using automatic analysis of real-time video images to detect the presence of flame. A Video Image Smoke Detector (VISD) operates on the principle of using automatic analysis of real-time video images to detect the presence of smoke.

- **Heat detectors** are designed to detect either abnormally high temperature or rate of temperature rise or both. They are generally located at or near the ceiling. Spot type heat detectors generally operate by one of four principles: fixed-temperature operation, rate-of-rise operation, rate-compensated operation, or electronic operation. Linear heat detectors are used for more specialized applications, and generally operate by either the discrete sensing principle or the integrating principle.

Except for flame detectors, video imaging detection and heat detectors, all of the other detectors referenced above function, or can function, by detecting smoke particles in the protected enclosure. Most wet collection storage areas should be devoid of ordinary combustibles, so the only fuel burning will typically be alcohol-based preservatives. These fires burn so cleanly, that smoke detection has been found to be ineffective[9]. Heat detectors

[9]Regardless of housekeeping it should never be assumed that there will be no Class A type combustibles present, in any hazard area, including furniture, paper documentation, ignitable liquid or wet collection container components, rolling carts used for transporting or transferring ignitable liquids, insulation covered wiring or contained specimens that might have spilled out onto the floor.

generally respond more slowly to ignitable liquid fires than some of the other detectors such as flame detectors or video imaging detectors.

When protecting against ignitable liquid fire hazards, optical flame detectors or radiant energy-sensing fire detectors, that respond to Ultraviolet (UV) and/or Infrared (IR) light given off by a fire, are considered to have the most rapid response time for the detection of a flaming fire.

Operating characteristics and technical data for each of the various initiating devices, along with selection, spacing and installation information can be found in the manufacturers' manuals and technical data sheets.

As mentioned above in the discussion of ventilation systems, gas detection systems are a means to provide notification of the presence of ignitable vapor in an enclosure. Gas detection systems should be considered in addition to fire detection as part of the risk assessment.

More detail on detection and control systems for special hazard fire suppression systems is available in the **FSSA Application Guide Detection & Control for Fire Suppression Systems.**

The Fire Suppression Systems Association (FSSA) publishes the following guidelines:

Guide to Clean Fire Extinguishing Agents & Their Use in Fixed Systems (CAG-01)

Design Guidelines for Total Flood Clean Agent Fire Extinguishing Systems (CAD-01)

Guide for use with Water Mist Fire Extinguishing Systems (WM-01)

Guide for use with Hybrid Water & Inert Gas Fire Extinguishing Systems (HGG-01)

General Information Guide for Carbon Dioxide Fire Extinguishing Systems (CGG-01)

Design Guidelines for Carbon Dioxide Local Application Rate-by-Volume (CRV-01)

Design Guide for Use with Carbon Dioxide Total Flooding Applications (CTF-01)

Application Guide Detection & Control for Fire Suppression Systems (DCG-01)

Pressure Relief Vent Area for Applications Using Clean Agent Fire Extinguishing Systems (PRG-03)

Pipe Design Handbook, Third Edition (PDH-03)

Inspection and Test Guide, Fourth Edition (CSG-04)

Fire Protection Systems Inspection Form Guidelines (IFG-01)

These guides may be purchased through the FSSA website.

For Additional information contact:

Fire Suppression Systems Association (FSSA)
3601 East Joppa Road, Baltimore, MD 21234
info**@fssa.net**