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Technical Article

Spray Nozzles Selection for Water Spray Systems

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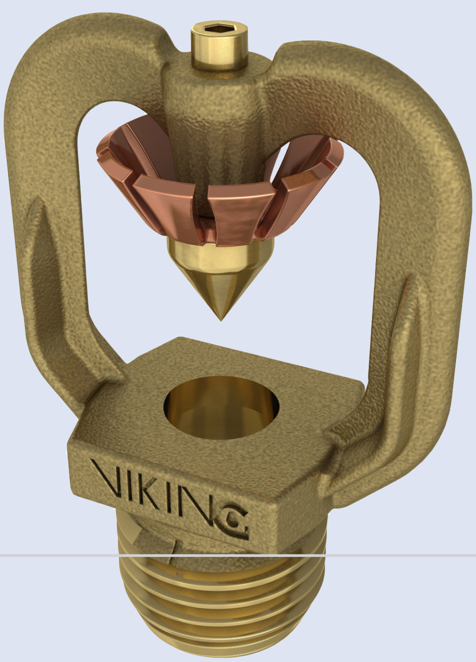

Water spray systems as defined in NFPA 15 can provide some of the most complex and challenging system designs encountered by fire protection professionals. The selection of the proper spray nozzle that achieves the coverage area and water density required for the hazard being protected is one of the most important steps necessary to ensure the successful operation of the system. Of course, there are many other steps of equal importance and complexity that are taken during the design and layout process for water spray systems, but it is the selection of the proper spray nozzles that can present one of the largest challenges and may ultimately determine whether or not the water spray system will perform as required. Because of the wide variations in the characteristics of water spray nozzles including discharge patterns, velocities, distances of projection and the variables of the hazards being protected, a careful evaluation of the nozzle selection should be completed by a professional with an in-depth knowledge of special hazards applications and water spray system design.

The complexity of nozzle selection can be increased in some cases where a limited amount of technical information is available describing the specific features or proper application for the spray nozzle being considered. In other cases, confusion may result from the terminology used in a manufacturer's technical data, such as high, medium and low velocity nozzles and the term velocity's relationship to the application. Given the substantial number of hazards where spray nozzles can be applied, and the various listings and approvals granted by Underwriters Laboratory, Factory Mutual and LPCB, the design engineer and layout technician are presented with a demanding selection process. This paper will attempt to clarify spray nozzle selection criteria for several of the most complex water spray applications and the terminology used to identify the unique characteristic of the spray nozzles.

Water Spray and Nozzles

The applications where spray nozzles are utilized can be severe. Primarily spray nozzles are used for exposure protection of bulk storage flammable and combustible liquid tanks to cool the shell, prevent explosion or collapse of the tank and extension of the fire. In addition, when designed properly and correctly installed water spray systems can be successfully utilized for extinguishment and control of some flammable liquids fires, some combustible liquid fires, Class A combustibles, and electrical transformer applications. Extinguishment of a fire using water spray is achieved "by cooling, smothering, emulsifying or diluting of flammable liquids or by a combination of these factors."[1] "Controlling of a fire can be achieved with the same mechanisms that achieve extinguishment, however due to different characteristics of the fuel, suppression is not possible."[2]

Picture: Electrical Transformer Fire

FM Global defines the mechanisms of fire extinguishment in the following manner:

Cooling action results to some extent from absorption of heat by water particles but mostly from the conversion of water to steam. When converted into steam, 1lb of water at 60^{o}F absorbs 1150 Btu. When the surface of the burning material is cooled to a point where flammable vapors are no longer evolved, the fire is extinguished.

Smothering action is obtained when the water spray is converted to steam by the heat of the fire, expanding its volume approximately 1,750 times. As the steam envelops the fire area, oxygen is excluded which helps to extinguish the fire.

Emulsification is obtained by mechanical agitation of water with oil or other non-water soluble liquids so that droplets of both materials become closely interspersed. Such an emulsion is produced by the action of water spray striking the surface of certain flammable liquids, rendering the liquid surface nonflammable. With liquids of low viscosity, emulsification is probably temporary, existing only during the application of the spray. With materials of higher viscosity, the emulsion will last longer and provide some protection against re-flashing.

Dilution of water-soluble liquids is usually a minor factor in extinguishing a fire because of the high degree of dilution required.[3]

Spray Nozzle Selection and Operation

The selection of spray nozzles involves consideration of several factors, primarily their ability to distribute water in a manner which allows the proper mechanism of extinguishment or control for the hazard to be achieved. Spray nozzles are available in a wide range of capacities and angles. The design elements used within the spray nozzle to manipulate the movement of water through the spray nozzle will impact the discharge velocity of the water droplets and the discharge pattern's reach or range.

The velocity of the water droplets discharged from spray nozzles is not a factor for consideration of water spray system design within NFPA 15 or 13. However, terms referencing velocity are used extensively within manufacturer's technical data and within the testing and installation standards of the Loss Prevention Certification Board (LPCB) which are used in many parts of the world. The exact meaning of this terminology and how it applies to the spray nozzle application can be confusing and at times misleading, but it can be helpful to put a definition to the terms low, medium and high velocity if for no other reason than to help the designer and layout technician gain a better understanding of the nozzle application. The only written definitions for spray nozzles that can be found within the fire protection industry commonly referenced text are within the LPCB Standard 1277.

LPCB Standard 1277 defines medium velocity spray nozzles as "sprayers with deflection plates producing conical discharge patterns having bores not less that ¼ inch (6.3 mm) and meeting the test requirements of this standard apart from the fire test. These sprayers may be opened or sealed; the seal is identical to that of a sprinkler" and "sprayers with swirl chambers producing conical discharge patterns and having internal waterways not less than 1/8 inch (3.1 mm) and final exit bores not less than ¼ inch (6.3 mm) and meeting the requirements of this standard at a pressure of 20 psi (1.4 bar) apart from the fire test". High velocity spray nozzles are defined as "sprayers with swirl chambers producing conical discharge patterns and having internal waterways not less than 1/8 inch (3.1 mm) and final exit bores not less than ¼ inch (6.3 mm) and meeting the requirements of this standard apart from those for cone angles and distribution."[4]

From these definitions several of the key differences between medium and high velocity spray nozzles can be identified; for instance, the incorporation of a deflector on some medium velocity nozzles and high velocity nozzles will have to meet different cone angle and distribution requirements. Also the term "swirl chamber" is introduced for some medium velocity and all high velocity nozzles. A "swirl chamber" is used within a nozzle to spin the water so it emerges as a solid cone jet.

Historically, the term velocity and distribution of the size of water droplets has been understood to describe the reach or area of coverage of the nozzle's water spray pattern.[5] However, it is the velocity and dispersion of the water droplets themselves which will determine a spray nozzle's ability to achieve the mechanisms of extinguishment or control of a fire.

Fixed nozzles have certain velocity or pressure ranges of effectiveness. Below the lower limit of the force range, the discharge pattern is ineffective; above the upper limit, velocities may be reached that will result in decreased effectiveness due to reduction in the discharge pattern, delivery distance and/or the water droplets.[6] At the point where a droplet of water is discharged from a nozzle, it is carried forward by its momentum, downward by the force of gravity, and is retarded by friction in the air. The forward velocity of water droplets becomes very important in the reach of the nozzle.[7] Spray nozzles are designed to have various spray angles. The volume of water being discharged and the spray angle of the nozzle will determine the actual velocity of the water droplets and the range of the spray.

The size and velocity of the water particles will have an impact on the ability to extinguish or control a fire. If the droplets are too small, they cannot penetrate to the seat of the fire but are carried upward by the fire plume. If they are too large, their surface-to-mass ratio is small and they cannot effectively cool the fire gases.[8] When being used to suppress flammable liquid fires with high flash points above 200°F, the water droplets must be traveling at a velocity sufficient to penetrate the surface of the flammable liquid.

Defining the ranges of water droplet velocities is difficult given the lack of published information available for spray nozzles. There are many factors which impact the actual velocity of water droplets including the water droplet size, orientation or angle of placement of the nozzle and the operating pressure. The large range of spray nozzles available on the market makes it almost impossible to clearly define the three velocity categories. However, for the purpose of understanding the potential application of each type of nozzle, in addition to the information provided above, one potential method of defining the velocity terms is as follows.

Low velocity spray nozzles are similar in discharge characteristics to standard spray sprinklers. The water droplet size is within the same range. A review of two studies from the U.S. Department of Commerce, National Institute of Standard and Technology (NIST) called "Determination of Water Spray Drop Size and Speed from a Standard Orifice, Pendent Spray Sprinkler"[9] and "Understanding Sprinkler Sprays: Trajectory Analysis"[10] place the measured water droplet velocities for K 5.5 spray sprinklers between 2 ft/sec and 27 ft/sec flowing 15 gpm at 7 psi. It would be expected that a spray nozzle with similar characteristics may have water droplet velocities in the same range.

High and medium velocity spray nozzles cover a much broader range of application. Due to a wide range of K factors and operating pressures the water droplet size can range from the larger droplets found in the discharge of a standard sprinkler to the much smaller water droplets that would be similar to the sizes found in water mist systems. At least one manufacturer publishes water droplet velocity information for a medium velocity nozzle. When the water pressure range is between 20 psi (1.4 bar) and 50 psi (3.5 bar) the water droplet velocity is 49 ft/sec (15 m/sec) to 82 ft/sec (25 m/sec). High and medium velocity spray nozzles are used primarily within this pressure range so it can be anticipated that the water droplet velocity may be similar to this published information for many spray nozzles.

Water, Spray Nozzles and Flammable or Combustible Liquids

NFPA 30, the Flammable and Combustible Liquids Code, provides the definitions for flammable and combustible liquids. Flammable liquids are defined as any liquid that has a closed-cup flash point at or below 100°F. Combustible liquids are defined as any liquid that has a closed-cup flash point at or above 100°F.[11] Water can effectively utilize several of the control and extinguishment mechanisms on a flammable or combustible liquids fire.

Extinguishing a flammable liquid fire is possible if the flammable liquid is miscible with water, and large quantities of water can dilute the liquid to the point where it is no longer flammable and cool the liquid below its flash point; however extreme care must be taken when using this approach to ensure the container which is holding the combustible liquid does not overflow and inadvertently spread the fire. One technique that can be used to prevent this situation is to select a nozzle which discharges a fine spray with droplets less than .4mm. The fine spray will dilute and cool the surface layer of the flammable liquid limiting the amount of water introduced to the container and reducing the possibility of an overflow. Fires involving flammable liquids that are not completely miscible with water such as ether and ketones can be controlled utilizing water spray.[12] Low to medium velocity solid cone nozzles are well suited for this type of application (figure 1).

Figure 1

Fires involving combustible liquids with flash points above 200°F that are not miscible with water such a lubricating oil, can be suppressed using high velocity solid cone nozzles (figure 2). When the water is discharged with a velocity that is sufficient to penetrate the surface of the combustible liquid, suppression is achieved by cooling the surface below the liquid's flash point.

Figure 2

Extinguishing or controlling a flammable of combustible liquids fire with water is complex. It involves many considerations beyond the spray nozzle selection. The successful application of water to a flammable liquids spill will probably cause the burning flammable liquid to spread, unless a dike is present. Another problem is encountered if the liquid has a high flash point and is less dense than the water. In this case, water droplets, even if applied gently, will sink below the surface and turn into steam, causing eruption of the flammable liquid into the flames and increasing the burn rate.[13] In addition, when combustible liquids burn in depth for long periods of time the liquid can take on the characteristics of a flammable liquid. Careful consideration should be given to the application, the volume of water that will be introduced and the potential impact on the situation.

Water and Electrical Equipment

Water spray systems are often used to provide fire protection and complete water impingement for oil-filled electrical transformers (figure 3). Transformers are available in many different sizes and configurations and a complete understanding of all the relevant transformer information is necessary to ensure the proper nozzle selection. However, high velocity spray nozzles can be extremely effective in extinguishing the high flash point non-miscible combustible liquids fire that results from the catastrophic failure and explosion of the electrical transformer. Additional considerations in the selection of the proper nozzle outdoor transformers include the effect of wind, the nozzle capacity and placement of the nozzle. Electrical clearances may require the selection of a nozzle capable of a large water discharge to achieve the proper range and coverage of the water spray.

Figure 3

The water spray system is also designed to provide cooling for the structural and metal elements while the combustible liquids are being extinguished. NFPA 15 outlines the specific requirements for placement of the spray nozzles to avoid the live un-insulated electrical equipment and it is critical that the water spray system be designed in a manner to remove power before water is applied.

Exposure Protection of Bulk Storage Flammable and Combustible Liquid Tanks

Water spray systems designed for exposure protection as defined in NFPA 15 provide "absorption of heat through application of water spray to structures or equipment exposed to a fire, to limit surface temperature to a level that will minimize damage and prevent failure". The nozzle selection for this application will be based on the nozzle discharge capacity, spray angles and patterns such as the shaped spray pattern nozzle in figure 4. The objective of the water spray is to keep the tank cool. This prevents the liquid from boiling away. If the liquids within the tank boil away, the heat will not be transferred away from the shell. This could cause the shell to rupture in the case of direct flame impingement.

Figure 4

It is important that the nozzle discharges overlap to prevent dry spots on the surface of the tank and that overspray of the storage container be limited to achieve the most efficient hydraulic design. Consideration must also be given to the effects of wind and possible updrafts from a fire in close proximity to the tank and evaporation of smaller water droplets from heat. Typically the nozzles are placed to discharge the water spray at the top of the equipment to allow the water to run down the surface. The actual amount of water run down is difficult to predict because of the effects of wind and the shape of the tank (figure 5).

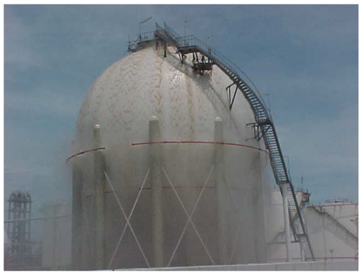

Figure 5

Conclusion

The selection of spray nozzles can be a complex and challenging process. The variables that affect the selection can be numerous. It is important for the fire protection professional to keep the goal or purpose of the water spray system in mind during the selection process. The characteristics of the spray nozzle will determine its effectiveness in extinguishing a fire, controlling a fire or cooling a surface. For example, when extinguishment or control of a flammable or combustible liquids fire is the purpose of the water spray system then a nozzle should be selected that can accomplish the appropriate mechanism of extinguishment for the flammable or combustible liquid being protected. When the purpose of the water spray system is to cool a bulk storage fuel tank the nozzle selected should have the discharge capacity and spray angle required to the appropriate water density over the surface area of the tank.

Although the terminology can seem confusing, it can actually assist the design engineer and layout technician in quickly identifying the most appropriate group of nozzles for an application. NFPA 15 and 13 are the basis for these designs, however as you can see because of the complex nature of the hazards involved a considerable amount of additional research may be necessary to develop an effective fire protection design. In these cases it is always prudent to consult the spray nozzle manufacturer for specific technical information of the performance expectation of the spray nozzle being considered.

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