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FIRE PROTECTION HISTORY-PART 125: 1954
(SPRINKLER SYSTEM HYDRAULIC CALCULATIONS)

By Richard Schulte

The fifty-eighth annual meeting of the National Fire Protection Association was held at the Hotel Statler in Washington, DC in mid-May, 1954. Of all the various presentations made at this meeting, one presentation stands out-a presentation titled "*Water Flow Characteristics of Sprinkler Systems*" made by Malcolm H. Nickerson, the assistant director of Factory Mutual Laboratories. The following is the text of Mr. Nickerson's presentation:

"*At the January meeting of the Water Spray Committee in New York, the question of how best to compute a water spray system was discussed. No well defined methods have been published for this computation and some of the procedures followed are reported to yield calculated results which differ considerably from water flow tests of newly installed equipment.*

Any one unfamiliar with the subject may well ask: "Why is it necessary to compute a system?" There are several reasons, the principal ones being:

(a) Where open head systems are installed, such as on transformers, process equipment, or in aircraft hangars, or in high hazard areas where we know practically all the closed heads might operate, it is very important to have available an adequate water supply both as to pressure and volume. Since water supplies must be planned in advance, we must have a reliable method of computation.

(b) A reliable method of computation is also essential in order to develop a satisfactory sprinkler pipe schedule or to check a suggested revision.

In the earlier days of automatic sprinkler installation, the pioneer hydraulic engineer in the fire protection field, Mr. John R. Freeman, carried on extensive flow testing and evolved a method of computing the flow characteristics of sprinkler systems which was used as a basis for the sprinkler piping schedule developed in 1890. Unfortunately, records of his methods of computation have been lost.

During recent years, the Factory Mutual Laboratories have had occasion to make many tests of pressures and flows in sprinkler piping arrangements. The results of this work have been used in the development of methods of computation which give results comparable with those found by actual flow tests, within reasonable limits of experimental error and expected variations in piping and fittings.

This paper is being presented for the purpose of informing those interested in the hydraulics of automatic sprinkler systems, and spray systems, of the work that has been done recently and especially that carried on during the past year in the Factory Mutual Laboratories. By means of this report, we hope to make available a method of sprinkler and spray system hydraulic computation which will be adequate for the needs of those designing such systems. We will also point out some of the limitations in the application of the methods of computation, and the agreement that can be expected between such computations and actual performance.*

The detailed methods of making computations will be outlined in an Appendix to this paper as such computations are somewhat tedious and they are likely to be uninteresting for a group such as is present here. We believe, however, that certain basic considerations will be of interest, as well as a brief description of our tests.

The amount of water discharged from any nozzle or sprinkler is proportional to the square root of the pressure. A theoretical discharge can be computed from well established hydraulic principles, but actual values depend upon characteristics of particular devices, which can only be determined by simple tests. Furthermore, the friction loss in piping is approximately proportional to the square of the water velocity.

It may well be asked then why this problem of sprinkler system computation has been so troublesome for such a long time.

One source of error is in the variation in the discharge from different nozzles of apparently the same size and design. This may be as much as 8%. As far as the pipe is concerned, its friction loss is dependent upon its interior roughness which is designated by the Williams-Hazen Coefficient "C". This can vary through quite a wide range due to the effect of corrosion and deposits, both of which are dependent upon time and the corrosive effect of the water. This roughness factor is taken into account by the coefficient "C" in the commonly used Williams-Hazen formula for flow of water in pipes.

* *By Mr. R. H. Ellis and Mr. G. E. Gunderson of Factory Mutual Engineering Division.*

In our experimental work, sample lengths of pipe have been kept filled with water, the ends being capped, and over periods of three months their "C" values have been rechecked. Although it is too early to predict accurately what will happen, so far we have found that, following an initial large drop in the value of "C", the corrosive effect of the water is diminishing.

TABLE Ia

Reduction of "C" in new pipe, kept filled with water, over a three month period.

Size of Pipe	***New***	***3 Months Later***	***% Change***
1 in.	*129*	*116.5*	*-9.7%*
1[-]1/4 in.	*135*	*126*	*-6.7%*
1[-]½ in.	*135*	*125*	*-7.4%*
2 in.	*139.5*	*136*	*-2.5%*

TABLE Ib

Values of "C" found in 30 year old pipe from wet and dry sprinkler systems. (Corrected for pipe diameters according to Schedules 40 and 60 ASA 36.10.)

	Values of C	
Pipe Size	***Wet***	***Dry***
3/4 in.	*106*	*104*
1 in.	*110*	*90.5*
1[-]1/4 in.	*111*	*75*
1[-]½ in.	*82*	*77*
Average	*99.5*	*85*

Table Ia shows the changes in "C" during the first three months. Table Ib shows values of "C" which we found in 30 year old pipe from "wet" and "dry" sprinkler systems.

It is known that the corrosive effect of water standing in a pipe exhausts itself at a diminishing rate over a period of time. On the other hand, new moisture is introduced into a dry system along with the compressed air. Also, many dry systems have in the past been placed on "wet" during the summer months. The effect of these two factors is readily apparent in the lower values of "C" found in pipe from old dry systems.

Undoubtedly, one of the reasons why the calculated properties of the piping systems have not agreed with test results is that the assumptions made for the interior condition of the piping in the computations is not in accord with the actual condition of the pipe when the tests are made.

Consideration of the differences between individual nozzles and the differences in friction loss characteristics of piping shows that we should not strive for or expect to attain great accuracy in this computation work. By themselves, however, these two factors do not prevent computations being close enough for practical purposes.

In spite of the lack of complete uniformity between nozzles, the discharge is proportional to the square root of the pressure acting upon the nozzle.

Before going any further, we should consider the question "What pressure? In order to achieve agreement between computed and test results we must select the right pressure at each nozzle. If the water is not flowing in a pipe, the pressure is "static". On the other hand, where water is discharging from a nozzle all the pressure at the orifice has been converted to velocity pressure which we measure with a pitot tube. In a pipe carrying water under pressure, both the static and velocity components exist simultaneously.

Many tests in the Factory Mutual Laboratories have shown that the pressure reading taken at the end of a tee, the side outlet of which is supplying water to a nozzle, is the same pressure as that which acts on the nozzle installed in a large pipe or chamber where the velocity component is insignificantly small. Our laboratory setup is shown in Figure I. The pressure obtained in this manner, together with the measured flow, is used to calculate the constant in the nozzle discharge equation $Q = K\sqrt{P}$.

[FIGURE 1 OMITTED]

In our experimental work nozzles calibrated in this manner, and having uniform values of K, were installed in a branch line. Water was supplied to the branch line at a known rate, the pressure was measured at a tee at the end of the line, and the flow from each nozzle was measured as shown in Figure 2. We found that the pressure at the back of a tee having through flow is the same as that which would cause the metered flow of water from the nozzle installed in the tee. This discovery eliminated the need for catching the water in drums in all tests and instead we used mercury gauges connected to the backs of tees along the lines.

[FIGURE 2 OMITTED]

[FIGURE 3 OMITTED]

Having done this experimental work, we tried various systems of computation, seeking the one which yielded the right pressures at each nozzle. This method turned out to be that described in the Appendix to this paper. It agrees very well with hydraulic theory.

Our method of computation differs in one important respect from others in that it takes into account the fact that the total pressure within the pipe cannot act on a nozzle screwed into the side of the pipe if water is flowing past that point. Anyone who doubts this can prove it quite readily as shown in Figure 3. Attach a pressure gauge to the side of a piece of pipe which is carrying water at considerable velocity. Nearby insert an L-shaped tube pointing upstream as shown in the sketch and to the outlet from this tube attach a second pressure gauge. The pressure shown on the gauge attached to the pitot tube will be higher than the pressure shown in the gauge attached to the side of the pipe. This is true because the pitot tube senses total pressure, both the pressure due to the supply head, and the pressure due to the motion of the water through the pipe. On the other hand, the pressure gauge screwed directly into the side of the pipe can only sense what we call the net pressure which is the difference between the total pressure and the velocity head. A sprinkler head screwed into the side of the pipe is no different from our pressure gauge and it too will only be affected by this net pressure. This simple consideration is the secret of the success of our method of computing systems.

The slides show the experimental setup used at the Laboratories during the past year. Briefly, the work included calibration of our flow meter, friction loss tests in sample pieces of pipe in order to determine the value of "C" to use in our experimental work, calibration of sprinkler heads in the actual fittings in which they were used in our test setup, and, finally, a series of tests on the sprinkler system which you see in the pictures.

The piping arrangement was very flexible and permitted us to flow water through a maximum of 48 heads simultaneously. Various head spacings and branch line spacings were possible and tests were run with two lengths of nipples connecting the branch lines to the cross main. A further breakdown was obtained by varying the pressure at the end head for various tests. In all, we used three end head pressures, three head spacings, two branch line spacings, two lengths of nipples between branch lines and cross main, center and side feed arrangements, and four, six, and eight head branch lines.

TABLE II

Six and Eight Head Branch Lines
15 ft. Spacing

Head No.	***Computed Net Pressures***	***Measured Net Pressures****
1	*2.50*	*2.50*
2	*2.79*	*2.72*
3	*4.18*	*4.09*
4	*5.02*	*4.90*
5	*5.57*	*5.53*
6	*6.97*	*6.87*
7	*7.35*	*7.22*
8	*7.93*	*8.00*

**Average of six independent tests.*

Without going into too much detail, it is interesting to note how closely our experimental and computed results compare. Table II shows a comparison between the computed net pressures and the measured net pressures at the heads along an 8 head branch line and it will be seen that the maximum deviation is only +2.45%.

Table III shows a comparison between computed flow data and measured flow data. Again it will be noted that the maximum deviation is low, only +1.33%.

In the short time available this morning, it was, of course, impossible to present more than a very brief review of what we have been doing at the Laboratories. By means of the Appendix to this paper, we are presenting the details of the method of computation which will be of particular interest to anyone faced with the problem of laying out water spray and deluge systems.

TABLE III
Six and Eight Head Branch Lines
15 ft. Spacing

Head No.	***Computed Flow***	***Measured Flow GPM****
1	*8.60*	*8.60*
2	*9.10*	*8.97*
3	*11.10*	*10.99*
4	*12.20*	*12.04*
5	*12.80*	*12.78*
6	*14.40*	*14.29*
7	*14.75*	*14.61*
8	*15.30*	*15.38*

**Average of six independent tests.*

APPENDIX

[TEXT OMITTED]"

While a presentation on research on piping system hydraulic might not make very exciting listening, this research and the presentation on the research, along with the development of the rules for the use of the spray sprinkler in 1953, created a water shed in the development and use of sprinkler protection. The combination of the development of the spray sprinklers and a methodology to perform hydraulics truly revolutionized the field of fire protection. As with many other revolutionary concepts, the introduction of hydraulic calculations in the design of sprinkler protection took a number of years to percolate through the field. It wasn't for close to another two decades before rational rules for hydraulically designed sprinkler systems were introduced.

The introduction of procedures for performing hydraulic calculations allowed engineers to do a hydraulic analysis of the pipe schedule and to make the determination that the small pipe in a sprinkler system (the branch lines) designer per the pipe schedule was undersized and that the large pipe in a pipe schedule sprinkler system (the cross mains and bulk mains) were oversized. Hydraulic calculations eventually allowed engineers to "fix the error" in the pipe schedule and significantly reduce the cost of sprinkler installations. Of course, with reduction in the cost of sprinkler installations, came the feasibility of installing sprinkler protection in more and more buildings, particularly buildings classified as light hazard by the sprinkler installation standard.

The revolution in the design of sprinkler protection using hydraulic calculations wasn't completed until the early 1970's when the rules for hydraulically designed sprinkler systems were incorporated into the sprinkler installation standard and then refined.

The development of hydraulic calculations for sprinkler supply piping systems made the installation of sprinkler protection in high rise buildings feasible and ushered in the "Golden Age" of the fire protection field. Much of the progress we have made in the field of fire protection in regards to life safety, including sprinkler protection for residential occupancies, can be attributed to the development of the spray sprinkler and the procedures for performing a hydraulic analysis of sprinkler supply piping systems.

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