Whitepaper

Laboratory tests aged sprinkler heads

An effective and efficient approach to increase confidence in the effectiveness of sprinkler systems

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1.1 Sprinkler head testing is crucial

Provided they are properly tuned to the circumstances, sprinkler installations are very reliable installations that can last a long time. High reliability is important, because the proper functioning of these types of installations only really becomes 'visible' in a fire situation. To ensure the installation does its job at such a crucial moment, it is very important to maintain all components of the installation properly and to assess their correct operation.

Certified maintenance and independent inspection of the sprinkler system are important tools for maintaining confidence in sprinkler protection. The sprinkler heads are crucial components of a sprinkler system. Independent verification of these heads, in the form of product certification and extensive testing in the manufacturing process, provides confidence that sprinklers will activate in a timely manner and, if properly designed hydraulically, distribute the water in the correct amount and spray pattern. But what if these sprinklers have been installed quite some time ago? Is the confidence we have in the proper functioning of such a system still justified?

Testing representative samples of sprinklers provides insight into the functioning of these sprinklers. By subjecting the sprinklers to some of the same tests as during type approval, the effect of aging and contamination on the sprinkler's operation can be measured. Research proves it is not possible to make a good estimate of the proper functioning of a sprinkler on the basis of a visual assessment. Tests demonstrate that hardly contaminated sprinklers can have large K-factor reductions due to a hard rim that cannot be washed away. A slight contamination can also cause the closing plate not being released at all (not even at higher pressures).

In connection with this, the sprinkler regulations include time limits when testing the sprinklers is necessary and also state the required amount of samples to test with. These periods depend on the type of sprinkler and the 'quantity' to be measured, but are always linked to the period of use. The sample size is related to the expected spread of test results.

In this whitepaper we give our view on which sprinklers should be tested, when they should be tested and against which criteria in order to maintain confidence in their security. We have used relevant (international) regulations, including NFPA 25, CEA4001, EN12845 and VdS2091. These documents describe the testing of sprinklers in the use phase. In NFPA 25, such tests are referred to as field service tests.

2 Which test for which kind of sprinkler

The sprinklers used in sprinkler installations are extensively tested before they are put on the market. For example, all sprinklers are tested for issues such as resistance to static pressures, dynamic pressures (water hammer), aging (corrosion testing), functional testing, capacity (K-factor), opening temperature, thermal sensitivity (RTI), spray pattern, vibration sensitivity, etc. In order to determine that aged sprinklers still function reliably, a repetition of the type tests would give a clear picture of the effect of aging and contamination on the operation of the sprinklers. However, such an extensive test is time consuming and costly. There must be ways to make this more efficient.

It is therefore important to determine which specific performance of a sprinkler is crucial for the chosen protection concept and then estimate whether that performance can be negatively influenced over time. The relevant aspects are the functional test (does the sprinkler open and does this lead to a good spray pattern?), the K-factor (how much water does the sprinkler still deliver at a certain pressure?), the response temperature (at what temperature did the heat-sensitive element activate?) and RTI (the thermal sensitivity, i.e. how quickly does the sprinkler respond to hot gases?). Targeted testing can then be carried out on that sprinkler performance. The frequency of testing should be appropriate to the rate at which aging influences impact sprinkler performance.

2.1 K-factor and functional testing

For all sprinkler systems it is important to keep the cooling effect of water greater than the heat release of a fire. This means that the hydraulic conditions of the system must be monitored. For the sprinklers, this means that any reduction in the K-factor due to contamination and deposits must be monitored. This is possible through the flow test, which determines the K-factor. Subsequently, the measured K-factor can be compared to the nominal K-factor (the K-factor of the sprinkler, as stated in the datasheet and used in the design calculations) and the K-factor reduction can be determined. The results of the field service tests carried out by Kiwa FSS show that approximately 16% of tested sprinklers that are a maximum of 20 years old have a K-factor reduction of 10 to 30[1]%. In 8% of the tested batches a K-factor reduction of more than 30% was found. It is also striking that the K-factor decrease of sprinklers from the same batch varies widely. Of the aforementioned group of sprinklers, one or more sprinklers fail to open after activation in 4% of the tested batches. It is therefore important to get a clear picture of these undesirable situations for all types of sprinkler systems in due time. We also have to be aware of

[1] 10 and 30% K-factor reduction are threshold in VdS 2091, on which reports are made, and therefore data analysis is possible

the fact that for designs in which reduction of the maximum spray area has been allowed on the basis of a certain K-factor, this check is even more important.

2.2 Opening temperature

The opening of a sprinkler is triggered by a heat-sensitive element. This can be a glass bulb or a fusible link. The heat sensitive elements of the installed sprinklers must respond in a predefined temperature range. If aging of the sprinkler leads to 'variation' of the opening temperature, this can lead to an undesirable order of activation (so called skipping) in the event of a fire, resulting in a different spray area than for which the installation was designed. Our tests show that for sprinklers up to 20 years old, in approximately 10% of the batches examined, one or more sprinklers have a small deviation in the opening temperature (less than 10°C deviation). In 2% of the tested batches there are sprinklers with a greater deviation (more than 20°C deviation).
For sprinkler protection systems in which a reduction in the maximum spray area can be allowed by selecting of a certain opening temperature, monitoring the opening temperature is particularly important. NFPA uses the temperature ratings ‘ordinary temperature’ (57-77°C), ‘intermediate temperature’ (79-107°C), and ‘high temperature’ (121-149°C) for sprinklers. Based on these temperature classifications, maximum spray areas are determined, reductions in spray areas are possible or spray density requirements are linked. To ensure that the performance requirement of a sprinkler system is based on a specific opening temperature of the installed sprinklers, it is important to monitor that opening temperature.

2.3 Thermal sensitivity (RTI)

In addition to the opening temperature, the thermal sensitivity of the heat-sensitive element is essential, especially for NFPA and FM-based systems. With fire protection systems that use fast-response sprinklers (RTI≤50), guaranteeing the high response speed is crucial. This is achieved by minimizing the mass of the heat-sensitive elements and thus accelerating the response to temperature rises. In addition to a possible effect of aging on sensitivity, fouling of the sprinklers can have a strong negative effect on thermal sensitivity. The importance of the RTI is evidenced by the fact that NFPA 25 sets requirements for determining the RTI of installed sprinklers after 20 years[1] in for example storage risks, with rejection criteria for fast-response sprinklers being 50 $(m*s)^{1/2}$. A limited decrease in RTI is therefore accepted over time (type approval requirements for ESFR sprinklers is 36 $(m*s)^{1/2}$). Just like for opening temperature and K-factor, RTI monitoring must be given extra attention if a sprinkler is chosen with a certain RTI value which leads to a reduction in spray area, for example.

[1] NFPA25:2023; 20 years for ‘ESFR and CMSA with fast-response elements’ and 25 years for other ‘fast-response’ under favorable conditions, like in offices and homes.

3 The sample size

The purpose of testing is to obtain a representative overview of the effect of aging and contamination on the operation of the installed sprinklers. In order to determine the correct sample size, it is important to understand the spread of test results and any differences between different types of sprinklers. If certain tests show a relatively large spread in test results, a larger sample size will be needed to get a clear picture than for tests whose test results have less spread.

3.1 K-factor and functional test

As stated in section 2.1, there is a considerable spread in the K-factor decrease of sprinklers from the same batch. In particular, the K-factor decrease due to fouling appears to be highly dependent on local conditions. This also applies to the sprinkler not opening, because the seal remains stuck. A large sample size is necessary to obtain a representative overview. The minimum batch size set by VdS2091 for the functional and K-factor test (at least 16 pieces) does match our findings and seems to be a good basis. We do note that we observe major differences per type of sprinkler from the same installation, and therefore believe that the batch size mentioned should apply per brand/type of sprinkler. The sample size that VdS2091 prescribes reduces to 0,32% of installed sprinklers per building, which is very low given the spread in test results and sample size. NFPA 25:2023 uses a 1% sample size for field service test to assess RTI. Because here too the variations in test results strongly depend on the circumstances, this sample size is also justifiable for K-factor and functional test. The minimum batch size of 4, as stated in NFPA 25 for field service testing, is insufficient for this specific test.

3.2 Opening temperature

The analysis of our test results shows that the 'sliding' of the opening temperature cannot be ruled out. It does appear, however, that the variations in opening temperature observed within the same batch of identical sprinklers are smaller than the variations of the K-factors within a batch of the same type of sprinklers. As a result, a smaller sample size seems justifiable to provide a representative picture of the installed sprinklers. The batch size mentioned in VdS2091 of 4 per 5000 sprinklers per building and equal conditions amounts to 0.08%. This sample size is too limited if the choice of the opening temperature has led to a reduction of the performance requirements (reduction of spray density or spray area). Comparing the functional and K-factor test results with those of the opening temperature results (8% vs 2%), a similar batch size reduction seems justifiable (0,25% with a minimum of 4 sprinklers). The sample size should apply at least per brand and type of sprinkler, whereby the same definition can be used for the type as used by NFPA for the sample size for field service testing on RTI.

3.3 Thermal sensitivity (RTI)

In the field service testing, NFPA only describes the assessment of the RTI. The K-factor test and functional test are not part of the field service testing. The sample size of NFPA is 1% of the number of sprinklers with a minimum of 4 per sampling area. It is important that the sample is representative of the sampling area and that all types and manufacturers of sprinklers in that area are part of the sample. Because local conditions can cause large differences in the type and degree of pollution, a considerable spread of the test results can be expected. This justifies the minimum sample size of 1% per brand and type of sprinkler. It is important to realize that to determine the RTI, two different tests must be carried out in the wind tunnel. During these tests the test results of opening temperature [°C] and speed [s] are used to calculate the RTI. If several types and manufacturers of sprinklers are present in an object, the minimum sample size must be set at four per type and manufacturer.

4 The test frequency

As stated, the purpose of the tests is to determine the effect of aging and contamination on the performance requirements of the installed sprinklers. The effect on the effectiveness of the sprinkler system, due to the reduction of certain performance requirements, differs per protection concept. It is therefore important to determine quickly what the expected decrease in performance requirements is over time and what effect that decrease will have on the operation of the chosen sprinkler concept. A rapid decrease in a certain performance requirement that has a major impact on the reliable operation of the sprinkler system, triggers the need to determine that possible decrease in the performance requirement as quickly as possible. With the current insights, we have experience with sprinklers that are being tested for the first time. The effect of aging and time is expected to increase exponentially. NFPA has already gained experience with this, and has therefore increased the follow-up frequency for the field service test.

4.1 K-factor and functional test

The test results of the tests carried out by Kiwa FSS testing (see 2.1) show that the K-factor reduction of sprinklers that were installed no longer than 20 years ago can be substantial. The same goes for blocking the outflow after activation, caused by the closing plate not being released. Based on the findings of Kiwa FSS, the starting point of VdS2091 (to perform a functional and K-factor test for sprinklers that have been in operation for 25 years), does not seem too soon. Our data show that testing after 20 years in operation is quite justifiable.

4.2 Opening temperature

The spread of the test results with regard to opening temperature is less than that of the K-factor and functional test, but here too, sprinklers up to 20 years old still show substantial deviations. Given the limited percentage of deviations of more than 10°C, a test after 25 years of assembly, in line with VdS2091, seems useful. For practical reasons, this frequency could be increased to that of the K-factor and functional testing.

4.3 Thermal sensitivity (RTI)

In the Netherlands we do not yet have any experience with the effect of aging and contamination on the RTI. Based on data from UL, NFPA does have insight into this and has recently adjusted the frequencies to the new statistics. NFPA 25:2023 has set the frequency for determining the RTI of fast response sprinklers in polluting conditions such as storage risks unchanged at 20 years. The frequency for such sprinklers in more favorable conditions, such as office environments, has been increased to 25 years. For both conditions, the sprinklers should be retested every 10 years to monitor the RTI.

5 When are sprinklers good?

The purpose of testing is to determine whether sprinklers activate in a timely manner and distribute the water in the right amount and spray pattern. What is 'in time' and 'in the right amount' depends on the chosen security concept and circumstances.

5.1 K-factor and functional test

When it comes to the functionality of the sprinklers, the requirement in NFPA 25 is: 0,5 bar or minimum 'listed' opening pressure. NFPA 25 does not provide criteria for the allowable K-factor reduction. In America, many installations are connected to public water supply systems. These water supply systems have higher capacities and pressures than in Europe. For European sprinkler installations, we should therefore focus on the European regulations and our available test results for the K-factor test.

For the K-factor, assessment criteria for sprinkler installations based on CEA 4001 have been formulated in the VdS2091. A reduction of the K-factor of an individual sprinkler to 10% of the nominal value is considered normal after 25 years of operation. The rejection criteria of VdS 2091 are a combination of the test results of the response temperature and those of the functional test and K-factor test. Basically, the K-factor means that an average K-factor reduction of up to 15% is acceptable if the K-factor reduction of each individual sprinkler does not exceed 30%.

As stated in 2.1, the K-factor reduction cannot be considered separately from the hydraulic conditions of the pipeline network as well as the user conditions (i.e. how much hydraulic change is available). However, the VdS 2091 considers the assessment of the sprinklers separately from the hydraulic condition of the pipe network. Exceeding the rejection criteria of VdS 2091 should therefore not be seen as a limit for the possible replacing of the sprinklers, but as a limit for additional investigation.

In addition, in systems where the spray areas are smaller than the CEA 4001 systems, such as ESFR, the question must be asked whether an average K-factor reduction of 15% is acceptable. The malfunctioning of sprinklers in such systems has a greater effect on the proper functioning of the whole, as is the case with CEA 4001 systems. An average K-factor reduction of 10% compared to the nominal value seems more justifiable for such systems.

5.2 Opening temperature

For the opening temperature, VdS 2091 has formulated assessment criteria that have a bandwidth of 20°C with respect to the type approval criteria from before 1999. As a result, glass cartridge sprinklers with a nominal response temperature of 68°C, for which the upper limit of the type approval criteria is 86° C, will exceed the assessment only at 106°C. For sprinklers

manufactured after 1999, for which the type approval criteria has an upper limit of 71°C (for CEA 4001 and equivalent systems after 1999) an upper limit of 91°C would be more appropriate.
For systems where reductions of spray surfaces have been realized on the basis of the temperature classifications, a bandwidth of 20°C with regard to the type approval criteria is still very wide. Considering the test results as stated in section 2.2, a bandwidth of 10°C is more appropriate here.

5.3 Thermal sensitivity (RTI)

As can be seen from section 2.3, timely activation of the sprinkler is very important. Insufficient European test results are available regarding the effect of aging and contamination on the RTI. Regarding to the conditions in which sprinklers are located (and which have an effect on aging and contamination), there are no significant differences with the American installations, which are maintained and tested on the basis of NFPA 25.
In NFPA 25:2020, the following rejection criteria are indicated for testing old sprinklers with regard to RTI. Exceeding these rejection criteria leads to replacement of the sprinklers, for which the batch was a representative sample.

Type sprinkler	Maximum RTI $[(ms)^{1/2}]$
Standard response	250
Quick response and residential	65
ESFR	50

6 In conclusion

The impact of aging and fouling of sprinklers on the effectiveness of a sprinkler protection system depends on the protection concept chosen. In addition, the spread of the test results determines the sample size and an effective test frequency can be determined on the basis of existing experience and test results. To make laboratory tests reproducible and mutually comparable, the tests must be performed according to the test methods as described in EN 12259-1, ISO 6182-1, UL199 and FM2000 or FM2008.

Based on the experiences and analyses mentioned in this whitepaper, the tables included in this paragraph indicate for each type of protection system which tests, sample size, inspection criteria and test frequencies would lead to an effective and efficient approach to increase confidence in the effectiveness of sprinkler protection.

K-factor and functional test					
Type security	Sample size	Minimum batch size	Rejection criteria	Frequency	
				Initial	Follow-up
All systems	1% per manufacturer/type sprinkler per building	16	• Opens not at 0,5 bar (or min. listed opening pressure) • Individual K-factor < 70% van $K_{nominal}$ • Consider average K-factor batch related to hydraulic condition of network.	20 years	15 years

Opening temperature					
Type security	Sample size	Minimum batch size	Rejection criteria	Frequency	
Reductions on spray surfaces and/or spray density requirements	1% per manufacturer/type sprinkler per building	16	More than ±10°C in relation to type approval criteria	20 years	15 years
Other systems	0,25% per manufacturer/type sprinkler per building	4	More than ±20°C in relation to type approval criteria	20 years	15 years

<table>
<tr><th colspan="8">Thermal sensitivity (RTI)</th></tr>
<tr><th rowspan="2">Type security</th><th rowspan="2">Sample size</th><th rowspan="2">Minimum batch size</th><th rowspan="2" colspan="2">Rejection criteria $[(m.s)^{1/2}]$</th><th colspan="3">Frequency [year]</th></tr>
<tr><th>First test</th><th>Follow-up</th><th>Age ≥ 75 year</th></tr>
<tr><td>ESFR and CMSA fast response sprinklers</td><td>1% per manufacturer/type sprinkler per building</td><td>4</td><td colspan="2">>50</td><td>20</td><td>15</td><td>5</td></tr>
<tr><td>Other fast response sprinklers</td><td>1% per manufacturer/type sprinkler per building</td><td>4</td><td colspan="2">>65</td><td>25</td><td>15</td><td>5</td></tr>
<tr><td rowspan="3">Sprinklers under harsh (corrosive) operational circumstances</td><td rowspan="3">1% per manufacturer/type sprinkler per building</td><td rowspan="3">4</td><td>Standard response</td><td>>250</td><td rowspan="3">5
10[1]</td><td rowspan="3">5</td><td rowspan="3">5</td></tr>
<tr><td>Quick response and residential</td><td>>65</td></tr>
<tr><td>ESFR</td><td>>50</td></tr>
<tr><td rowspan="3">Solder joints ≥163°C</td><td rowspan="3">1% per manufacturer/type sprinkler per building</td><td rowspan="3">4</td><td>Standard response</td><td>>250</td><td rowspan="3">5</td><td rowspan="3">5</td><td rowspan="3">5</td></tr>
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<tr><td>ESFR</td><td>>50</td></tr>
<tr><td rowspan="2">Dry sprinklers</td><td rowspan="2">1% per manufacturer/type sprinkler per building</td><td rowspan="2">4</td><td>Standard response</td><td>>250</td><td rowspan="2">20</td><td rowspan="2">10</td><td rowspan="2">5</td></tr>
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<tr><td>Quick response and residential</td><td>>65</td></tr>
<tr><td>ESFR</td><td>>50</td></tr>
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[1] If listed as ‘corrosion resistant’