Warehouse Protection of Exposed Expanded Group-A Plastics with Electronic Sprinkler Technology

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Abstract

The focus of the current work was to demonstrate that electric fire sprinklers operated by an “intelligent” electronic detection and control system could achieve adequate ceiling-only protection of exposed expanded group-A plastic commodities stored on racks without the need for additional engineering controls such as in-rack sprinklers or vertical barriers, and with significantly lower total water demand than current ceiling-only alternatives. A prototype system was assembled and a series of full scale fire tests were conducted. The results support a number of the potential benefits of electronic sprinkler technology as compared to existing mechanically operated fire sprinkler technology.

Keywords: Warehouse, Electronic Sprinkler, Exposed Plastics

Introduction

Since its invention in the late 1800’s, the basic operating principles of automatic sprinkler technology have remained fundamentally unchanged. Automatic sprinklers utilize thermally responsive elements which mechanically operate once they achieve a specific fixed temperature. Arguably, the widespread adoption of the automatic sprinkler can be attributed to its simplicity since it requires no power beyond pressurized water and the presence of heat from a fire to operate. However, continued progress and modern construction practices have pushed automatic sprinkler technology to the limits of its practical use in many applications.

One specific application that exhibits the challenge to existing sprinkler technology is the modern warehouse. Growing demand for the storage of exposed plastic materials and the advent of modern lift technology allowing for higher storage heights have presented increasingly challenging fire hazards. Exposed expanded group-A plastics (EEP) present a particular challenge in that they produce fires that grow and spread much faster than similar products stored in cardboard containers, and similarly do not readily absorb water making fires difficult to contain. While recent advancements in the application of ESFR sprinkler technology have presented viable options for the protection of EEP materials, such systems require significant water demand and additional engineering controls such as vertical barriers between rack sections to slow lateral fire spread. These measures are necessary to mitigate the effects of uncertainty in sequence and location of sprinkler activation observed in full scale testing [1, 2]. Vertical barriers can be both expensive and intrusive to warehouse operations and the large water demand requirements can add significant infrastructure and installation cost to the sprinkler system.

The focus of the current work was to demonstrate that electric fire sprinklers operated by an “intelligent” electronic detection and control system could achieve adequate ceiling-only protection of exposed expanded group-A plastic commodities stored on racks without the need for additional engineering controls such as in-rack sprinklers or vertical barriers, and with significantly lower total water demand than current ceiling-only alternatives. The basic theory was that effective fire suppression performance could be achieved by simultaneously operating an array of sprinklers surrounding the point of fire origin during the early stages of fire development – thus maximizing the amount of water applied onto burning materials and pre-wetting adjacent unburned fuels to prevent lateral fire spread. An electronically operable sprinkler system was constructed using components that are readily available and commonly used in the fire protection industry and a series of full scale fire tests were conducted at the Underwriters Laboratories large burn lab facility in Northbrook, IL

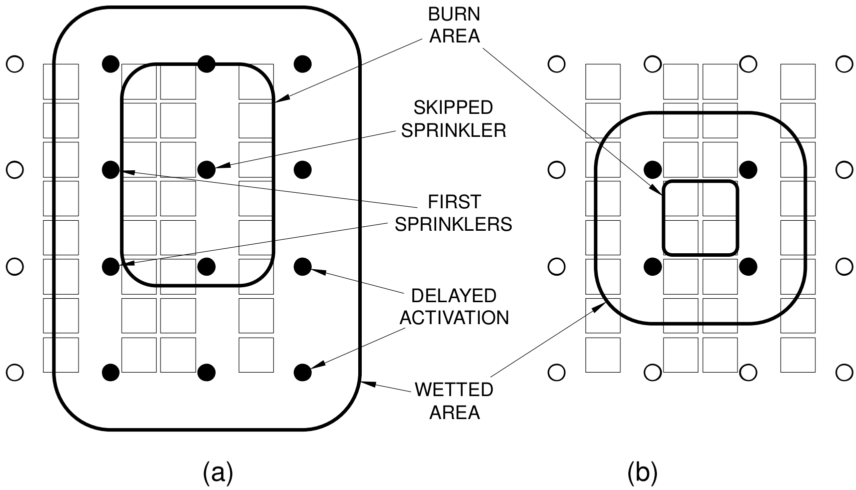


Fig. 1. (a) Typical sprinkler operation (b) Hypothetical future state.

Electronic Sprinkler System

The sprinkler used in the testing consisted of an existing commercially available ESFR sprinkler with a k-factor of 241.9 LPM/bar$^{1/2}$ (16.8 GPM/psi$^{1/2}$) that was modified to operate electrically. The detection and control system utilized standard addressable heat sensors that were hard-wired to a commercially available fire alarm control panel (FACP). There was a single heat sensor for each sprinkler. The FACP was programmed to operate up to 9 sprinklers simultaneously through basic control logic. Sprinklers were selected for operation using a sensitive rate-of-temperature-rise detection algorithm, and activated once specific triggering criteria were achieved. Fig. 2 shows a diagram of the electronic sprinkler system as tested.

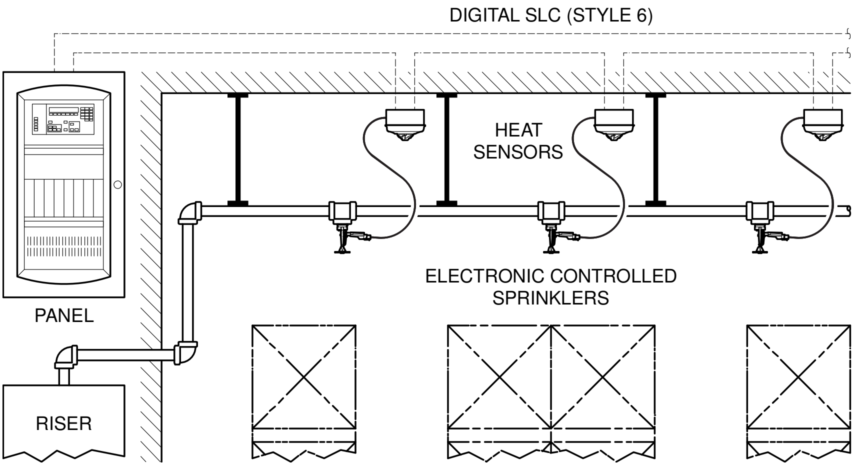


Fig. 2. Electronic sprinkler system overview as tested.

Fire Performance Evaluation

A series of four fire tests were conducted in UL LLC's large-scale fire test facility located in Northbrook, IL to evaluate the level of fire protection that could be achieved using the Electronic Sprinkler to protect a double-row rack storage arrangement of Exposed, Expanded Group A Plastic commodity. The test setup consisted of standard EEP commodity – polystyrene meat trays shrink wrapped on oak pallets – stored on double-row racks under a 10.7 meter (35 ft) and 12.2 meter (40 ft) smooth flat ceiling. Storage ranged from 4.6 meters (15 ft) to 9.1 meters (30 ft). Ignition location varied.

Sprinklers were installed 35.6 cm (14 in) from the ceiling and at a 3 meter (10 ft) spacing. Detectors were installed 30.5 cm (12 in) below the ceiling surface and 30.5 cm (12 in) laterally from each sprinkler.

Results

A summary of the test parameters and results is shown in Table 1.

Table 1a. Summary of test parameters and results SI units.

Test #	**Test 1**	**Test 2**	**Test 3**	**Test 4**
Test date	**9/25/2015**	**5/27/2016**	**6/2/2016**	**6/7/2016**
TEST PARAMETERS				
Storage Type	Double row rack			
Commodity Type	Exposed expanded Group A plastics			
Nominal Ceiling Height (m)	12.2	10.67	10.67	10.67
Nominal Storage Height (m)	9.14	9.14	9.17	4.57
Vertical Barrier	None			
Ignition Location	Under 1	Between 2	Between 4	Between 2
Aisle width (m)	1.22	2.44	2.44	2.44
Sprinkler spacing (m x m)	3.05 x 3.05	3.05 x 3.05	3.05 x 3.05	3.05 x 3.05
Sprinkler type	Electronic suppression	Electronic suppression	Electronic suppression	Electronic suppression
Sprinkler k-factor (LPM/bar$^{1/2}$)	241.9	241.9	241.9	241.9
Operating pressure (bar)	3.59	3.59	3.59	3.59
Sensor type	Heat detector	Heat detector	Heat detector	Heat detector
Sensor vertical distance from ceiling surface (cm)	7.62	30.48	30.48	30.48
Sensor horizontal distance from sprinkler location (cm)	30.48	30.48	30.48	30.48
TEST RESULTS				
Length of test (min)	31	31	31	31
First sprinkler activation (min:s)	0:43	0:44	0:45	0:43
Last sprinkler activation (min:s)	0:43	0:44	0:45	0:43
Number of sprinklers operated	9	9	9	9
Peak ceiling gas temperature above ignition (°C)	60	125	160	88
Maximum 1 min. avg. gas temp. above ignition (°C)	49	69	79	35
Peak steel temp. at ceiling above ignition (°C)	46	62	71	29
Max 1 min. avg. steel temp. above ignition (°C)	39	57	63	28
Fire spread across aisle?	YES*	NO	NO	NO
Sustained combustion at outer edges of target array?	YES*	NO	NO	NO
Fire spread to outer edges of main array	NO	NO	NO	NO

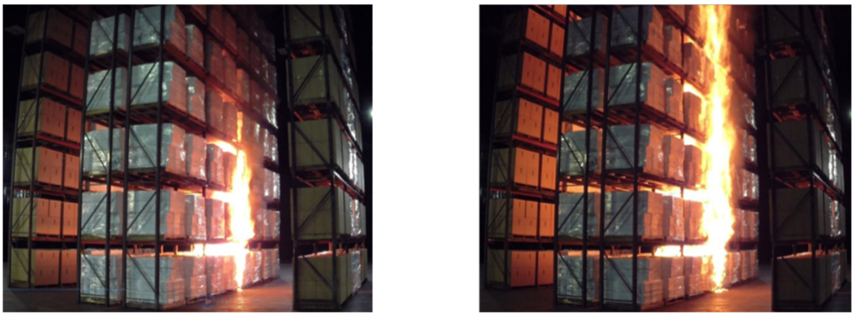
*Burn through of a single pallet at very bottom of target array ignited by falling debris from main array.

Table 1b. Summary of test parameters and results US customary units

Test #	Test 1	Test 2	Test 3	Test 4
Test date	**9/25/2015**	**5/27/2016**	**6/2/2016**	**6/7/2016**
TEST PARAMETERS				
Storage Type	Double row rack			
Commodity Type	Exposed expanded Group A plastics			
Nominal Ceiling Height (ft)	40	35	35	35
Nominal Storage Height (ft)	30	30	30	15
Vertical Barrier	None			
Ignition Location	Under 1	Between 2	Between 4	Between 2
Aisle width (ft)	4	8	8	8
Sprinkler spacing (ft x ft)	10 x 10	10 x 10	10 x 10	10 x 10
Sprinkler type	Electronic suppression	Electronic suppression	Electronic suppression	Electronic suppression
Sprinkler k-factor (gpm/psi$^{0.5}$)	16.8	16.8	16.8	16.8
Operating pressure (psi)	52	52	52	52
Sensor type	Heat detector	Heat detector	Heat detector	Heat detector
Sensor vertical distance from ceiling surface (in)	3	12	12	12
Sensor horizontal distance from sprinkler location (in)	12	12	12	12
TEST RESULTS				
Length of test (min)	31	31	31	31
First sprinkler activation (min:s)	0:43	0:44	0:45	0:43
Last sprinkler activation (min:s)	0:43	0:44	0:45	0:43
Number of sprinklers operated	9	9	9	9
Peak ceiling gas temperature above ignition (°F)	140	257	320	190
Maximum 1 min. avg. gas temp. above ignition (°F)	120	156	174	95
Peak steel temp. at ceiling above ignition (°F)	115	144	160	84
Max 1 min. avg. steel temp. above ignition (°F)	102	135	145	82
Fire spread across aisle?	YES*	NO	NO	NO
Sustained combustion at outer edges of target array?	YES*	NO	NO	NO
Fire spread to outer edges of main array	NO	NO	NO	NO

*Burn through of a single pallet at very bottom of target array ignited by falling debris from main array.

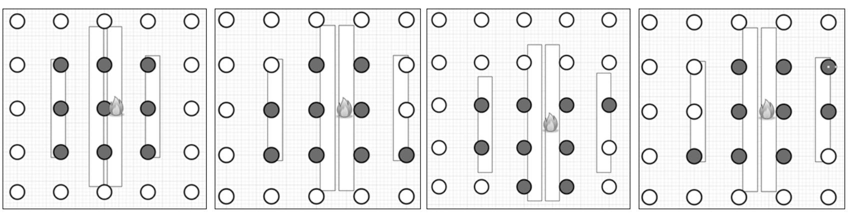
In all tests, 9 sprinklers operated simultaneously at or before the estimated time that the first 101 °C (214 °F) ESFR sprinkler activation would typically have been observed based on time and temperature comparisons against existing test data [3]. An example of the observed fire size at electronic sprinkler system activation as compared to the estimated fire size at first ordinary temperature ESFR sprinkler activation for test 2 is shown in Fig. 3



(a) (b)

Fig. 3. (a) Fire size at electronic sprinkler activation (b) Estimated fire size at typical 101°C (214°F) ESFR sprinkler activation.

In all tests, regardless of ignition location, sprinkler operating arrays were contiguous and roughly centered around the point of fire ignition and significant fire suppression was achieved within approximately 90 second from initial sprinkler operation.



(a) (b) (c) (d)

Fig. 4. (a)Test 1 activation pattern (b) Test 2 activation pattern (c) Test 3 activation pattern(d) Test 4 activation pattern.

In all tests the damage was limited to within 2 pallet loads laterally in either direction from ignition, well within the envelope of sprinkler operation with a significant wetted margin. In addition, the relative amount of damage was observed to be significantly less than that of similar tests conducted with ESFR sprinklers.

Minor aisle jump was observed in Test 1 only, and was principally caused by burning commodity falling into the narrow 1.2 m (4 ft) wide aisle and igniting a single pallet load on the target array opposite ignition. During the course of the test this single pallet load was partially consumed. Due in part to this observation, Tests 2 - 4 were conducted using a wider 2.4 m (8 ft) aisle.

Discussion

Based on the results of this study, the application of electronic sprinkler technology presents a number of potential benefits when compared to existing mechanically operated automatic fire sprinklers.

First, the sprinkler k-factor, pressure and spacing tested was selected to be comparable to existing prescriptive ceiling only ESFR sprinkler system designs for warehouses of a similar height, but lower commodity classification. The results of the test program demonstrated that existing systems designed based on similar parameters could be extended to protect EEP commodity without the need to upsize the system piping or water supply equipment. This could potentially minimize the costs associated with upgrading dated warehouse fire protection systems by maximizing the use of existing system infrastructure.

Second, through the simultaneous operation of an array of sprinklers surrounding the point of fire origin early in its development, the system was observed to provide a significant degree of fire suppression, preventing fire spread and limiting damage to the region proximal to the point of ignition. This observation coupled with the elimination of uncertainty associated with unintended thermo-mechanical sprinkler operation suggests the potential to substantially reduce the number of open sprinklers considered during the system design process – further reducing hydraulic demand and increasing system design flexibility. For example, ESFR sprinkler systems designed in accordance with NFPA 13 typically require at least 12 operating sprinklers be considered during the hydraulic design process [2]. This study suggests that number could be reduced to 9 or fewer for the electronic system tested.

Finally, the electronically controlled sprinkler system investigated in this study was configured such that the location of the heat sensors and the sprinkler were physically separated. In practice this could allow the detection system to be located and configured as to maximize detection performance, for instance proximal to the ceiling surface, and the sprinklers to be placed where they will provide the most effective fire suppression, for instance below obstructions to water discharge and/or proximal to the top of the protected commodity – providing a potential improvement in both system performance and installation flexibility.

Conclusion

The results of this investigation demonstrate that electric fire sprinklers operated by an “intelligent” electronic detection and control system can achieve adequate ceiling-only protection of exposed expanded group-A plastic commodities stored on racks without the need for additional engineering controls such as in-rack sprinklers or vertical barriers, and with lower total water demand than current ceiling-only alternatives. Critical to the observed performance improvements for EEP are the simultaneous activation of up to 9 fire sprinklers surrounding the point of fire ignition early in its development.

Acknowledgements

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References

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