From Fire Test Lab to NFPA 13 - An Overview of the ESFR Obstruction Testing Program and Resulting Application to NFPA 13

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Abstract

Early Suppression Fast Response (ESFR) sprinklers are the preferred sprinkler technology for warehouse fire protection. Obstructions created by ceiling structural members, lighting, piping, or cable trays, can hinder ESFR sprinkler performance. ESFR sprinkler obstruction sensitivity however, is mostly unknown. The requirements found in the current edition of National Fire Protection Association Standard 13, Installation of Sprinklers (NFPA 13), are considered conservative and have created hardship in application.

Acknowledging the importance of this issue, NFPA's research affiliate, the Fire Protection Research Foundation, embarked on a multi-year testing program. The fourth and final phase of the project was completed in the fall of 2019 with the inclusion of K14 ESFR Actual Delivered Density (ADD) and full- scale testing. To date, approximately 60 ADD tests and nine full-scale tests have been completed using a combination of K14 and K17 ESFR sprinklers. The goal of the project was to obtain relevant data to substantiate and update (if necessary) the ESFR obstruction requirements found in NFPA 13.

This paper presents an overall summary of the ESFR sprinkler obstruction project including the results of the recently completed K14 ESFR testing. In addition, the application of the results of the testing project to the requirements found within NFPA 13 will be reviewed.

Storage occupancies have undergone significant changes since the introduction of the spray sprinkler in 1956. The increased use of plastic packing material, in conjunction with the increased demand for plastic products, creates extreme challenges for storage sprinklers. The lighter product weight allows much higher storage. In addition, the heat release rate of plastic materials is much higher than that of wood or paper products [1].

The characteristics of modern storage fires include very fast fire growth rates and high fire plume velocities [2].

In the 1970's, FM Global scientists embarked on a dedicated storage research program to address this problem. The program explored sprinkler performance characteristics, including response time (Response Time Index) and the relationship between the actual amount of water delivered to the fire source (Actual Delivered Density) compared to the required amount of water delivered (Required Delivered Density). These concepts were instrumental in the invention of the ESFR sprinkler in the 1980's [3].

ESFR sprinkler obstruction requirements remain unchanged since the early development of the sprinkler. The requirements outlined in the current edition of NFPA 13 provide prescriptive language for the placement of ESFR sprinklers in regards to obstructions in the near field. These requirements are surmised to be based on proprietary testing completed by FM Global. Overall, published ESFR obstruction fire test data is sparse.

The 2016 edition of NFPA 13 requires pendent ESFR sprinklers to be located a minimum of 12 inches horizontally from the nearest edge of any bottom chord or bar joist where the bottom chord does not exceed 1 ft in width. A bridging member of 2 inches or less in width is required to be located a minimum of 24 inches below the elevation of the sprinkler deflector or positioned a minimum of 12 inches horizontally from the sprinkler deflector. The ESFR design standards also require a minimum clearance of 36 inches from the top of storage to the sprinkler deflector [4].

The third generation ADD (Actual Delivered Density) apparatus was used to perform preliminary testing. The ADD apparatus consists of a fire source in the form of 12 heptane burners used to simulate a rack storage fire of cartoned unexpanded Group A plastic commodity stored up to 30 feet in height. This configuration correlates to a heat release rate of 2.5 MW. There are 48 square collection pans with dimensions of 0.5m by 0.5m used to collect water into cylinders below the apparatus. A pressure tap located in each cylinder allows the calculation of the amount of water in each container over time which may be used to calculate the water flux in each region in gpm/ft2. An air duct located in the center of the apparatus provides an airflow of 530 cfm to simulate a fire plume. Flue spaces are provided at a spacing of 6 inches in between each pan configuration. Water is sprayed at the underside of the pans to prevent warping caused by the radiative heat caused by the flames.

The results of the ADD testing were used to identify trends in the degree of reduction of sprinkler discharge as a function of obstruction vertical and horizontal position, and sprinkler K factor. These trends were then compared to full-scale fire test results to establish acceptable sprinkler obstruction placement parameters.

Two fundamental trends were discovered from the results of the ADD testing:

1. The reduction in ADD due to an obstruction located directly below the sprinkler increases as the vertical distance from the obstruction to the sprinkler decreases.
2. The reduction in ADD due to an obstruction offset horizontally from the sprinkler increases as the vertical distance from the obstruction increases.

These relationships can be explained by the characteristics of the ESFR sprinkler discharge pattern. The center core of the ESFR sprinkler delivers the largest amount water flux. For example, the largest average unobstructed ADD for both K14 and K17 ESFR sprinklers, 1.34 and 1.64 gpm/ft² respectively, was delivered to the Central 4 pans of the ADD apparatus. This large central core water distribution is designed to address a fire located directly below one sprinkler, with a high storage to ceiling clearance. When the ESFR sprinkler discharge travels downward the pattern expands horizontally, drawing obstructions located horizontally from the sprinkler towards the center core region. Obstructions located directly below the sprinkler experience the inverse. As these obstructions move vertically away from the sprinkler the obstructed area of the center core region decreases.

Review of the K14 sprinkler ADD data shows similar trends to that of the K17 sprinkler. The ADD data collected for the bar joist scenarios shows the greatest similarities as shown in Figure 1.

Full-scale Test No. 1 tested the scenario of a 36 inch deep bar joist located 6 inches horizontally from the K17 sprinkler. The 36 inch bar joist, when offset horizontally from the sprinkler, is considered the most rigorous bar joist depth within the boundary conditions established (22 -36 inch deep bar joist) because the bottom chord is the greatest distance below the sprinkler. The test was successful, operating only one sprinkler. Given the similarities of the K14 and K17 ADD data, it is postulated that the obstruction created by a bar joist between the depth of 22- 36 inches, located 6 inches horizontally from the sprinkler will not reduce sprinkler ADD to terminal levels.

In conclusion, the ESFR Obstruction project has made significant progress in the understanding of the effect obstructions have on ESFR sprinkler performance. Both K14 and K17 ESFR sprinkler behavior has been studied. This data was used to refine the obstruction requirements of NFPA 13.

Fig. 1. K14-K17 ADD Comparison.

The presentation will showcase the results of the most recent work, including full-scale fire testing of K14 sprinklers. The approved changes to NFPA 13 will be reviewed as well.

Keywords: Early Suppression Fast Response Sprinklers, Actual Delivered Density, Obstruction.

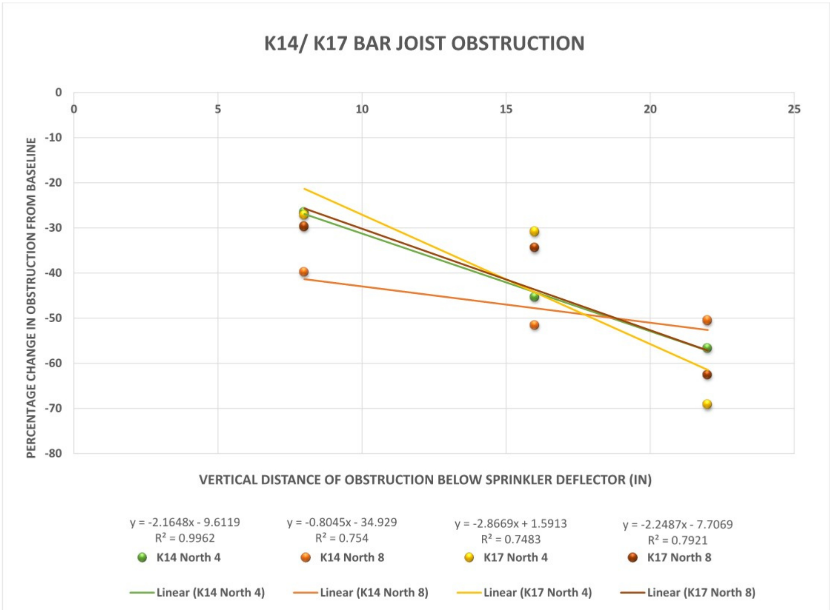
References

[1] The heat of combustion of thermoplastic polymers range between 15.5 to 46.5 kJ/g with a medium of 41.6 kJ/g, while natural polymers (cellulose) have a significantly lower heat of combustion of 16.1 kJ/g. (Drysdale, Dougal. “An Introduction to Fire Dynamics”, 2011, Table 1.2).

[2] Kung, H.C., FM Global. “Experimental Study of Actual Delivered Density for Rack Storage Fires”, Fire Safety Science- Proceedings of the Fourth International Symposium on Safety Science and Technology, 1994.

[3] Kung, H. C., Victaulic. Fire Protection Engineering, Edition Q1, 2011.

[4] National Fire Protection Association, “Standard for Installation of Sprinkler Systems, 2016 Edition”, Section 14.2.3.1.


K14/ K17 BAR JOIST OBSTRUCTION
PERCENTAGE CHANGE IN OBSTRUCTION FROM BASELINE
VERTICAL DISTANCE OF OBSTRUCTION BELOW SPRINKLER DEFLECTOR (IN)
0
5
10
15
20
25
-10
-20
-30
-40
-50
-60
-70
-80
y = -2.1648x - 9.6119
R² = 0.9962
y = -0.8045x - 34.929
R² = 0.754
y = -2.8669x + 1.5913
R² = 0.7483
y = -2.2487x - 7.7069
R² = 0.7921
K14 North 4
K14 North 8
K17 North 4
K17 North 8
Linear (K14 North 4)
Linear (K14 North 8)
Linear (K17 North 4)
Linear (K17 North 8)