Impact of Sprinkler K-Factor and Operating Pressure on Sprinkler Spray Discharge Characteristics and Spray Patterns

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Abstract

The impact of sprinkler operating pressure on spray characteristics was examined for three different k-factor sprinklers, each operating over three pressures. The presented results and analysis represent a subset of a larger study to determine how the pressure effects spray pattern, initial drop velocities, droplet size and distribution. The difference between the flow distribution on the initialization sphere, observed to converge when normalized by the sprinkler flow, and the azimuthally average flow distribution measured from the line patternation, normalized by total flow rate, can be attributed to effect of drop momentum, specifically drop size and initial velocity. Initial spray distribution simulations demonstrate that overall spray patterns are similar amongst pressures for several sprinklers evaluated while additional analysis is required to determine the contribution of individual drop sizes to the sprinkler wetting performance.

Keywords: Sprinklers, Suppression, Sprays

Introduction

Sprinklers have been used in fire protection systems for over 100 years and a number of studies have examined the general effectiveness of water as a means of suppression as well as the specifics of droplet formation and impact of deflector geometry on droplet formation and sprinkler spray patterns [1,2]. Many of these studies have primarily focused on the characterization of a spray with regards to drop size distribution and drop velocity but have not directly examined the effects that pressure or k-factor may have on the spray field or on the delivered density [1-4].

This paper examines the impact that a change in pressure has on three different k-factor sprinklers, each operating over three pressures. The representative k factors are: 8, 16.8 and 25.2 gpm/ft^2, hereafter referred to as sprinkler: A (k-8), B (k-16.8), and C (k-25.2). The objective of the study is to determine how the pressure effects the spray pattern, overall velocities, and droplet distribution.

Methodology

The Spatially-resolved Spray Scanning System (4S) has been presented in detail elsewhere, however a brief summary of the measurement approach is provided to contextualize the analysis [1,2]. Utilizing the measurement methodology of the 4S, a sprinkler spray can be characterized at a specific pressure to measure volume flux, drop size and velocity distributions over the surface of an initialization sphere surrounding the candidate sprinkler. The resulting spray characterization, generated from terabytes of raw data, contains sufficient information to reconstruct a complete, statistically valid, virtual representation of the sprinkler spray for spray dispersion simulations using any currently available CFD or spray dispersion software. The initial 4S measurement device, developed at the University of Maryland, provided the fundamental foundation for advanced spray measurements. However, due to physical size and performance restrictions, the device was limited in the range of sprinkler k-factors and pressures the facility could test. As a result, a second generation 4S was designed and built with the intent of characterizing the full range of sprinklers presently on the market, including those with expanded pressure and flow requirements. The present iteration of the 4S was designed to handle operating pressures over 100 psi or flow rates up to 250 GPM. Both iterations of the 4S measurement system are divided into four subsystems supported by well-established testing procedures and automation, instrumentation, and data acquisition processes.

- **Rotation and Flow Control:** The unique patented design of the 4S allows for all measurement equipment to remain at a fixed azimuth relative to the initial sprinkler installation. After test flow and pressure conditions are established at the nozzle orifice, the sprinkler is rotated at a specified angular velocity, ω_{rot}, through at least one complete 360° rotation to collect the required characterization measurements.

- **Mechanical Patternation:** Mechanical patternation techniques are used to measure the volume flux of water passing through the surface of an initiation sphere with a radius r_{init} such that $0.8\,m \geq r_{init} \geq 0.2\,m$ based on the spray under evaluation. An array of 11 water collection funnels, representative of a gore section of the initialization sphere, were used to characterize the spatial variation in flow rate through the measurement surface between the elevation angles of 80° and 180° with the 0° elevation angle datum defined as the northern pole of the initialization sphere.

- **Integral Line Patternation:** Line patternation are applied to characterize the throw of the sprinkler spray and measure an azimuthally averaged spray distribution to a plane nominally 1 m below the sprinkler orifice by evaluating the amount of water captured over a single sprinkler rotation.
- **Optical Spray Characterization:** Detailed optical patternation data is collected on the same arc path as mechanical patternation, between elevation angles of 80° and 180°, with optical data from each 10° arc captured during one full rotation of the sprinkler. A shadowgraphy imaging technique is used to capture drop size measurements while a particle tracking velocimetry approach is applied to determine particle trajectory. Azimuthally resolved drop size and velocity distribution data is calculated from each elevation dataset. During a characteristic spin, approximately 5,000-18,000 photos are captured for analysis resulting in a final spray characterization data set of approximately 1.25 terabytes.

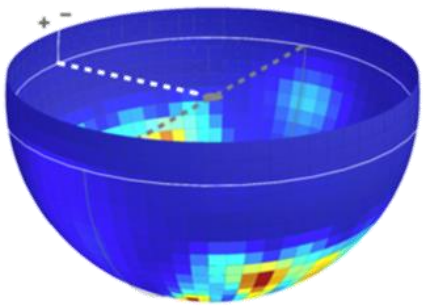
Results

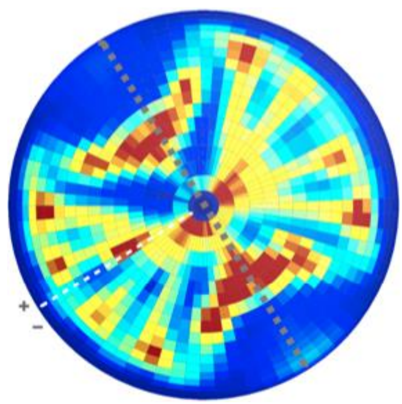
Three fire sprinklers were characterized in the 4S with each sprinkler characterized at three different operating pressures, Table 1, yielding nominally 10.5 terabytes of information. The raw data is processed using the 4S analytical framework to generate spray characterizations for each test scenarios which can be used to visually display the spray details at each elevation and azimuthal angle across the surface of the initialization sphere. Sprinkler spray details characterized through the 4S measurement approach include volume flux, volume median diameter, drop size distribution parameter gamma, and volume weighted velocity as a function of elevation and azimuthal angle.

Table 1. Sprinkler k-factor and test pressures.

	Sprinkler A	Sprinkler B	Sprinkler C
k-Factor	115 $LPM/bar^{0.5}$ (8 $GPM/psi^{0.5}$)	242 $LPM/bar^{0.5}$ (16.8 $GPM/psi^{0.5}$)	363 $LPM/bar^{0.5}$ (25.2 $GPM/psi^{0.5}$)
Test Pressure	0.7, 3.5, 6.9 bar (10, 50,100 psi)	1.7, 2.4, 3.5 bar (25, 35, 50 psi)	1.7, 2.4, 3.1 bar (25, 35, 45 psi)

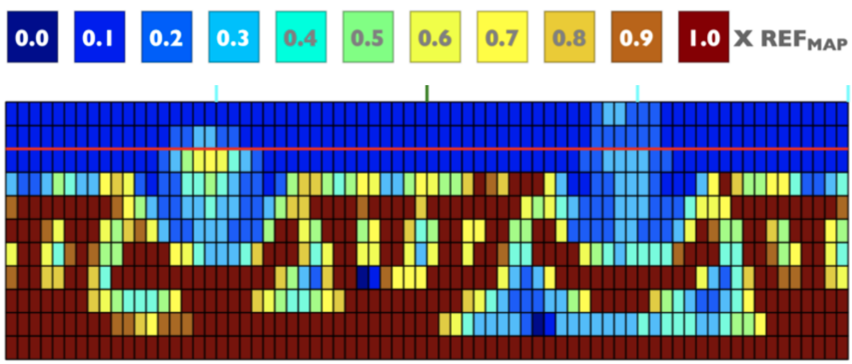
The volume flux, $\dot{V}''$, measured over the surface of the initialization sphere in millimeters of water per minute for Sprinkler A operating at 6.9 bar (100 psi) is shown in Fig. 1(a) from an isometric perspective and in Fig. 1(b) from the bottom of the initialization sphere through the centerline of the sprinkler orifice. From the representation of the data in the polar coordinate system, the effect of the sprinkler deflector geometry on the resulting spray pattern is readily observed. Within the spherical representation of the volume flux measurements, the 0° azimuthal position is indicated by a white dotted line while the dotted grey lines denote the sprinkler frame arm locations. The solid white band around the diameter of the sphere designates the 90° elevation angle. Fig. 1(c) presents the same information in a 2-D cartesian coordinate layout such that the sphere is “flattened" for alternative examination of the data. The presented data in this analysis represents a small subset of the full data set available; similar data is collected and analyzed for droplet diameter, distribution parameter, and velocity. All data representations within Fig. 1 are normalized based on a defined spray mapping reference volume flux, REF_{MAP}, equivalent to 1000 mm/min for this example.





(a.) Isometric representation across initialization sphere surface.

(b.) Initialization sphere observed from below centerline of sprinkler orifice.



(c.) 2-Dimensional cartesian-mapped representation of the measured volume flux across the initialization sphere surface.

Fig. 1. Volume flux distribution measured for Sprinkler A across initialization sphere surface at 6.9 bar (100 psi).

Analysis

The presented analysis consists of a subset of a larger experimental study focused on examining the interdependence of sprinkler orifice size, or k-factor, and operating pressure on the measured spray characteristics that determine sprinkler wetting performance. This analysis, based on the testing conducted for a range of sprinkler k-factors, demonstrates the non-negligible effects of pressure and k-factor on the volume flux distribution for the measured sprinklers. Additionally, observations from the measured drop size data show that as the pressure increases, the volume median droplet size, d_{V50}, is reduced.

To evaluate the effect of sprinkler operating pressure on the flow split between the slot and tine geometries of a given sprinkler, the spatially resolved volume flux values were used to calculate the flow rate over the surface of the initialization sphere, normalized by the measured sprinkler flow rate. The relative variations in flow distribution are presented and evaluated based on sprinkler operating pressure. While volume flux increases with pressure, the normalized flux, Fig. 2 and Fig. 3, show that the overall pattern in both azimuthal and elevation angles are similar. Though, it is clear from the data collected that, at the frame arms, increases in pressure can amplify the observed frame arm effect as demonstrated for Sprinkler A but not for Sprinkler C.

The overall consistency of the volume flux distribution when evaluated over the elevation and azimuthal planes is notable as it indicates that, for the sprinklers characterized in this analysis, the flow split variation is nominal throughout the range of measured pressures. In contrast, when observing the measurements collected from the 4S line patternation measurement, the volume fraction of sprinkler flow delivered to the measurement plane as function of radial measurement location presents a different perspective, Fig. 4. The difference between the flow distribution on the initialization sphere, observed to converge when normalized by the sprinkler flow, and the azimuthally average flow distribution measured from the line patternation, normalized by total flow rate, can be attributed to effect of drop momentum, specifically drop size and initial velocity.

In evaluating the resulting spray distributions calculated for a cold flow, first order approximation, the resultant spray patterns remain generally consistent; with increasing pressure the predicted pattern indicates more spread resultant from higher exit velocities as demonstrated in Fig. 5. This is partially offset by the higher fluxes at each azimuthal angle however the ultimate effect on the suppression performance of the sprinkler still requires examination. Variation in drop size and initial velocity due to pressure variations is a component of the larger ongoing experimental study and requires further investigation to determine the impact smaller droplets may have on the ability of a spray to penetrate the smoke plume and reach the intended protection surface.

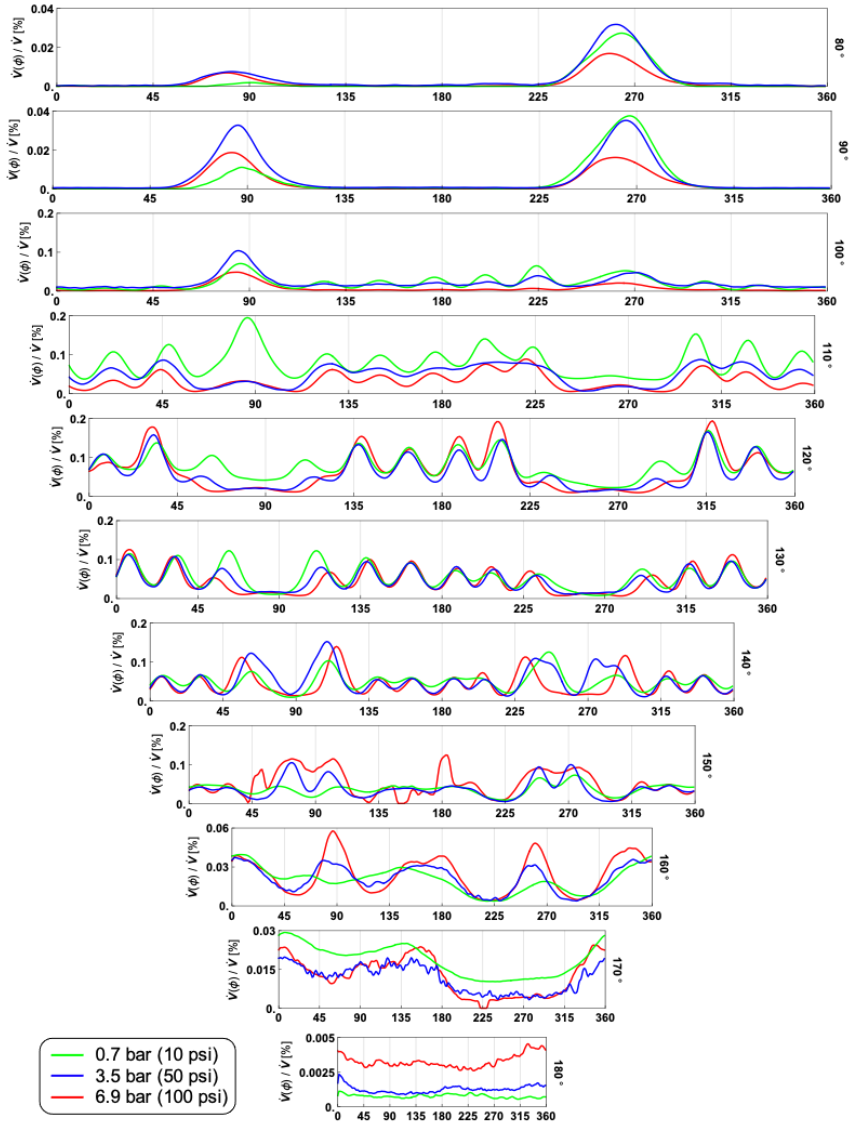


Fig. 2. Volume flow as a function of location and injection pressure for Sprinkler A.

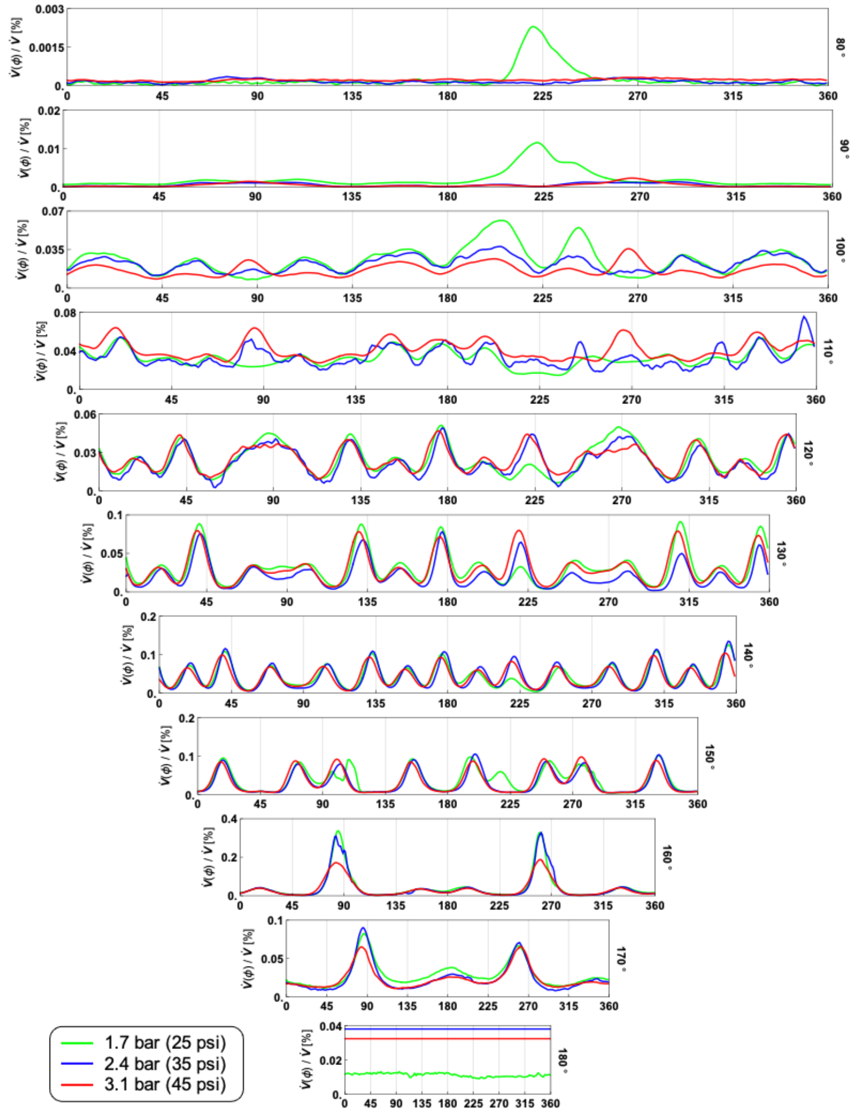


Fig. 3. Volume flow as a function of location and injection pressure for Sprinkler C.

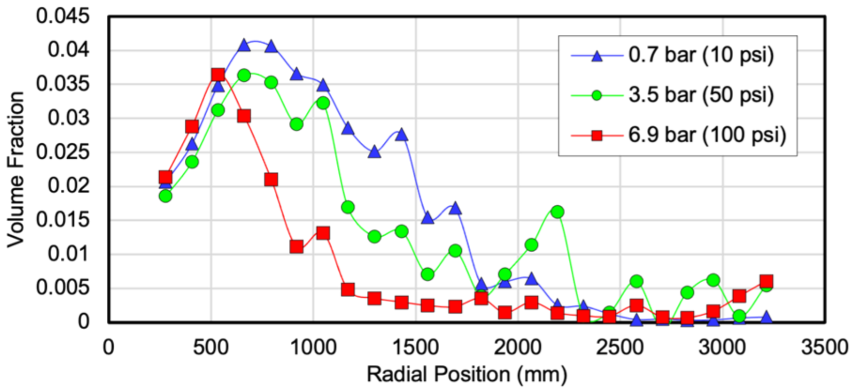
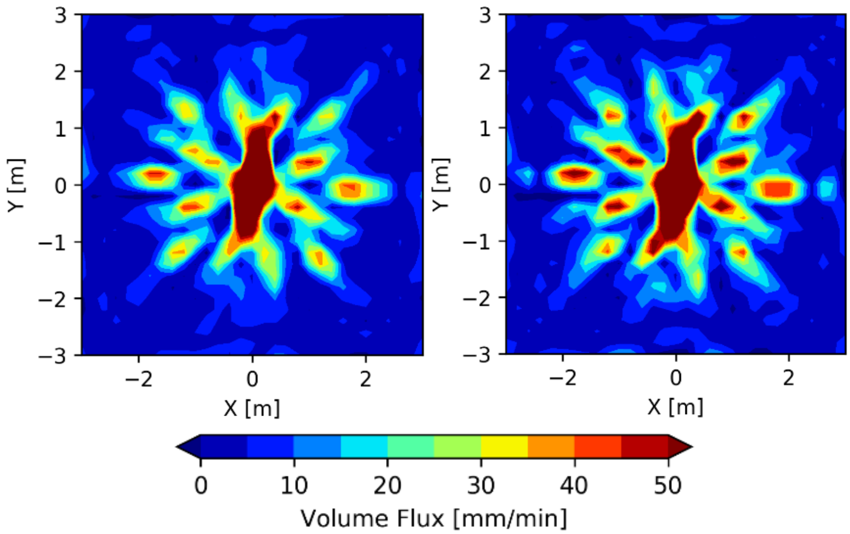


Fig. 4. Radial volume fraction as a function of injection pressure measured for Sprinkler A.



(a.) Sprinkler C; 2.4 bar (35 psi) (b.) Sprinkler C; 3.1 bar (45 psi)

Fig. 5. Volume flux distribution predictions from two operating pressures.

References

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