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A Technical Analysis:

Variables That Affect The Performance Of Dry Pipe Systems

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INTRODUCTION

Previously, there have not been any readily available methods for predicting the time required to deliver water to the test connection of a dry sprinkler system. The Fire Protection Engineering Handbook[1] publishes a method to calculate the trip time of a dry pipe valve, but this is only a relatively minor part of the water delivery time. Until now, a designer could never know whether his system met the 60 second water delivery criterion for dry systems with a capacity greater than 750 gallons (2839 liters) until it was installed and actually tested. If it didn't meet the criterion, it was far too late to find that out! Only when you have stood at the inspectors test valve, opened it while staring at a stopwatch, and wondered what to do when the water took 68 seconds to reach the test outlet can you appreciate the frustration of the engineers/designers task. Now, Tyco Fire & Building Products has introduced an innovative tool that permits a user to accurately simulate the acceptance trip test of dry pipe systems prior to the actual installation.

Those familiar with dry pipe system designs know there are four basic factors that affect the design, installation and performance of dry pipe systems. These four principles are:

1. Air and Water Supply Pressures:

a. System Air pressure – The air pressure within dry system piping that keeps the dry valve closed and prevents water entering the system. This is dictated by the static water supply pressure and the dry pipe valve design.

b. Static water pressure – The water supply pressure at the base of the riser with no flow into the sprinkler system. This pressure dictates the system air pressure required to keep the dry pipe valve closed.

c. Residual water pressure and flow – The water supply pressure at a given water flow rate. Each water supply follows a unique curve in which the pressure drops as the flow rate increases. This significantly impacts the time required after the dry valve trips for a steady discharge of water from the test connection to be established.

2. System Capacity and Piping Configuration:

a. Capacity – Total volume of all piping on the system side of the dry pipe valve. Affects the amount of air that must be discharged from the system before steady water discharge is established at the test connection.

b. Piping Configuration

i. Tree – Consists of dead-end branch lines, cross-mains, and feed main. Only the feed main, cross-main, and the one branch line with the test connection must have air displaced by water in order for water to reach the test connection. Air in the remainder of the system can be compressed into dead-end piping. This piping configuration produces the fastest water delivery times.

ii. Loop – Has dead-end branch lines but cross-mains are looped. Increases the amount of air that must be displaced by water in order for water to reach the test connection.

iii. Grid – Currently not allowed in dry systems because the air in all branch lines and cross-mains must be displaced by water in order for water to reach the test connection, resulting in very long water delivery times.

3. Size of Test Sprinkler

a. The orifice size of the test sprinkler controls the rate at which air is discharged from the system piping. The rate of discharge and volume of air being discharged control the water delivery time after the dry pipe valve has been actuated.

4. Dry Pipe Valves

a. Dry pipe valves have traditionally been designed as differential- pressure valves. The clapper, which holds water out of the dry system, is designed with the surface area of the airside greater than the surface area of the water side. In this way, a lower air pressure can hold back a higher water pressure, thus reducing the volume of air in the dry system that must be discharged in order for water to reach the test connection.

b. Other designs of dry pipe valves include "low pressure latch type" that depend on actuators and a quick opening device to work together for the valve to function properly.

This paper will concentrate on the traditional ratio valve but will discuss the latch type from time to time.

SYSTEM OPERATION AND PERFORMANCE

To fully understand dry pipe system performance, we must look at the sequence of events that occur and the impact each has.

When dry pipe sprinkler systems are 'trip tested' for acceptance, the following events occur after the inspectors test valve is opened.

1. Air pressure begins to drop in the system as a result of the open inspectors test valve. The loss of air pressure in the system causes the dry pipe valve to trip at its designed air/water ratio, or when an optional accelerator trips the valve on loss of air pressure.

2. When the valve trips, water begins to fill the system by compressing trapped air and forcing air from the inspector's test connection.

3. Water reaches the test connection and a steady water discharge is established.

With this basic understanding, let's review these steps in a little more detail to understand the effects of variables.

1. Valve Trip Time:

In order for the valve to trip without an accelerator, the air pressure must drop to the point that water pressure forces the valve to open. The time required is determined by the rate at which air can be discharged from the system and the amount of air that must be discharged in order for the trip pressure to be reached. This is controlled by two factors:

a. Air pressure: A higher air pressure in the system will cause a faster discharge of air at the test connection, but a larger volume of air must be discharged for the valve to reach its trip point. Conversely, lowering the initial air pressure will slow the air discharge from the system, but a smaller volume of air must discharge before the valve trips. (See Figures 1 and 2) Note that in Figure 1, the time required for a 1500-gallon (5678-liter) system to drop 5-psi (0,3 bar) from 35-psi (2,4 bar) to 30-psi (2,0 bar) is 30 seconds. The same system shown in Figure 2 shows a significant increase in time to drop the same 5-psi (0,3 bar) when the pressure drop is from 15-psi (1,0 bar) to 10-psi (0,7 bar). The time required for this system is 53 seconds. This is 23 seconds longer than the same psi drop at higher initial air pressure.

b. Test orifice size: A larger orifice at the test connection will allow air to discharge more rapidly from the system. (See Figure 3) This figure clearly shows that for a given dry pipe system volume, the test orifice size can significantly change the air discharge rate.

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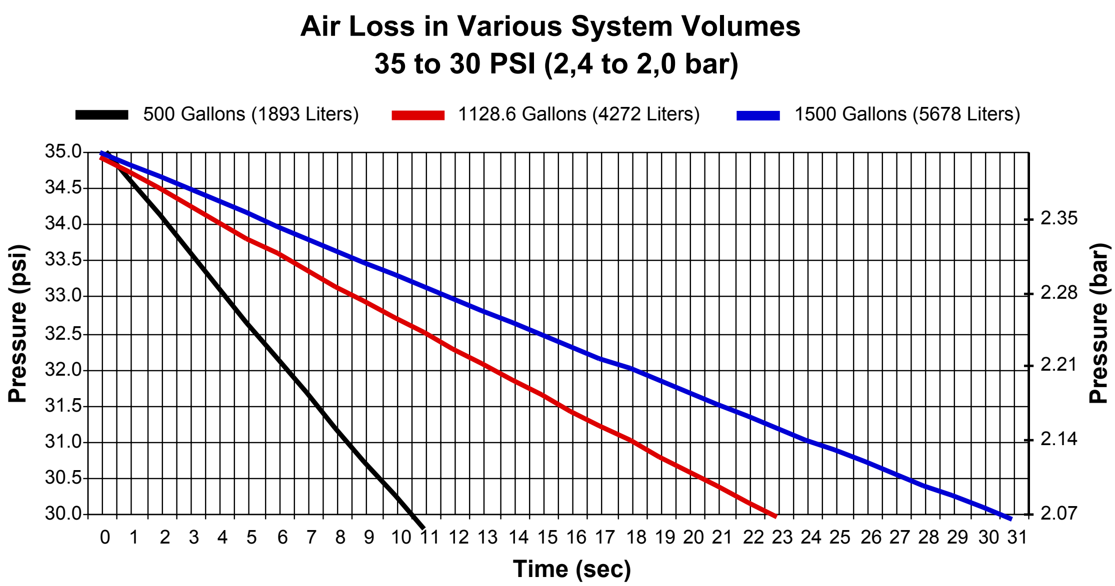


Figure 1 – Air pressure vs. Time for 35-psi to 25-psi (2,4 to 1,7 bar) Pressure Drop through a K5.6 (K80) sprinkler

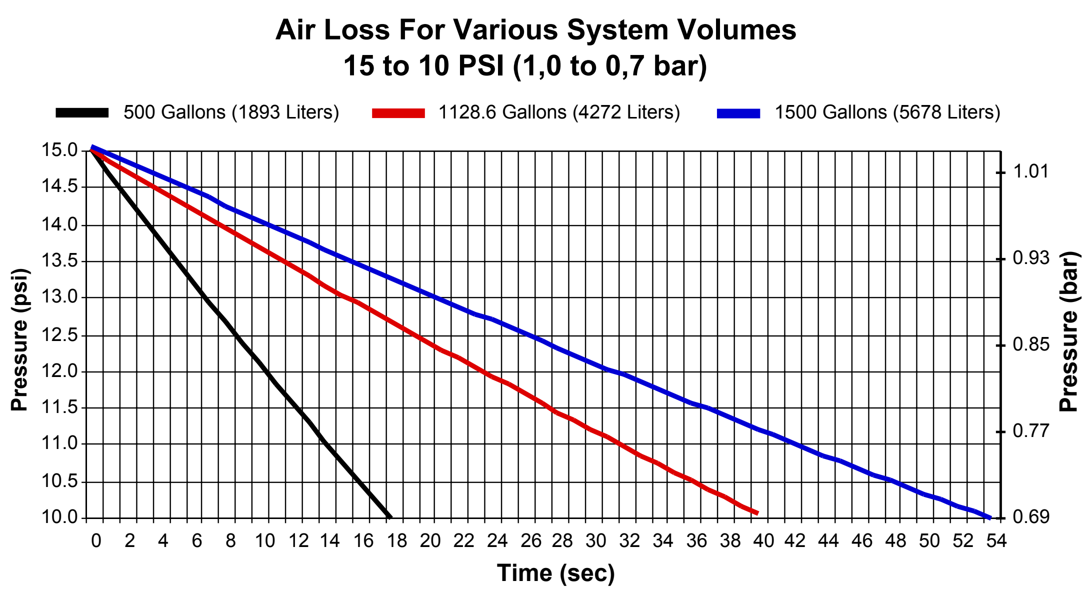


Figure 2 – – Air pressure vs. Time for 15-psi to 10-psi (0,1 to 0,7 bar) Pressure Drop through a K5.6 (K80) sprinkler

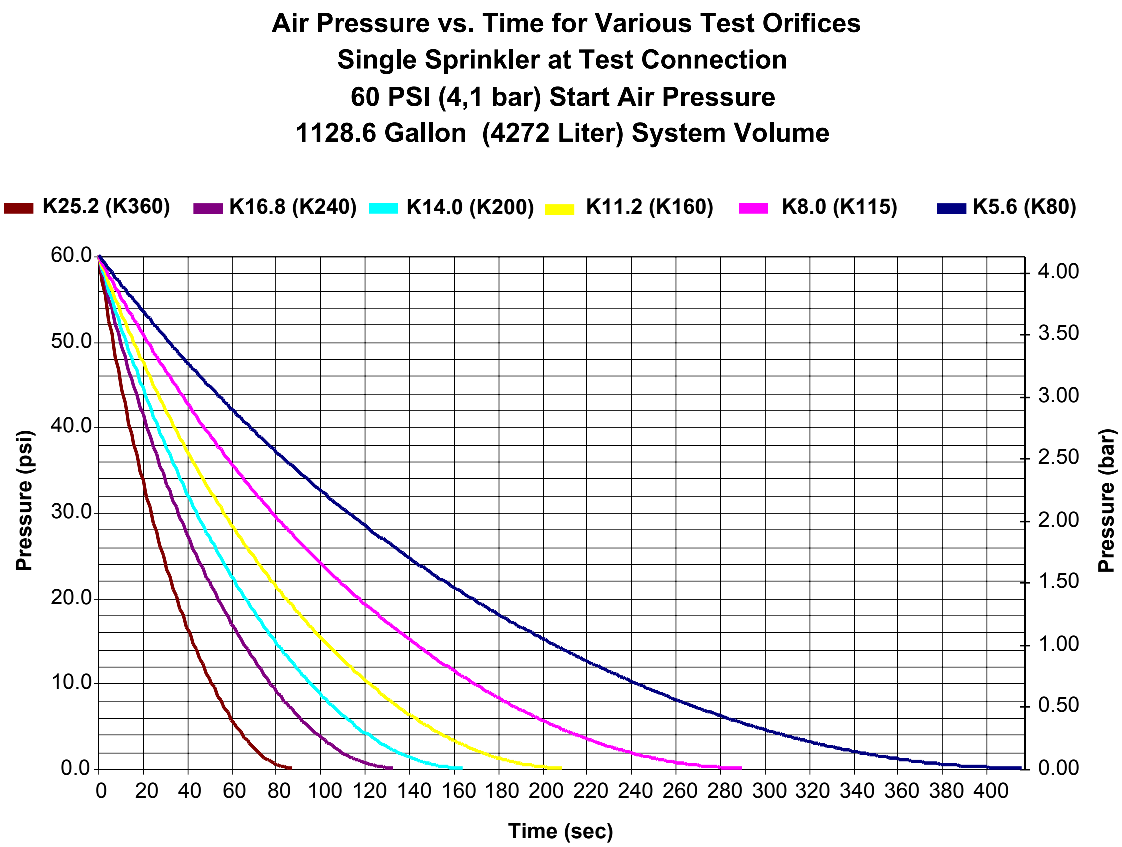


Figure 3 – The Effect of Test Orifice Size on the Rate of Pressure Drop in a Dry System

c. **The dry pipe valve trip pressure:** Different models of dry pipe valves trip at different water to air pressure ratios. A typical ratio is 5.5:1. A system using this type valve with a static water supply of 75-psi (5,2 bar) would trip at 13.6-psi (0,9 bar) (5.5:1 = 75-psi: 13.6-psi or = 5,2 bar: 0,9 bar). The air pressure as recommended by the manufacturer would typically include a safety factor plus the compressor on-off differential settings. These are added to the trip pressure of 13.6-psi (0,9 bar) to obtain the maximum set air pressure. A Central, Gem or Star DPV-1 dry pipe valve has a 5.5:1 trip ratio, and the recommended maximum set air pressure is 39-psi (2,7 bar). This is sufficient for a static water pressure of approximately 75-psi (5,2 bar). Refer to Figure 3 for the time required to lose air pressure from a 39-psi (2,7 bar) set pressure to a 13.6-psi (0,9 bar) trip pressure, this represents a 25.4-psi (1,8 bar) loss. One can quickly see why a system as large as 1128.6 gallons, with a K8.0 (115 lpm/bar1/2) sprinkler, can require as much as 98 seconds (148 – 50 from Figure 3) to trip due to dropping the air pressure from 39-psi (2,7 bar) to 13.6-psi (0,9 bar). For this reason, accelerators, which quickly react to the rate of pressure drop in lieu of fixed pressure are very commonly used for large dry pipe systems.

Low pressure latch clapper dry pipe valves operate by use of an additional device called an actuator. The actuator operates as a simple differential device wherein loss of air pressure in the system at a greater rate than the threshold limit causes the actuator to move from its set position to an open position. This vents water from the diaphragm chamber of the main valve and releases the rod and latch that hold the clapper closed inside the main valve. Because there is no published actuation data for these valves, an actuator from another manufacturer was purchased to test the activation times. Since these actuators are designed for use with "low pressure dry pipe valves", one can expect the air movement to be slow. This is obvious as shown in Figure 3. The recommended air setting pressure of these systems varies with static water pressure and can be as low as 10-psi (0,7 bar). The performance of a 1,000-gallon (3785 liter) system with a K5.6 (80 lpm/bar1/2) inspectors test and a 100-psi (6,9 bar) static water supply was tested. A manufacturer recommended 15-psi (1,0 bar) set pressure resulted in 76 seconds to achieve full (relief) flow. As with traditional dry pipe valves, latch clapper dry pipe valves will normally require the use of an accelerator to compensate for the slow activation time.

d. The use of an accelerator: An accelerator shortens the time required to trip a dry pipe valve since they are very sensitive to pressure changes and significantly reduce the effect of system volume. Different models of accelerators offer different performance. Products manufactured by Central, Gem and Star typically trip a dry pipe valve in 4 to 10 seconds from the opening of the inspectors test valve. Other manufacturers publish times that range from 4.5 seconds to 25 seconds. The activation time is dependent on the system volume, system configuration and test orifice size. The use of an accelerator can significantly reduce the trip time of a dry pipe valve, but has a negative impact on the water delivery time after the valve trips. The water delivery time is increased due to higher air pressure in the system when the valve trips since the accelerator will trip the valve before the air pressure in the system drops to the valve differential pressure. The combined effect, though, of a properly operating accelerator is to reduce the overall time required to deliver water to the test connection. It is very important that we not lose sight of the fact that, by their very nature as sensitive devices, accelerators require a high level of testing and maintenance in order to operate dependably. Unfortunately, history shows us that they do not always receive the required level of attention.

2. Water transition time:

This is the time required after tripping of the dry pipe valve for water to displace air in system piping and begin water flow from the test orifice. Figure 4 represents a typical dry pipe system that will be used in this section. Dry pipe valve trip times are not included in this section. Water transition time is the most complex and difficult phase of dry system performance to predict. The water transition time is affected by all of the following:

System Volume - 1128.6 gallons (4272)
Supply-Static 80-psi - Residual 60-psi - 1500 gpm (5,5 bar - 4,1 bar - 5678 Lpm)
20 Branch Lines, 20 Sprinklers, 10' x 10' (3m x 3m)
Branch Lines - 2" (51mm) Schedule 10
Riser Nipples - 2 1/2" (65mm) Schedule 40
Cross-Main - 6" (150mm) Schedule 10
Feed Main - 6" (150mm) Schedule 10

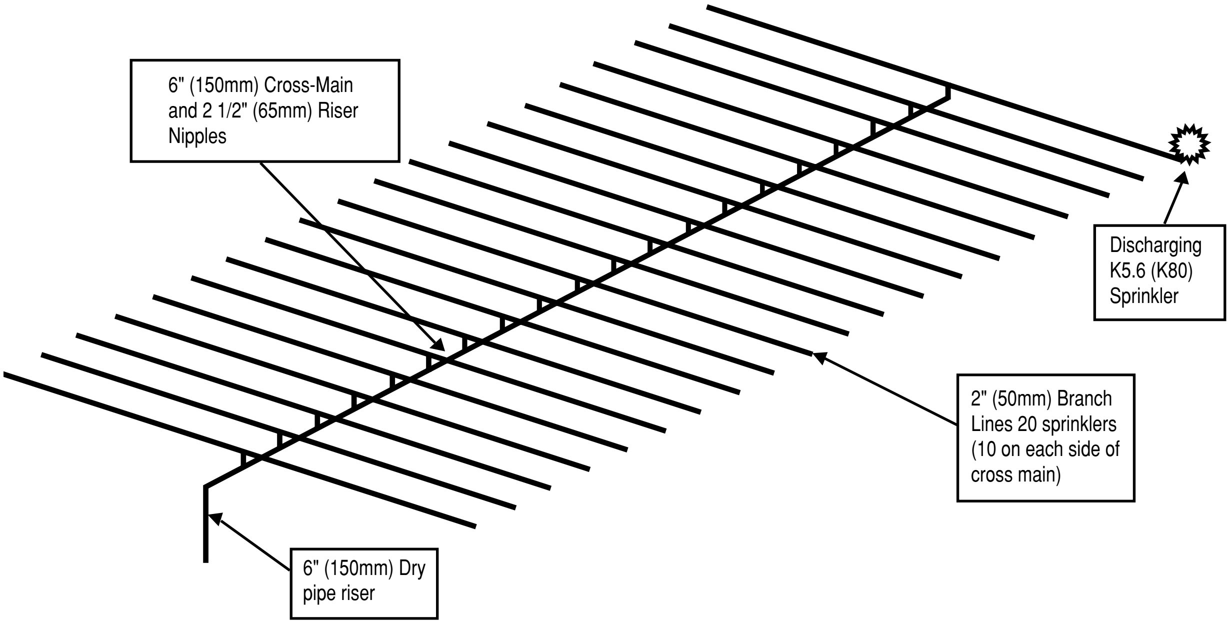


Figure 4 - 1128.6 gallon dry pipe system

a. Size of the test orifice: The size of the inspectors test orifice will not only affect the trip time as previously discussed, but will affect the water transit time. In order for water to fill the piping between the dry pipe valve and the test connection, it must displace air. The size of the test orifice determines the rate at which air leaves the system through the orifice. Figure 5 shows three examples where the only variable changed from the system shown in Figure 4 is the size of the inspectors test orifice.

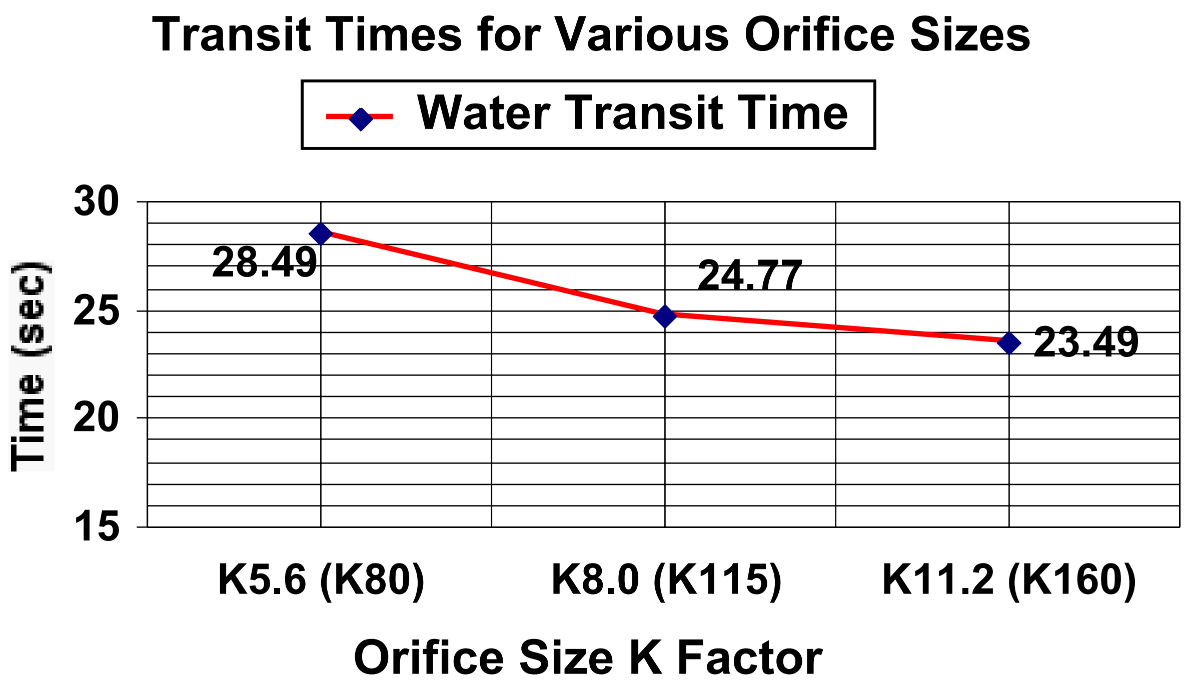
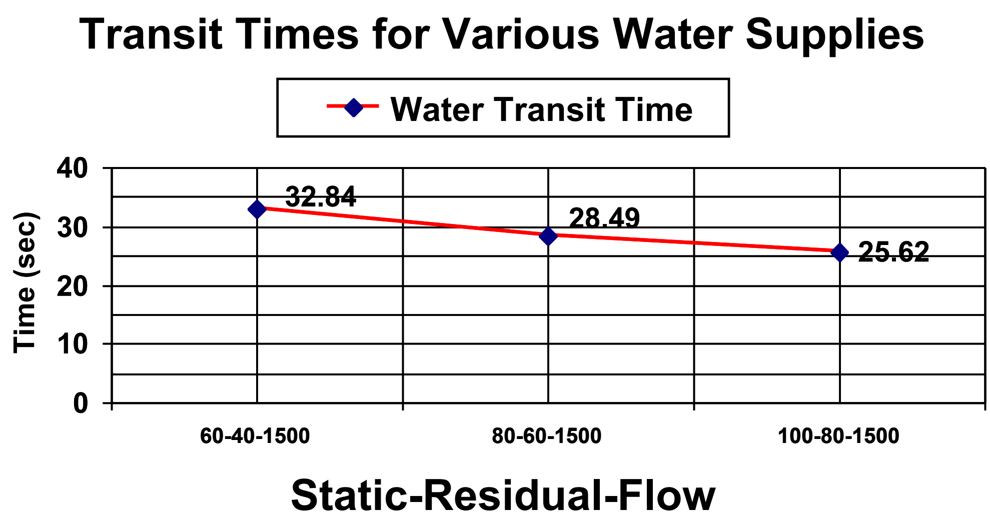


Figure 5 – Comparison of a single K5.6, K8.0 and K11.2 (K80, K115 and K160) water transition times.

b. Water supply: While all water supplies are unique, they share one common trait for any given flow; there is a corresponding pressure. As flow increases, the pressure available decreases. For any given flow, the higher the pressure and the greater the flow, the faster the water will displace air and reach the inspectors test in a dry pipe system. A weak water supply is resisted by air pressure in the system as well as lower flow rates that delay the transition time. Prior to dry pipe valve actuation, the system air pressure setting is dependent upon the static water supply pressure to the system and will vary by location. The valve trip pressures for the water supplies shown in Figure 6 are 10.9 (0,75), 14.6 (1,00) and 18.2-psi (1,25 bar) respective to the 60 (4,1), 80 (5,5), and 100-psi (6,9 bar) water supplies. Air pressures will be further detailed in Section C. Figure 6 shows the water transit times for the system shown in Figure 4 with varying water supplies.



Metric = (4,1 – 2,8 – 5678) (5,5 – 4,1 – 5678) and (6,9 – 5,5 – 5678) respectively.

Figure 6 – Comparison of residual water supply.

c. **Air pressure in system when valve trips:** Air pressure in the system resists the fill rate of the water supply. Figure 7 clearly shows the effect of air pressure in the system shown in Figure 4 when the dry pipe valve trips, specifically when the test orifice is as small as K5.6 (K80). Figure 7 shows the effect of the air pressure in a given system.

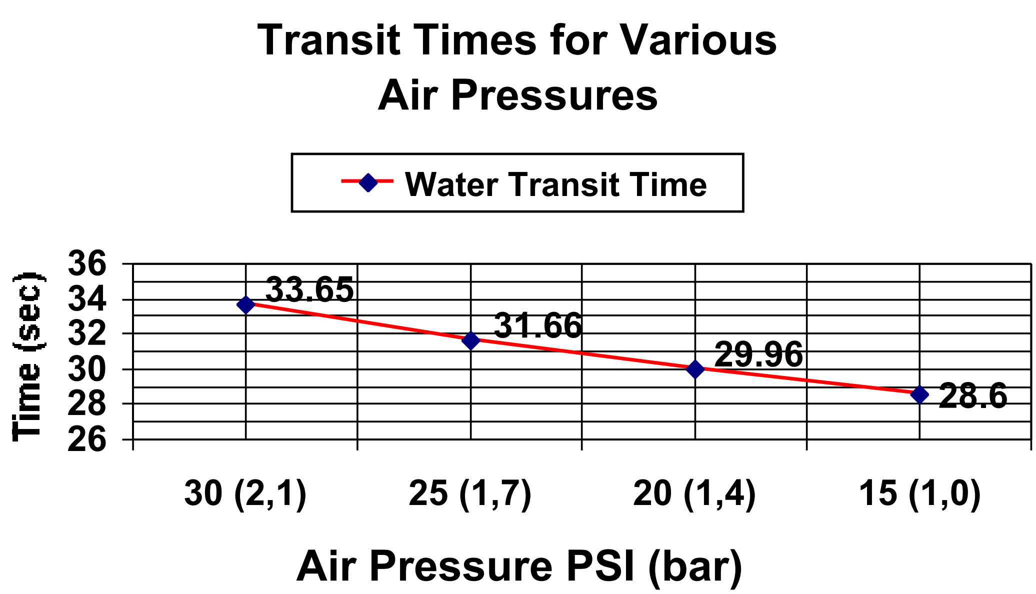


Figure 7 – Comparison water transition times with different air pressures in the system.

d. System piping volume and arrangement: This is based on how much of the system volume will fill with water during the transition period (the remainder of the volume is trapped air) and the physical distance the water has to travel to the inspectors test valve. Figure 10 shows a comparison of a 30-branch line by 30-sprinkler 2226.1-gallon (8426 liter) system, 20-branch line by 20-sprinkler 1128.6-gallon (4272 liter) system (shown in Figure 8), and a 10-branch line by 10-sprinkler 410.8-gallon (1555 liter) system (shown in Figure 9). The pipe sizes remained the same. The volume of a system is very difficult to change without changing another variable such as trapped air (pipe size) or distance. Keeping the same size pipe and shortening the system to change the volume will add a distance factor. In this comparison, the cross main is 200 ft (61m) shorter with 20 fewer branch lines, and the branch lines are 200 ft (61m) shorter with 20 fewer sprinklers. Keep in mind the reduction of trapped air in the branch lines, as this will be referenced in the piping configuration section below. Some of the results shown in Figure 10 are also affected by the distance reduction factor. Reference Figure 10 as a guide for the effect of a volume change and realize that there are other factors involved with the results.

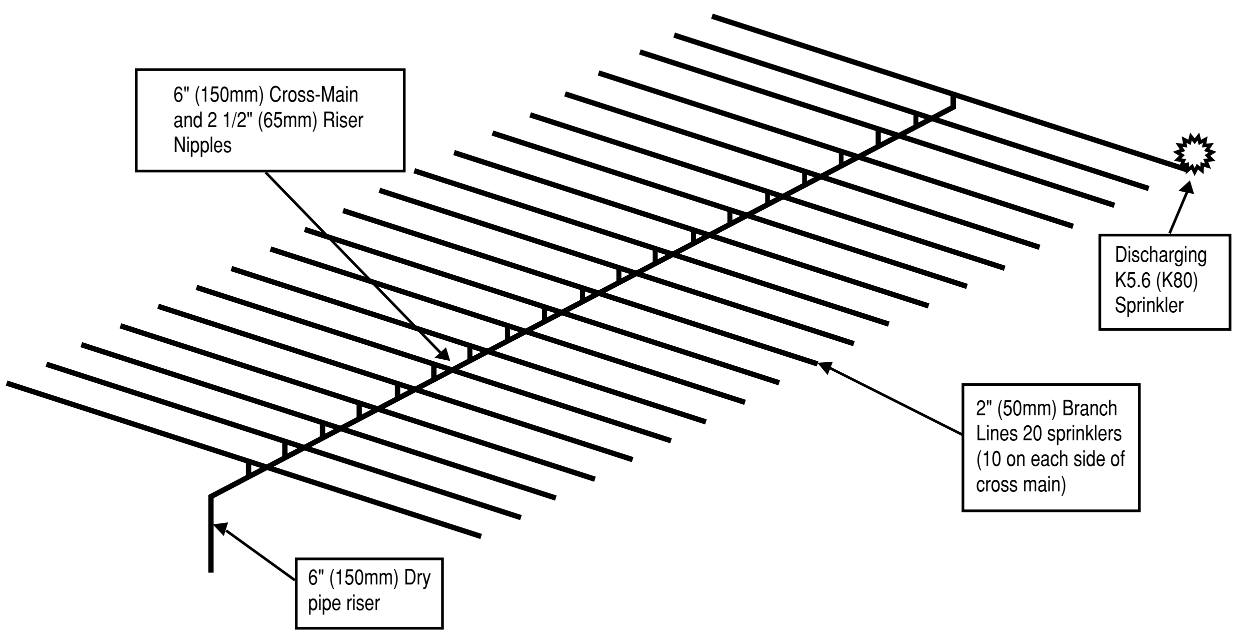


Figure 8 - Isometric of center feed tree - 1128.6 gallon (4272 liter) capacity (20 lines by 20 lines sprinklers)

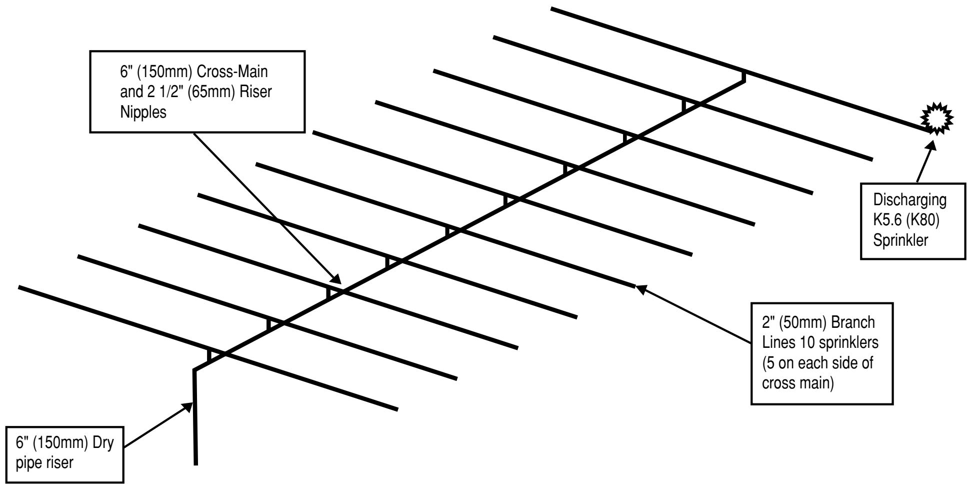


Figure 9 - Isometric of a center feed tree - 410.8 gallon (1555 liter) capacity (10 lines by 10 lines sprinklers)

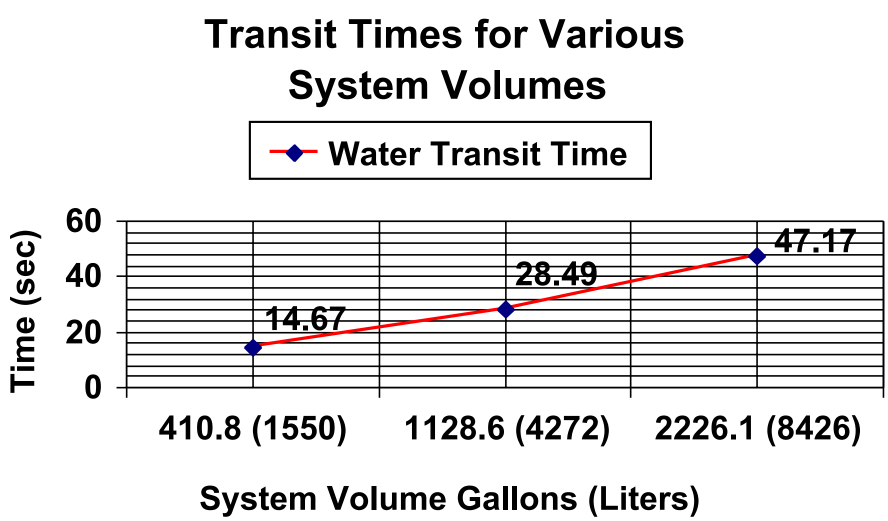


Figure 10 – Comparison of water transition by volume.

Piping arrangement plays an important role in the performance of water transition time. Through several examples, an understanding can be derived of the variables that are to follow. For example, the 1128.6-gallon (4272 liter) system in Figure 4 is a center feed, 20-branch line by 20-sprinkler per line system. If we cap 19 of the branch lines and half of the end line as shown in Figure 11, the results may be a surprise. This 421-gallon (1594 liter) system (Figure 11) will take

8 (36.5 versus 28.5) seconds longer to deliver water (transition time) than the original 1128.6 gallon (4272 liter) system shown in Figure 4. Why? All of the trapped air in the system has to be vented from the sprinkler prior to water arrival. In the smaller system, there are no pockets of air to compress, or non-flowing volumes for the water front to push the air except out of the open sprinkler. The single open sprinkler cannot exhaust air as fast as the 6"(150mm) riser can fill the system causing back pressure of air and slowing the fill rate of water.

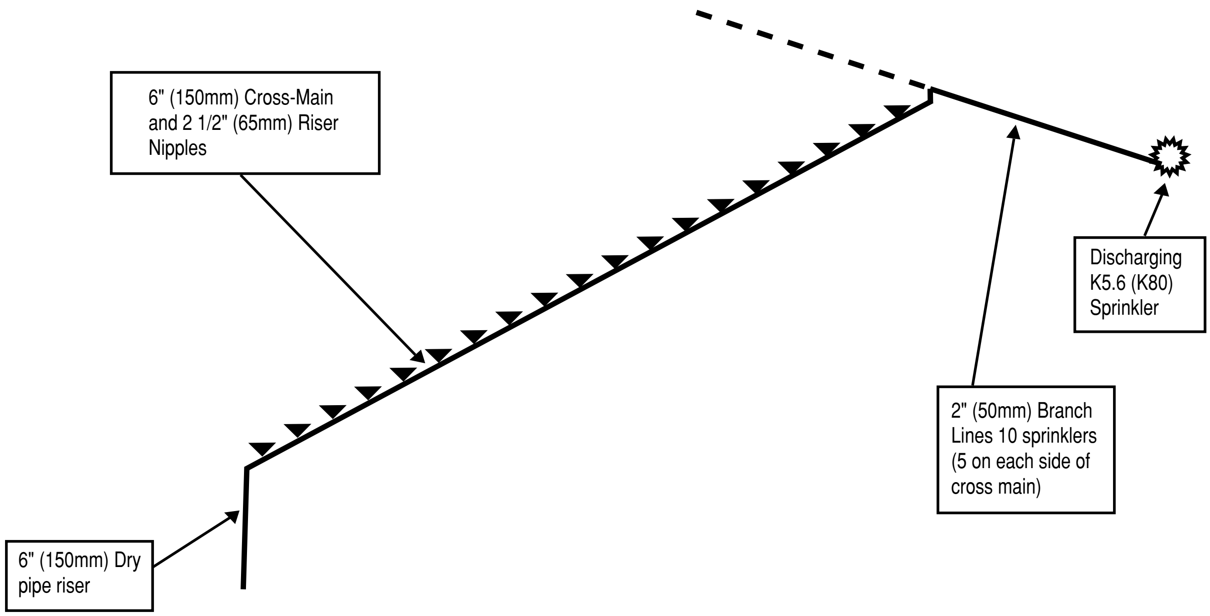


Figure 11 - Isometric of a single branch line tree - (same systems as Figure 4 with exceptions noted)

If the above example begins to bring an understanding of the effects of the piping configuration with respect to trapped air, reference Figure 12. This system represents the identical system shown in Figure 11, except that cross main and four branch lines beyond the open test sprinkler line have been added. The additional main and lines bring the system volume from 421-gallon (1594 liter) capacity to 633 gallons (2396 liters). With the added pipe in Figure 12, the trapped air located in the cross main with the plugged branch lines has an additional volume beyond the flowing line that allows air compression as the water enters the system. Even though the test sprinkler is the same distance from the source with the same pipe size as Figure 11, the water transition time is reduced from 36.5 seconds to 18.7 seconds. The water front filling the system pushes air in the cross main into the trapped volume beyond the test sprinkler faster than it could push the air out of the open sprinkler in the single path shown in Figure 11. This brings the water to the open sprinkler in less time as shown, despite the fact that the volume has been increased!

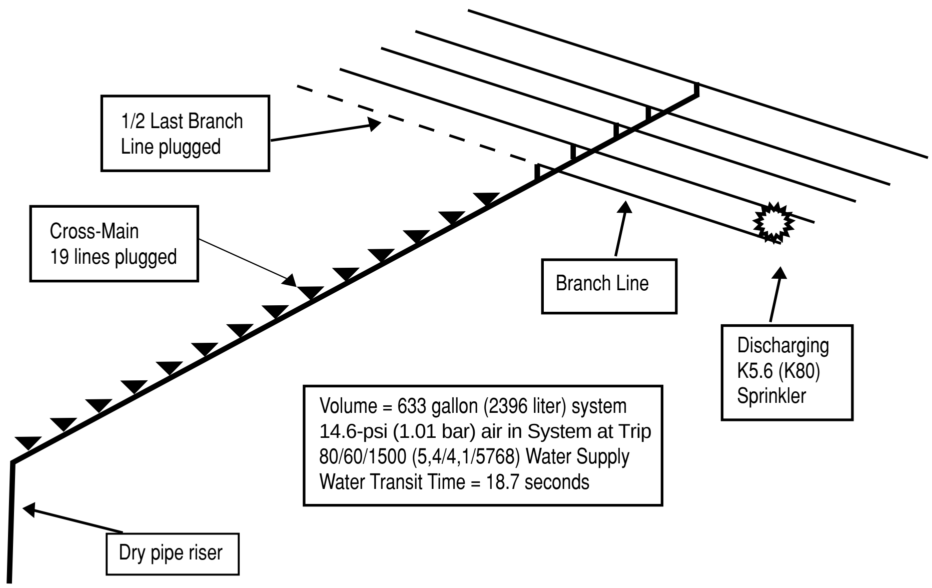


Figure 12 - Isometric of a single brahcn line tee (Figure 11) with 4 additional branch lines beyond the Inspectors test valve.

Now refer to the original system with 20 branch lines shown in Figure 4. This piping network contains a large amount of non-flowing volume that allows the water front to displace air by compressing it into the trapped branch lines. The original 20-branch 1128.6-gallon (4272 liter) volume system had a water transition time of 28.5 seconds. This is a much faster water transition time than the 36.5 seconds of the system shown in Figure 11 and slower than the 18.7-second water transition of the system shown in Figure 12.

When a dry pipe valve is equipped with an accelerator, the valve will trip faster, as we have previously discussed. When the valve actuation time is decreased through the use of an accelerator, the residual air pressure in the system is much higher than would have been experienced had the air pressure been allowed to reach the normal trip ratio. The result is that when using a quick opening device on a dry valve, the incoming water front is subjected to more air pressure in the system at the instant the valve trips. As previously shown, additional air pressure at the time of the valve trip will delay the water transition time.

Piping arrangement plays a significant role in water transition as demonstrated in the examples above. Volume is not always the key indicator for transition times. Volume and piping configuration must to be considered. These are variables that have never been previously addressed by any codes or design standards.

3. Compression:

This is the time water first reaches the test outlet to the time when the water pressure is maintained above the minimum required. This is often referred to as "full flow" or "when the outlet stops spurting air". This value is easier to establish by computer calculations than the judgment of three people standing at the test outlet debating the definition. The most definite description of full compression is the point or time at which the water volume entering the riser equals the water volume discharging from the sprinkler. This truly means that all of the trapped air is compressed and stable (no longer fluctuating). This value is not known in the field and can be identified by computer validation. The more critical measure for adequate fire protection is the point at which the discharging sprinkler meets or exceeds its minimum flow or density requirement. A field test or delivery time calculation should end when the sprinkler is functioning at the minimum designed flow. Additional air escaping from the sprinkler is not significant as long as the discharge density is not disrupted.

SprinkFDT

Computer calculations will soon be available for dry pipe system performance. NFPA #13[2] 2002 edition allows calculations to be submitted in lieu of a field validation test. Tyco Fire Products (Central, Gem and Star) has invested a considerable amount of time and money to develop this technology in a form that is available to the fire sprinkler industry. This program is called the SprinkFDT.

This dry pipe model is characterized by a system of straight pipes connected by nodes. Nodes can represent either a point of transition from one pipe size to another, elbows or bends, tees and laterals for dividing or mixing streams and valves, and exit nozzles such as a open sprinkler. The water supply can be modeled as either a static water supply or variable water supply like a pump driven water supply. Currently, the model accepts only one water supply source but can be easily adapted to accept water from more than one source, if desired. The dry pipe system modeled is the conventional tree-type system (i.e., single cross-main supplies water to branch lines that are fitted with automatic sprinklers). Each pipe/node in the model is categorized as members of a Feed Main, Cross Main, Riser Nipple, Branch Line and drop/sprig portion of the dry pipe system.

The SprinkFDT equations for flow properties of the gas and liquid are based on equations for unsteady fluid flow. These equations are used to solve for flow properties in the regions of fluid flow and gas flow in the system at any point in time, with the appropriate boundary and continuity conditions coupling the equations for water and gas. Additionally, the program models such phenomena as bubble flow and mixing between gas and liquid.

The input screens are as simple as tree generators as in most computer hydraulic programs or node-by-node input for more complicated systems. The output information will be similar to hydraulic calculations, only the summary data is based on trip and transition times verses water flow and friction loss. The detailed design criteria are specified in NFPA #13[2] as shown in Figure 13. A system can be calculated to meet these criteria in lieu of the field validation test. See NFPA 13 2002 edition[2] for more information. The SprinkFDT model will allow more than one sprinkler to activate as required by Figure 13.

Hazard	Number of Most Remote Sprinklers Initially Open	Maximum Time of Water Delivery
Residential	1	15 Seconds
Light	1	60 Seconds
Ordinary I	2	50 Seconds
Ordinary II	2	50 Seconds
Extra I	4	45 Seconds
Extra II	4	45 Seconds
High Piled Storage	4	40 Seconds

Figure 13 – NFPA #13 2002[2] Water delivery criteria for calculated systems.

Single head water supply testing may be necessary for maintenance and inspection per NFPA #25[2] to measure and record changes over time. These tests from a test outlet are for reference only and are not required to meet the 60-second rule if the system was designed by the calculation method described above.

Conclusion

Individual variables affect system performance as has been demonstrated. It is difficult to show the true effect of certain variables when they cause other factors to change as well, such as water supply, volume and air pressure.

The SprinkFDT model made the exploration all of these variables in dry pipe systems possible. Too many other factors change between systems and project sites to have a true comparison of variables on installed systems.

Dry system performance will be greatly improved with the knowledge of actual water delivery times. Future performance based designs can take advantage of actual water delivery in modeling versus the prescriptive volume time rules in older editions of NFPA.

The following items were found to deviate from traditional beliefs about dry systems and may lead to new considerations when designing dry pipe sprinkler systems:

- The K factor of the test orifice can influence trip, water transition and compression times.
- The system volume will not always be a good indicator of system performance.
- Changes in the critical path of water to the test outlet and the volume of trapped air between the two can greatly affect the water transition and compression time.
- Strong water supplies such as 80-psi residual and above tend to dampen the effect of variables and provide more consistent water transition times.
- Air pressure in the critical path can delay the water transition time.

Reference 1 – The Fire Protection Engineering Handbook, Published by the National Fire Protection Association – Quincy MA and Society of Fire Protection Engineers

Reference 2 – NFPA Standards, Published by the National Fire Protection Association – Quincy MA.

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Mr. Golinveaux's areas of interest include the research, design and applications of automatic fire sprinklers as well as their history. His interest in the fire sprinkler industry was sparked by his father's 27 years in the fire service.

Beginning as a designer in the early 1980's and later as a design manager for a fire protection firm in California, he applied local and national standards to develop working drawings for automatic fire sprinkler systems. Mr. Golinveaux became active and continues his involvement today through his membership on numerous committees such as the National Fire Protection Association (Member of NFPA 13 Discharge & Installation), International Conference of Building Officials, Society of Fire Protection Engineers and Southern Building Code Congress International. By 1991, Mr. Golinveaux's strong application knowledge of the automatic fire sprinkler industry afforded him the opportunity to work on the East Coast as the Director of Technical Services for Central Sprinkler Company. Mr. Golinveaux was responsible for the technical responses to worldwide production of automatic fire sprinkler system components. He continued his involvement in the industry and represented Central on many national committees including the National Fire Protection Research Foundation, Research and Advisory Council on Fire Suppression Futures and Underwriters Laboratories Industry Advisory Committee for automatic sprinklers. Mr. Golinveaux's many talents and wealth of knowledge were recognized by Central where he was Senior Vice President of Engineering and was directly responsible for the Production Plant with over 600 employees, the Engineering/R & D, Quality Control and Technical Services operations. Currently, Mr. Golinveaux is Senior Vice President of Research and Development for Tyco Fire & Building Products, which represents Central, Gem and Star branded products.

In addition to the support of the industry through his numerous committee memberships, Mr. Golinveaux also contributes his time as a speaker for national education seminars sponsored by organizations such as the Society of Fire Protection Engineers, Universities, Highly Protected Risk (HPR) Insurance Companies, National Apprenticeship and Training, and Trade Associations as well as state and local fire authorities. He has educated many on the latest sprinkler technology and its associated codes and standards.

Mr. Golinveaux's co-authored the published article "*Fire Test Performance of Extra Large Orifice Sprinklers in Rack Storage of Group A Plastics in Warehouse-Type Retail Occupancies*." He is also named on numerous U.S. Patents relating to automatic sprinklers.

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