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Development and Experimental Evaluation of a Sprinkler Resistant to Skipping

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EXTENDED ABSRACT

Introduction

The phenomenon identified as sprinkler skipping occurs when a sprinkler operates substantially before a nearby sprinkler that is closer to the fire plume. The recent publication, "An Investigation of the Causative Mechanism of Sprinkler Skipping," by Croce, Hill and Xin in 2005 [1] indicated that sprinkler skipping can be primarily attributed to drop impingement from nearby operating sprinklers. This occurrence can reduce the effectiveness of the sprinkler system due to sprinkler operations that are not discharging water onto the burning combustibles, allowing for increased fire, smoke, and water damage.

This project proposes that proper shielding of a sprinkler's heat sensing element can reduce the likelihood of wetting from nearby operating sprinklers, thereby reducing sprinkler skipping and increasing overall sprinkler system performance.

Sprinkler selection and shield design

The primary criteria for sprinkler selection were: 1) well characterized performance, 2) incidences of sprinkler skipping in previous large-scale fire tests, and 3) beneficial construction geometry for easy shield design. An adequate sprinkler shield should have at least the following attributes: 1) no significant delay on sprinkler response to the fire, 2) no interference with sprinkler actuation process, 3) negligible impact on sprinkler discharge pattern, and 4) good interception capability of impinging water drops.

A model was developed for the response time of a sprinkler outfitted with a shield to reduce the potential for drop impingement on the sprinkler link. The model was useful in establishing several guidelines for the selection of the sprinkler and design of the shield. Based on the abovementioned guidelines, the selected sprinkler was pendent-style, having a nominal 18 mm diameter orifice, 70 ^{o}C temperature rating, and K-Factor[a] of 200 L/min/bar$^{1/2}$. The actuation mechanism was a fusible link rated at a nominal RTI of 28 $m^{1/2}s^{1/2}$. Three candidate shields, each of similar design with slightly different geometry, were fabricated to encompass the range of design values recommended in the model.

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[a] The K-Factor is a parameter indicating sprinkler nozzle discharge capacity. It is defined as $K=Q/p^{1/2}$, where Q is the water discharge rate (l/min) and p is the sprinkler nozzle discharge pressure (bar).

Validation of the shield's effect on the operating characteristics

To measure the effect of the three candidate shield designs on the sprinkler's thermal sensitivity, the Plunge Tunnel apparatus was used to measure the Response Time Index (RTI)[b] values for the selected sprinkler with and without the shields installed. Of these three candidate designs, the shield resulting in the smallest increase in RTI of the sprinkler and the greatest potential to mitigate drop impingement on the sprinkler link was selected for inclusion in this project. For this shield, the RTI remained nominally within the range specified for an Early Suppression Fast Response (ESFR) [2] sprinkler of 19 to 36 $m^{½}s^{½}$. When water drops were introduced into the gas flow to simulate the conditions that cause skipping, the shielded sprinkler operated, while the unshielded sprinkler did not.

The effect of the shield on the water distribution of the selected sprinkler was then qualitatively assessed by visually inspecting the flow of water out of the sprinkler both with and without the shield installed. No obvious change in the water distribution was observed either near the sprinkler deflector or several meters down from the deflector.

Intermediate-scale experimental evaluation

An intermediate-scale evaluation was conducted under the movable ceiling in the Calorimetry Lab to evaluate a sprinkler shield's propensity to mitigate skipping. Using Froude modeling principles [3,4,5] the test design was based on a 1:3 ratio of real world installation practices for the selected sprinkler. One hundred tests were conducted to determine the combination of fire intensity and sprinkler operating pressure under which the shielded sprinkler operated while skipping of an unshielded sprinkler occurred. To identify these conditions, a discharging sprinkler was centered above the fire at the ceiling. Skipping was then assessed by the operation times of four orthogonal pairs of adjacent shielded and unshielded sprinklers. These tests were successful in identifying several test arrangements where the shielded sprinkler operated and the unshielded did not operate. The results also indicated that, above a certain fire intensity, skipping will not occur because both shielded and unshielded sprinklers will operate. These tests were valuable for relating the fire size to the propensity for skipping in a given test configuration.

Large-scale fire test validation

A series of pan fire tests were conducted as a proof-of-concept that proper shielding of a sprinkler can reduce skipping in a large-scale arrangement. The sprinkler spacing, ceiling clearance, and discharge pressures were chosen to be consistent with a previous project where significant skipping was observed. In addition, these configuration parameters satisfy modeling principles used in the intermediate-scale testing. Pan fires were chosen as a simple way to evaluate the sprinkler operation pattern because they are relatively unaffected by the sprinkler discharge and have a fast fire growth rate. The effect of the shield at reducing sprinkler skipping was assessed by comparing the number of sprinkler

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[b] Response Time Index (RTI) is a quantitative measure of sprinkler link sensitivity. Under identical operating conditions, sprinklers with low RTI values are expected to actuate faster that those with high RTI values.

operations from tests with and without sprinkler shields installed. For the chosen test arrangement, shielding of the sprinklers resulted in a 30 to 50% reduction of the number of operations.

Conclusions

Experimental analysis in an intermediate- and large-scale arrangement have shown that proper shielding of a sprinkler's heat sensing link can reduce sprinkler skipping. Several design tools have been established to aid in the development of the shield, including a model for the response time of a shielded sprinkler and a complementary modification to the Plunge Tunnel apparatus to quantify the response time in a drop-laden gas flow. Froude modeling principles were utilized to develop an intermediate-scale test protocol that accomplished a 1:3 ratio of real-world installation practices for the chosen sprinkler. Testing in this environment allowed relatively easy evaluation of the influence on sprinkler skipping propensity of many test configuration parameters, including: fire size, ceiling clearance, and discharge pressure. Scaling principles were then applied to two intermediate-scale configurations where substantial skipping of an unshielded sprinkler occurred. The resulting large-scale pan fire evaluation served as a proof-of-concept that proper shielding of a sprinkler can reduce skipping. In these tests, the shielded sprinkler reduced the number of operations by 30 to 50%. In addition, an upper bound to the fire intensity that can cause skipping in the first sprinkler ring was observed.

References

[1] Croce, P.A., Hill, J.P. and Xin, Y., "An Investigation of the Causative Mechanism of Sprinkler Skipping," J. of Fire Protection Engineering, Vol. 15, No. 2, 2005, pp. 107-136.

[2] NFPA 13, Standard for the Installation of Sprinkler Systems,1996 Edition

[3] G. Heskestad, *J. Fire & Flammability*, 6 (1975) 254-273

[4] H-Z Yu, "Froude-Modeling-Based General Scaling Relationships for Water-Spray-Fire-Plume Interactions," Proceedings of the 7th Asia-Oceania Symposium on Fire Science and Technology, September, 2007.

[5] Yu, H-Z, Zhou, X., and Ditch, B., "Experimental Validation of Froude-Modeling-Based Physical Scaling of Water Cooling of Enclosure Fires," 9th International Symposium on Fire Safety Science, September 21-26, 2008, Karlsruhe, Germany.