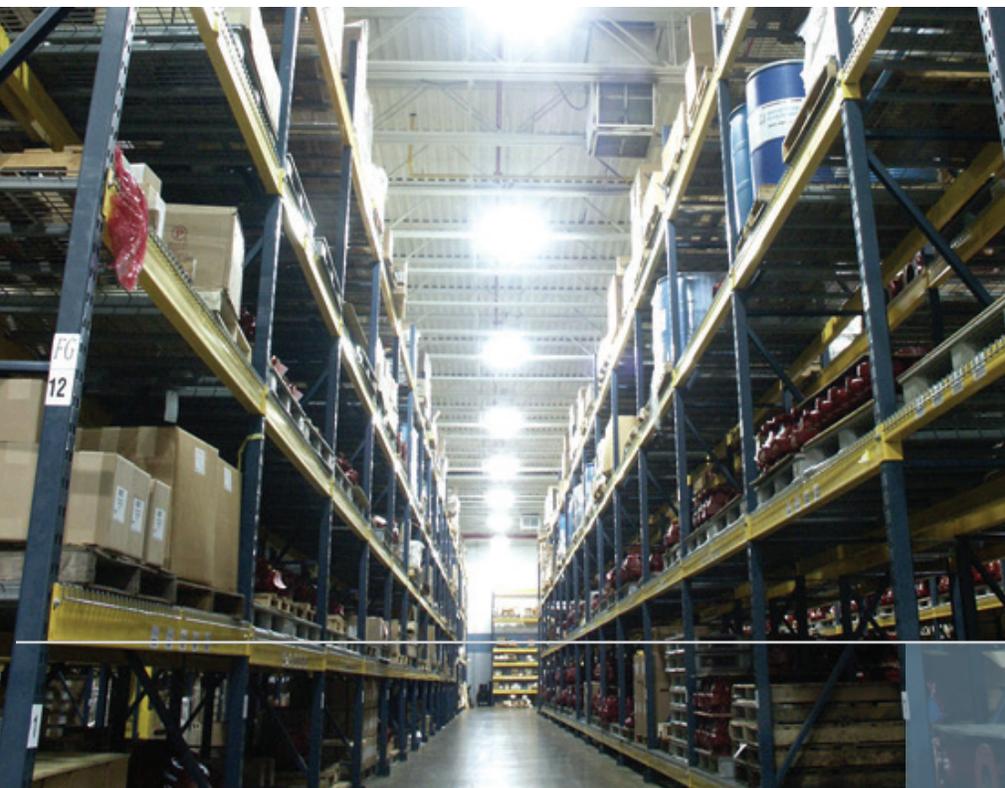


Technical Article

Sprinkler Protection for High Bay and Automated Storage in Warehouse-type Storage Facilities

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Warehouse-type facilities with rack storage present a complex fire protection problem. As indicated in the fire test data included in NFPA 13 and NFPA 30, large-scale fire tests have demonstrated that many of these fires can become very large and difficult to control within two minutes or less.¹ Determining the correct automatic sprinkler system solution can be a challenge. The increasing popularity of large storage warehouses that have rack storage heights from 12.1 meters to over 30.4 meters is increasing the level of complexity for the automatic sprinkler system design. Currently, very little full-scale fire testing with automatic sprinklers has been done with rack storage in excess of 12.1 meters, which limits the automatic sprinkler choices and protection schemes that are available for these applications. This article will review the current NFPA 13 requirements as well as concepts on possible future sprinkler protection based upon today's known and commonly accepted practices, science and technology.



3D Rendering of Automated Storage Warehouse

The complexity of protecting storage occupancies with sprinkler systems seems to originate with the large number of sprinklers and categories available. For those designing this type of sprinkler system, it is important to understand that the science and math involved is universal and obvious to those trained in the field. Sprinkler hydraulics, sprinkler spacing, response times, fire control and fire suppression are subfields of sprinkler technology that use the same mathematics and science that have been applied for over 100 years. There are six significant characteristics in the manufacture of automatic sprinklers that can be changed in the manufacturing process to achieve different performance. These are:

1. Thermal sensitivity
2. Temperature rating
3. Orifice size
4. Installation orientation
5. Water distribution characteristics
6. Special service conditions²

The science of thermal sensitivity is well documented. Transfer of heat governs all aspects of fire, from ignition through final extinguishment. Heat is transferred by one or more of three mechanisms: conduction, convection, or radiation.³ Convective heat transfer (heated air from a fire rising to the ceiling) is the primary means by which a sprinkler is activated.⁴ The heated air rises in a plume to the ceiling. When the plume hits the ceiling, it produces a ceiling gas jet. The heat responsive elements of the sprinklers within the jet are then heated by conduction of the heat from the air.⁵ When the heat responsive element reaches its operating temperature, the sprinkler will activate.

It is necessary to measure this process in order to determine the thermal sensitivity of the sprinkler. Thermal sensitivity is the measure of how fast a heat



Plunge Oven

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responsive element operates when installed in a sprinkler. Factory Mutual developed a method to measure thermal sensitivity that is used today which utilizes the concept of a Response Time Index (RTI). The device used to conduct this measurement is commonly referred to as a “plunge oven”; the test is referred to as an “oven heat test” in Underwriters Laboratories Standard UL 199.

Within the plunge oven an air stream is moving through a metal duct at a constant velocity and temperature. The sprinkler, which is at room temperature, is plunged into the heated air stream. A measurement is made of the time, in seconds, required to raise the temperature of the heat responsive element, approximately 63 percent of the temperature of the heated air stream. This measurement is called a “tau factor.”⁶ Multiplying this factor by the square root of the velocity provides the number which is the RTI of the sprinkler.

$$RTI = TU^{1/2}$$

T = tau factor

U = air velocity

NFPA 13 section 3.6.1(a)(1) defines the response time for fast response sprinklers as having a thermal element with an RTI of 50 (meter-seconds)^{1/2} or less, while section 3.6.1(a)(2) defines standard response as having a thermal element with an RTI of 80 (meter-seconds)^{1/2} or more. The standard does not have a separate defined RTI for quick response sprinklers. Section 3.6.2.9 defines quick response as a type of spray sprinkler that meets the criteria of 3.6.1(a)(1), making it a type of fast response sprinkler.

The sprinkler’s temperature rating can have a dramatic effect on the sprinkler’s performance in a storage occupancy fire. A good example of this is illustrated in the density/area curves for rack storage of class I through IV commodities less than 7.6 meters, and rack storage of class I through IV commodities above 7.6 meters. Full-scale fire testing in rack storage up to and including 7.6 meters indicated a more effective performance for high temperature rated sprinklers when compared to ordinary temperature rated sprinklers. Ordinary temperature rated sprinklers typically operate outside the actual fire area, which essentially robbed water from the sprinklers in the fire area.⁷ High temperature rated sprinklers did not operate in the same manner, which resulted in greater discharge in the fire area. As a result, the density/area curves for rack storage of class I through IV commodities up to and including 7.6 meters allow a reduction in density when using high temperature rated sprinklers.

Taking a look at Rack Storage of class I through IV commodities over 7.6 meters, we see the exact opposite, as NFPA 13 recommends the use of ordinary temperature rated sprinklers over high temperature rated sprinklers. Again, this is the result of full-scale fire testing. In these tests, in-rack sprinklers (which are now required) show their effect on the ceiling sprinklers. Essentially the sprinklers operating at the lower levels reduce the heat release rate of the fire dramatically. Therefore, the sprinkler operating area did not increase with ordinary rated sprinklers as it did with less than 7.6 meter storage without in-rack sprinklers.



In-Rack Sprinklers Being Installed in Racks

Sprinkler orifice size and K factor determine the amount of water that can be discharged from a sprinkler at a given pressure. The fundamental formula for water discharge from an orifice can be traced back to Torricelli’s Flow Theorem $Q=av$, discovered in 1644.⁸

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This Theorem has been used by hydraulics engineers, physicists, and all who have ever hydraulically calculated a sprinkler system as documented in Harold Wass's 1999 Second Edition book *Sprinkler Hydraulics and What It's All About*. Page 45 and 46 describe how this formula is mathematically converted to the standard formula used in the sprinkler systems (shown below):

$$Q = 0.0666cd^2Vp$$

This can be simplified further to $Q = kvp$

All sprinkler K factors, whether or not they are currently used in the sprinkler industry and/or storage occupancies, are developed from the same mathematical formula.

Installation orientation and water distribution are also critical to a sprinkler's performance. Installation orientation can have an impact on water distribution and the ability of the sprinkler to control or suppress the fire, when in close proximity to building structural members. The concepts of suppression and control are well-known and are linked to the actual delivered density of water (ADD) versus the required delivered density (RDD). The required delivered density will increase as the heat release rate of the expected fire increases. In other words, a more intense fire will require more water for control or suppression.

Current CMDA and In-Rack Sprinkler Design for Rack Storage of Class I through IV Commodities Above 7.6 meters.

Within the 2010 edition of NFPA 13, the requirements for rack storage protection are contained in chapter 16 for Class I-IV commodities and chapter 17 for plastics and rubber commodities. These chapters are separated into sections for rack storage below 7.6 meters, and storage above 7.6 meters. When required to use Control Mode Density/Area sprinklers, understanding the requirements of NFPA 13 can be simpler when rack storage is over 7.6 meters than when it is less than 7.6 meters. For rack storage over 7.6 meters, the size of the design area and the required density are established and very few adjustments are made; whereas they are not for rack storage less than 7.6 meters. However, additional difficulty comes in with the requirements for in-rack sprinklers.



Automated Rack Storage being constructed

When Control Mode Density/Area sprinklers have been selected for installations involving rack storage over 7.6 meters, in-rack sprinklers are required. While the hydraulic calculations are not overly difficult, the figures describing the in-rack locations within NFPA 13 will require the designer to dedicate some time to review the charts for a complete understanding of proper in-rack sprinkler locations.

Chapters 16 and 17 also allow for the use of Control Mode Specific Application (CMSA) and Early Suppression Fast Response (ESFR) sprinklers in specific situations. Using these types of sprinklers can provide several benefits, including elimination of in-rack sprinklers and in some cases a less costly design. The primary limitation to CMSA and ESFR sprinklers is the limit in storage and ceiling

height. If the rack storage and building ceiling height exceed 12.1 meter storage and 13.7 meter high ceilings as defined in Chapters 16 and 17 of NFPA 13, they cannot be considered for use. The designer is then limited to the selection of CMDA sprinklers with in-rack sprinklers. The rules for installation will be found in several different locations of the document, including chapters 8, 12, 16, 17 and 22.

NFPA 13 chapter 12 allows the following CMDA sprinklers to be used in storage applications. Standard response K80 sprinklers are allowed where the required density is 8.2 mm/min or less. Standard response K115 sprinklers are allowed where the required density is 13.9 mm/min or less. Where the required density exceeds 13.9 mm/min, standard response K160 sprinklers that are listed for storage must be used. Quick response sprinklers can be used if they have been listed for storage applications.

The lowest density for this application is described in Table 16.3.1.1 is 10.2 mm/min limiting the sprinkler selection to standard response K 115 sprinklers, no special listing required, or K160 and larger that have received a listing for storage. The majority of the required densities are in the range where K160 or larger would be the most hydraulically efficient. Chapter 8, Table 8.6.2.2.1 limits the spacing of standard pendent and upright sprinklers to 9.3 meter² where the required density is greater than or equal to 10.2 mm/min. Given that most of the required densities for this type of storage application are 12.2 mm/min or greater, the K160 becomes a likely selection for the ceiling sprinklers.

$$9.3 \times 12.2 = 113 \text{ L/min}$$

$$(113 \text{ L/min} / 160)^2 = .49 \text{ Bar end head pressure}$$



Example of In Rack Sprinkler

Section 8.13 provides the basic installation rules, including the maximum protection area for any single system of sprinklers in racks which is 3716 m². The in-rack sprinklers can be either standard or quick response and the allowed K factors are 80, 115 and 160.

This section of chapter 8 also clarifies that the installation rules for in-rack sprinklers do not follow the installation rules of ceiling sprinklers. For example, in-rack sprinklers are allowed to be placed less than 1.8 meters on center and do not have to meet the clearance and obstruction criteria of section 8.5. Chapters 12 through 20 will define the positioning of these sprinklers.

Another commonly overlooked section is 8.16.1.6, which requires separate control valves and drains for the sprinklers installed in racks. The only exception to this requirement is for systems with 20 or fewer in-rack sprinklers. The intent of this requirement is to allow for the isolation of the in-rack sprinklers from the ceiling sprinklers. Because in-rack sprinklers are susceptible to damage due to their location, it is essential to allow for the ceiling system to remain in service while repairs are being made.⁹

When CMDA sprinklers are used with in-rack sprinklers the ceiling sprinklers are intended to protect the upper level of storage, whereas the in-racks are intended to control the growth and spread of fire within the rack structure at the lower levels.¹⁰ Chapter 22, section 22.8 requires the pipe supplying the in-racks to be hydraulically calculated and the water demand for the in-racks to be added to the ceiling sprinkler water demand over the same protected area at the point of connection. The demand shall be balanced to the higher pressure.

Balancing can be done with the formula listed below:

$$Q_{adj} = (QI) (\sqrt{P_h/P_l})$$

Where:

Q_{adj} = the adjusted flow into the lower pressure line

QI = the calculated flow in the lower pressure line

P_h = the higher of the two pressures

P_l = the lower of the two pressures

Example: At the point of connection the sprinkler system demands 3724.8 LPM at 4.3 bar. The in-rack sprinklers have been calcu-

lated to require 1218.9 LPM at 3.9 bar. To balance the pressure and determine the adjusted required flow:

$$Q_{adj} = (1218.9) (\sqrt{4.3/3.9})$$

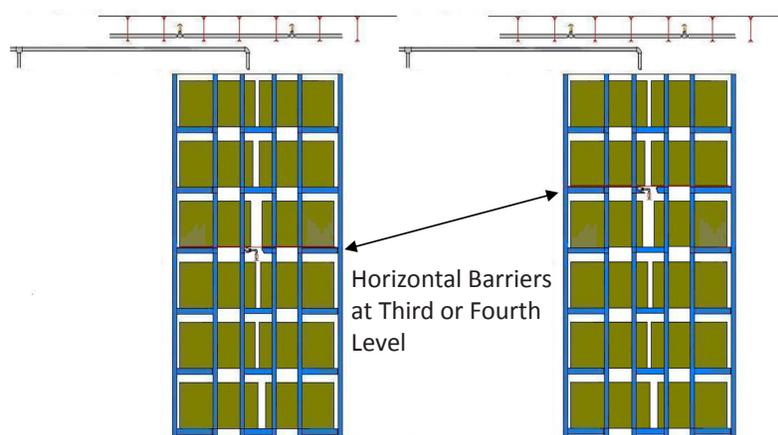
$$Q_{adj} = 1278.3 \text{ LPM}$$

1278.3 LPM will be added to 3724.8 at the point of connect for a total water demand of 5003.1 LPM

Concepts for the Future

Special service conditions for sprinklers used in racks will define new technology in the future. Unique applications such as automated storage will likely require special sprinklers. Automated storage systems utilize computer-controlled equipment to move and stack commodity, typically on racks with narrow aisle widths, or on racks that move horizontally, which are referred to as movable racks. These buildings can be designed for storage heights over 30.4 meters. The racks are typically connected to the walls and roof to provide support for the structure.¹¹ NFPA 13 will require a substantial amount of in-rack sprinklers to be installed in applications such as this. Manufacturers will surely seek alternative methods of protection in the future.

In order to develop new products that can benefit the end-user and provide the necessary fire protection for this challenging environment, manufacturers will look to expand upon the known math and science that is well-established within the sprinkler industry. Rack storage schemes using horizontal barriers have a history of success and have been well-documented within NFPA 13. This type of concept separates the rack storage into more manageable areas where fire control or suppression is more easily achieved. Viking worked with European furniture manufacturers in 2005 to conduct testing of rack storage using vertical barriers as an alternative to existing fire protection schemes defined within NFPA 13. While the tests were successful Viking sought improvement using the barrier concept. Seeking improved results lead to the concept of using horizontal barriers within the racks with improved in-rack sprinklers. The horizontal barriers would be placed at different elevations above the picking level of the forklift operators. This configuration will eliminate the flue space to the ceiling helping to prevent the fire from spreading vertically which will assist in containing the fire growth. It also reduced the volume of commodity being protected and exposed to activated sprinklers as shown below.



The European furniture manufacturer test used K 160 extended coverage sprinklers as the in-rack sprinklers. The flatter spray pattern helped to negate the obstructions presented by the rack structure and helped to reduce the overall amount of in-rack sprinkler required. The tests were conducted with the sprinkler flows at 227.1 LPM and 302.8 LPM. The sprinklers were positioned with the deflectors 31.7 mm inches below a simulated rack beam, and the framed arms were positioned both parallel and perpendicular to the simulated rack frame.

The test resulted in water spread within the simulated rack structure. The discharge spray was able to discharge in the rack structure and apply water to the face of the rack. Some dry spots were visible at 227.1 LPM discharge. Relatively no dry spots were visible at

302.8 LPM discharge. The results were relatively equal with the frame arms parallel or perpendicular to the simulated rack frame.

The results of this testing will likely lead to an extended coverage in-rack sprinkler designed to provide downward thrust in the flue space and spread water to the face. The use of extended coverage sprinkler technology will continue to expand in use within the storage market. This type of technology used in storage can expand upon the same concepts and rules established in the 1980s for ceiling protection, such as the square coverage areas for pendent and upright sprinklers. As described in the NFPA 13 2010 handbook, using the square coverage area will promote interchangeability and allow positioning on the branch lines without regard to the sprinkler frame arms. Those familiar with sprinkler design will see the natural benefit to such a concept.

Developing a concept for sprinkler system installations in warehouses will likely require different approaches and the use of new or existing technology to achieve improved performance. It is highly likely that these new protection schemes will use horizontal or vertical barriers for compartmentation. Ideas that are being evaluated include the use of interstitial space sprinkler technology for in-rack sprinklers. These sprinklers are designed to be installed in small combustible concealed spaces where there is limited space for water distribution to develop. The flat deflector technology combined with larger K factors and fast response thermal elements may address the installation issues encountered with in-rack sprinklers.

Another concept is to combine fast response thermal elements, K factors of 160 or larger, varying temperature ratings with the deflector technology used for suppression and specific application technology for in-rack sprinklers. This type of technology may result in improved fire control or suppression with a limited amount of sprinklers. Used in conjunction with horizontal barriers, this may result in lower overall water requirements and localize the number of sprinklers operating to a very small area of commodity. Other sprinkler technology being considered includes the use of directional type sprinklers, such as sidewalls and flat spray nozzles within rack storage. Each one of the existing technologies has the potential to be modified based on the six characteristics we discussed earlier in order to be applied in a new application.



Interstitial Space Sprinkler



Spray Nozzle with Heat Responsive Element



Control Mode Specific Application Sprinkler

Based upon the full-scale fire testing for rack storage covered earlier, the benefit of larger volumes of water with fire control and suppression are obvious and documented by numerous research agencies. This, combined with fire modeling, paints a clearer picture of how dry sprinkler systems operate in fire conditions. While the concept of fire modeling may sound new to some, using models to predict sprinkler performance on dry systems can be traced back to the early 1970s as discussed in an article The Number of Sprinklers Opening and Fire Growth by R. Baldwin and M.A. North, published in NFPA periodical Fire Technology. The models referenced in this paper predicted the number of sprinklers that would operate on a dry system as it relates to fire growth. The science used in these early models will continue to be used in research for dry systems in storage applications.

All current design criteria described within NFPA 13, actual full scale fire testing to date, current fire modeling as indicated in the report released by the NFPA Fire Protection Research Foundation in 2007, titled Review of NFPA 13 Dry System Water Delivery Provisions and fire modeling as described above indicates that more sprinklers will operate on dry sprinkler systems than wet sprinkler system during a fire due to the inherent water delay. With this knowledge and understanding of the science the use of concepts that address the large number of open sprinklers and larger volume of water needed for control and suppression will certainly be used in high warehouse storage applications in the future.

Conclusion

As the construction of warehouses with rack storage of commodities over 12.1 meters continues to grow, the fire protection industry must develop a variety of new sprinkler system solutions. We are fortunate that much of the way has been paved for us by the efforts of many professionals who have done the research. The math and the science will be consistent. What is old will be new again as manufacturers seek to apply fundamental principles discussed earlier to develop new products.

Selecting the most appropriate sprinkler to be used in storage applications can be a challenging activity. Designers should not allow themselves to become distracted by the terminology and language of the installation standards. The designer should be confident that the science and math are universal and that many of the principles described above remain the same for all types of sprinklers.

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