Response Characteristics of Glass Bulb Sprinkler Heads Mounted in a Paint Spray Booth

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Abstract

The response of sprinklers mounted in a paint spray booth is usually influenced by paint covering the heat-sensitive element. To avoid this problem, sprinklers are often covered to prevent the paint from accumulating on the heat-sensitive element. The influence of various numbers of paint layers and different types of covers on the response time of two different types of glass bulb sprinkler heads has been investigated. Both wind-tunnel tests and large-scale fire tests were performed in the test series.

It was found that covers delayed the activation of the sprinklers considerably, though a faster response was obtained with a quick response sprinkler than with a standard response sprinkler. It was found that the accumulated paint on the heat-sensitive element also affected the response time, but not nearly as much as the covers. It was also found that a paint layer covering both the glass bulb and the frame acted as a glue; the consequence was that the spray pattern of the sprinkler was considerably affected.

Introduction

Problems associated with the accumulation of paint on sprinkler heads, mostly in paint spray booths, have been recognized in Swedish industry. Corresponding problems may arise in redecoration, as when ceilings are painted, or when the sprinkler head is located in an environment where dirt and grease may accumulate on the heat-sensitive element. Very little is known about the effects of this on the response time of a sprinkler.

To avoid the problems in paint spray booths, the sprinkler heads are often covered with bags. These bags are usually replaced regularly to avoid excess accumulation of paint. The consequence may be that the response time is significantly prolonged. In this study, the response time was found, in most of the large scale-tests, to increase by factor of two to five when the sprinkler head was covered with a bag. This is, of course, a disadvantage as it will reduce the ability of the sprinkler system to control or suppress a fire. The function of the sprinkler system must not be jeopardized under any circumstances, as an ensuing fire may be very hazardous. However, the other choice–to let the paint accumulate on the heat-sensitive element–can have greater disadvantages as it can affect both the spray pattern and the response time. This can be solved by replacing the paint-covered sprinkler heads regularly, but this is obviously an

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expensive solution. Experience shows that some companies do not replace paint-covered sprinkler heads or the covers for up to three month or more. In many cases, the sprinkler heads will be covered with so much paint as to be unrecognizable as sprinkler heads.[1]

Recommendations concerning the problem of overspray residue on sprinkler heads can be found in the literature. The *Fire Protection Handbook*[2] says that the use of paper, polyethylene, or cellophane bags to protect sprinklers in spray booths is fairly common. The *Fire Protection Handbook* also recommends using a coating of grease, motor oil, or soft neutral soap to facilitate washing or wiping deposits off sprinklers that are conveniently accessible. In that case, however, they should be cleaned very frequently.

Another publication that addresses the problem of overspray residue accumulation on sprinkler heads in paint spray booths is NFPA 33, *Spray Application Using Flammable and Combustible Materials*.[3] Paragraph 7-5 states that sprinkler heads in paint spray booths "shall be cleaned and protected against overspray residue so that they will operate quickly in event of fire. If covered, polyethylene or cellophane bags having a thickness of 0.076 mm or less, or thin paper bags shall be used. Coverings shall be replaced or heads cleaned frequently so that heavy deposits of residue do not accumulate."

A literature survey showed that no response tests on sprinkler heads mounted in a paint spray booth had been undertaken in the U.S. or the U.K. The Fire Protection Association in the U.K. was unable to find any references in their library of tests undertaken elsewhere in the world.[1] An article in the *Mather and Platt Fire Protection Handbook* refers only to tests undertaken with sprinkler heads painted during the redecoration of ceilings and the underside of roofs; it does not refer to heads installed in paint spray booths. The need for tests with sprinkler heads covered with a bag or overspray residue was therefore evident.

One problem with glass bulb sprinklers, which is perhaps more important than the problem of prolonged response times, was investigated in the test series. A paint layer covering both the glass bulb and the frame may act as a glue, the possible consequence of which may be that the glass envelope and the release button become glued to the frame. This may affect the spray pattern of the sprinkler. In the current study, only glass bulb sprinklers were tested. This type of sprinkler is used extensively in Europe, but it is not the usual installation in paint spray booths in the U.S. or Canada.

Experiments

Both plunge tests[4] and large-scale fire tests were performed. The plunge test is a standardized testing procedure for investigating the response of sprinklers. The large-scale fire tests were performed in a test room measuring 9.6 m by 6 m by 3 m high. The sprinkler was mounted at the center of the ceiling, and a heptane fire was located 1.5 m or 2.8 m from the sprinkler. The gas temperature inside the covers over the sprinkler was measured during the tests, as was the gas temperature and velocity close to the sprinkler.

TABLE 1
Average Response Times and RTI Values from Plunge Tests

Sprinkler	Remarks	Average Total Thickness of Paint Layers (mm)	Average Time to Operation (s)	RTI ($m^{1/2}s^{1/2}$)
∅ 3 mm	No paint		7.5	37.8
	4 layers of paint	0.166	8.0	40.5
	8 layers of paint	0.289	10.2	51.4
∅ 8 mm	No paint		31.0	157.4
	4 layers of paint	0.139	33.5	170.3
	8 layers of paint	0.326	47.6	242.5
∅ 8 mm	Sprinkler covered with plastic bag (based on two tests)		155.7	793

Note: In each test series, five sprinklers were used except for the tests carried out with the sprinkler covered. The gas temperature was 197°C, the gas velocity was 2.5 m/s, and the initial sprinkler temperature was 22°C.

Two types of glass bulb sprinklers were tested: 3 mm quick response type (ϕ 3 mm) and 8 mm standard response (ϕ 8 mm) type. The ϕ 3 mm sprinkler head was a Viking QR Cu/p with a temperature rating of 68°C, and the ϕ 8 mm sprinkler was a TWF ECK 15, also with a temperature rating of 68°C. Both sprinkler types had an orifice diameter of 15 mm.

The sprinklers were painted with an atomizer at a fixed distance from the sprinkler. Each sprinkler was painted several times to build up a uniform layer over the sprinkler head. The atomizer was applied at four different angles, each for a fixed time of 2 seconds, to obtain an even thickness of each paint layer. The paint was allowed to dry after each application. The total thickness of the paint was determined with the aid of a microscope with which the thickness could be measured with an accuracy of up to 10^{-6} m. In Tables 1 (plunge test) and 2 (large-scale test), the total thickness of the paint is given as an average of three samples from each sprinkler head.

Knowledge of the realistic thicknesses of the paint covering sprinkler heads in a paint spray booth was limited before the tests. Later, it was stated[1] that, in a real installation, the paint thickness can be greater than tested, or from 1 mm to so much paint that the sprinkler head is unrecognizable. The maximum thickness of the paint on a sprinkler head tested in the large-scale test series was 0.39 mm. It was very

TABLE 2
Results of Large-Scale Tests on Glass Bulb Sprinklers

Test No.	Bulb Dia-meter (mm)	Test Conditions	Total Thickness of the Paint Covering the Sprinkler (mm)	Distance Between Sprinkler and Fire Source (m)	Time to Operation (s)
1	**∅ 8**	**No paint on the sprinkler**		**2.8**	**68.4**
2	∅ 8	No paint on the sprinkler		2.8	69.6
3	∅ 8	4 layers of paint	0.122	2.8	68.3
4	∅ 8	8 layers of paint	0.300	2.8	70.2
5	∅ 8	12 layers of paint	0.375	2.8	76.4
6	∅ 8	Plastic bag, no paint		2.8	193.0
7	∅ 8	Tea-bag, no paint		2.8	264.2
27	∅ 8	Tea bag, no paint		2.8	288.2
13	**∅ 8**	**No paint on the sprinkler**		**1.5**	**48.2**
20	∅ 8	4 layers of paint	0.140	1.5	42.4
21	∅ 8	8 layers of paint	0.305	1.5	63.1
14	∅ 8	12 layers of paint		1.5	51.5
15	∅ 8	Plastic bag, no paint		1.5	118.6
16	∅ 8	Tea-bag, no paint		1.5	115.8
8	**∅ 3**	**No paint on the sprinkler**		**2.8**	**24.8**
9	∅ 3	12 layers of paint	0.370	2.8	32.0
10	∅ 3	Plastic bag, no paint		2.8	148.3
11	**∅ 3**	**No paint on the sprinkler**		**1.5**	**21.4**
22	∅ 3	12 layers of paint	0.390	1.5	29.0
12	∅ 3	Plastic bag, no paint		1.5	81.8
17	∅ 3	Tea-bag, no paint		1.5	48.7
25	∅ 3	Tea-bag, no paint		1.5	73.7
23	∅ 3	Paper-bag, no paint		1.5	96.7
24	∅ 3	Paper-bag, painted		1.5	83.5
26	∅ 3	Very thin plastic film (Clingfilm) without paint wrapped around a steel wire frame		1.5	28.0
19	∅ 3	Tea-bag, nitrate string bent around the bag		1.5	22.3

difficult to obtain exactly the same total thickness for each sprinkler head. This explains the internal difference in thicknesses for the same number of paint layers (see Tables 1 and 2). The paint used in the tests was the same as that used to paint truck chassis at the SCANIA T& B plant in Södertälje. The paint was supplied by SCANIA T&B. The composition of the paint is as follows:

Exylene 30 to 60 %
Propyleneglycolmethylether 1 to 5 %
Alcydhartz 30 to 60 %
Pigment 5 to 30 %
Other materials 1 to 5 %

Plunge Tests

Before the large-scale test series, several wind-tunnel tests (plunge tests) were carried out to obtain an introductory knowledge of the variation in response to paint of different thicknesses. In this test series, the effect of a plastic bag on the response time was tested, as well. The maximum paint layer thickness of a sprinkler head tested in the wind-tunnel was 0.326 mm (see Table 1). The ϕ 8 mm sprinkler was painted with the glass bulb mounted in the frame, while the glass bulb of the ϕ 3 mm sprinkler was painted separately.

In the standardized plunge test[4] method, the gas temperature and velocity are kept constant. The sprinkler is "plunged" into the airstream, and the time to operation is registered. The wind tunnel used for the plunge test was constructed in accordance with the Fire Research Station[5] wind tunnel in the U.K.

The RTI (Response Time Index) [4,6] value of the sprinkler was calculated from the gas temperature, the velocity, and the response time. See Table 1 for the average RTI values (five sprinklers were tested in each test series except for the sprinkler tested with covers). The gas temperature in the plunge test was 197°C, the gas velocity was 2.5 m/s, and the initial sprinkler temperature was 22°C.

The conduction parameter *C* defined by Heskestad and Bill[7] was not determined for the sprinklers used. The *C* parameter includes the effects of heat losses from the heat-sensitive element to the sprinkler fitting.

Discussion of Results of Plunge Tests

For the ϕ 3 mm sprinkler, the response times were prolonged somewhat by the number of paint layers used in the tests (see Table 1). The maximum increase in response time and RTI value was 36%, compared to the sprinkler with no paint. The thickness of the paint used for this sprinkler was 0.289 mm. No ϕ 3 mm sprinklers covered with bags were tested in the plunge test. It was observed that, in one test, the glass bulb cracked and the sprinkler operated but the paint glued the glass envelope together and prevented the release button from falling down.

The ϕ 8 mm sprinkler was somewhat more sensitive to the total paint thickness. For 0.326 mm of paint, the response time and the RTI value increased by about 54%. For

0.139 mm of paint, the increase was only 8%. The increase in RTI value does not appear to be linear with increasing thickness. In Figure 1, the normalized response times (see Table 1) are shown as a function of the thickness of the paint.

The thick paint that covered both the glass bulb and the frame on the ϕ8 mm sprinklers had a tendency to act as a glue so that the glass envelope and the release button became glued to the frame. In the case of a real fire, this might affect the spray pattern of the sprinkler considerably. These effects were observed in the large-scale test series for the glass-bulb-type sprinklers.

The plastic bag affected the response time considerably, by a factor of five. The plastic bag consisted of polyethylene 0.04 mm thick, with flat dimensions of 80 mm by 140 mm. The plastic bag wrinkled immediately around the frame; in one case, the glass bulb broke, but the plastic bag did not tear.

The Large-Scale Tests

The large-scale fire tests were carried out in a test room constructed in a large hall at the Fire Laboratory of the Swedish National Testing Institute in Borås. The test room consisted of a horizontal ceiling and two vertical walls, which made up the sides of the test room. One side of the room was completely open. The internal dimensions of the

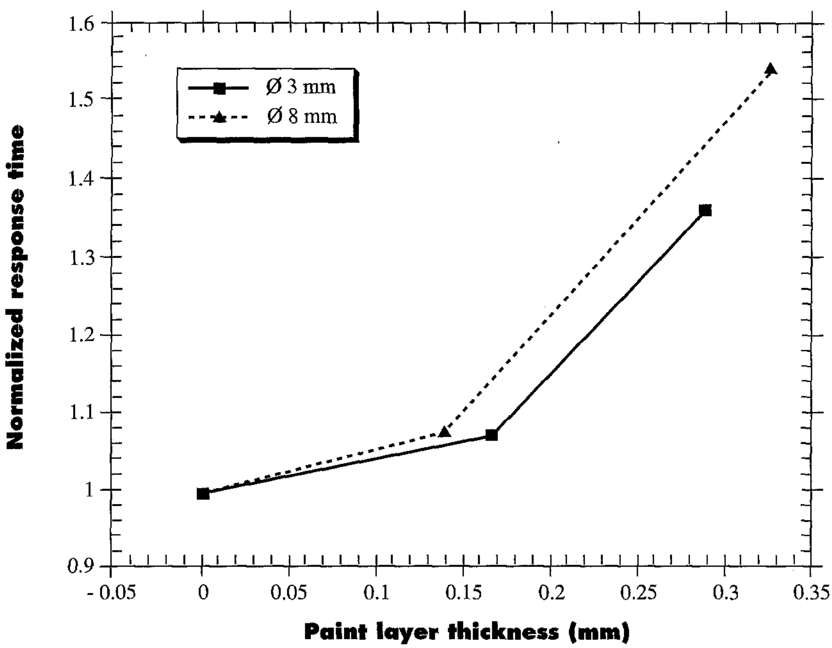

Figure 1. The normalized response time of the tested sprinklers in a plunge test is shown as a function of the thickness of the paint layer.

test room were 6 m by 9.6 m. It was 3 m high. The test hall measured 18 m by 22.3 m by 20 m high and consisted of an insulated steel construction. The fire source, which had a diameter of 0.87 m, was heptane floating on water. The ceiling clearance above the surface of the heptane fire was 2.55 m. The test set-up is shown in Figure 2.

The ceiling was made of Navilite N boards 9.5 mm thick mounted in a standard T-profile steel frame system. Each frame measured 1.22 m by 0.63 m. The thermal conductivity of the Navilite N board was 0.12 W/m°C and the density was 700 to 780 kg/m^3. These data were taken from Wetterlund.[8] The specific heat was assumed to be 800 kJ/kg. The heat loss through the ceiling was not measured. The walls were constructed of gypsum boards 13 mm thick attached to a wood frame measuring 3 m by 1.2 m.

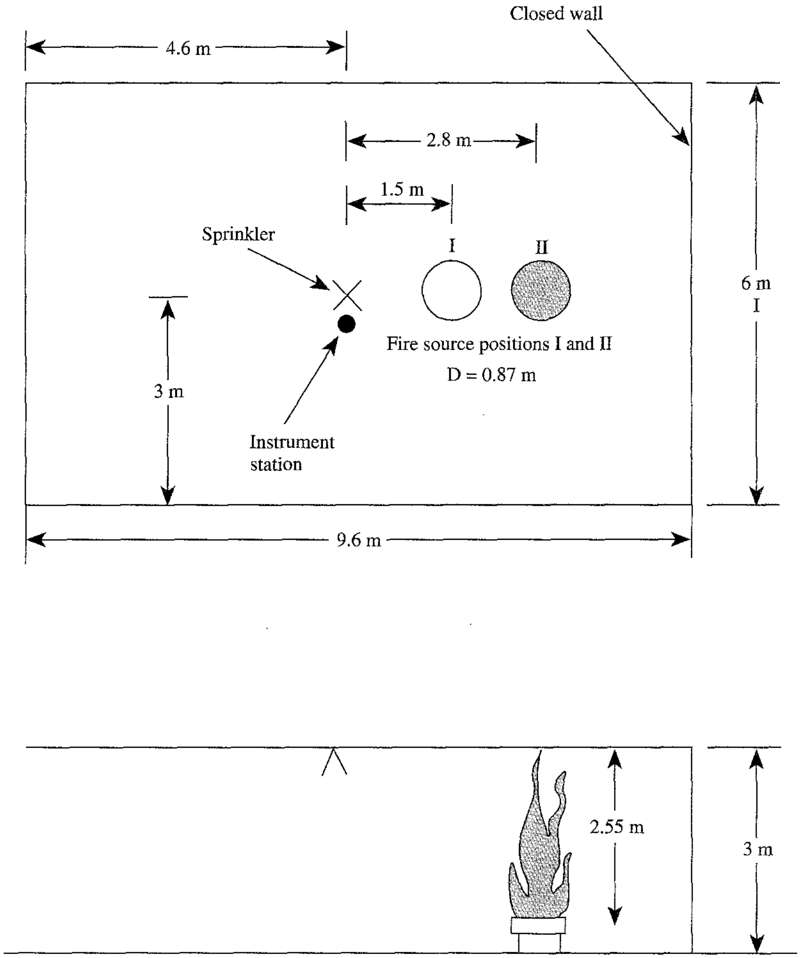

Figure 2. The test set-up for the large-scale tests.

The sprinkler, which was mounted at the center of the ceiling, was screwed into 19 mm steel pipe couplings that extended 0.06 m from the ceiling and were attached to pipe nipples just below the ceiling. The nipples were fitted to a 25 mm horizontal steel pipe above the ceiling. After a sprinkler had been installed for testing, the pipe on which it was mounted was filled with water. A manual air valve was connected to the horizontal steel pipe to avoid air entrapment. The steel pipe was connected to a water pump, and the water flow was monitored and recorded during the test. The water flow was adjusted to the minimum water flow allowed by the Swedish sprinkler rules RUS 120:3 1987, which is 56.61 l/s for sprinklers with a K-factor of 80. This corresponds to a pressure of 0.5 bar at the sprinkler. The sprinkler types used were the same as those used in the wind tunnel tests (ϕ3 mm and ϕ8 mm). The water temperature in the sprinkler's waterway was measured before each test and was found to vary between 16.5°C and 19°C. The response time of the sprinkler was recorded manually with a stopwatch.

Beside the sprinkler was an instrument station consisting of five thermocouples (Type K thermocouples with a diameter of 0.25 mm) used to measure the gas temperature and a bi-directional flow probe used to measure the gas velocity. The data were recorded by 3530 ORION Data Logging Systems and stored on a Digital PDP 11/23 Plus main-frame computer. Every 1 to 2 seconds, the temperatures and the pressure (velocity) were recorded. The pressure difference for the velocity measurements was recorded using a Furness micromanometer. All data analysis was carried out on a Digital VAX 8350 main-frame computer. The relation between pressure and velocity included corrections for the variation in the Reynolds number according to calibration curves reported in McCaffrey and Heskestad.[9] The instrument station was located 100 mm to one side of the sprinkler (see Figure 2). The thermocouples were mounted 50 mm, 100 mm, 150 mm, and 350 mm below the ceiling, and the bi-directional probe was mounted 100 mm below the ceiling. One thermocouple was mounted at sprinkler height. The center of the glass bulb was placed 80 mm below the ceiling. The sprinkler head was pendent, and the arms of the sprinkler frame were perpendicular to the ceiling jet flow.

The heptane fire typically reached steady state after about 30 seconds at a heat release rate of approximately 1200 kW. This value was found by measuring the heat release rate separately under a large fire product collector at the Swedish National Testing and Research Institute. The design of the fire product collector is similar to that used at the Factory Mutual Research Corporation in the U.S.[10] The flame tip of the heptane fire was deflected by the ceiling, and the flame leaned slightly towards the back wall of the test room. Figures 3 to 6 present gas temperatures and velocities measured by the ceiling instrument station for two different locations of the fire source, 1.5 m and 2.8 m. In the tests shown in Figures 3 to 6, the ϕ8 mm sprinkler was covered with a tea bag. In Figures 3 and 5, it can be seen that the temperature is almost the same between 50mm and 150 mm below the ceiling, while the temperature of the ceiling jet begins to decline between 150 mm and 350 mm.

Test Procedure and Results

The results of the large-scale test series are presented in Table 2. All tests were recorded on video. The ϕ 8 mm (standard response) sprinkler was tested with 4, 8, and 12 layers of paint on the sprinkler head, while the ϕ 3 mm (quick response) was tested with only 12 layers. The maximum total thickness of paint on a sprinkler head tested in the large-scale tests was 0.39 mm (see Table 2).

The covers over the sprinklers were of different types. One was a plastic (polyethylene) bag 0.04 mm thick with a flat dimension 80 mm by 140 mm. A tea bag 0.05 mm thick with dimensions of 90 mm by 130 mm was also used, as was an ordinary paper bag 0.08 mm thick measuring 125 mm by 180 mm. The fourth type of cover was a very thin plastic film called "Clingfilm." The covers were fastened to the sprinkler pipe above the sprinkler head with steel wire. The plastic film was wrapped around a steel frame built around the sprinkler. In one test (Test 19), a nitrate string was bent around a tea bag covering the sprinkler. The objective was to see whether the nitrate string would burn off very quickly and consequently burn off the bag.

The fire source was ignited with matches, and the response time was determined with the aid of a stopwatch. After the sprinklers activated, the characteristics of the spray were observed to ascertain whether it had been affected by the covering material or the paint. The gas temperature inside the bags was recorded in some of the tests.

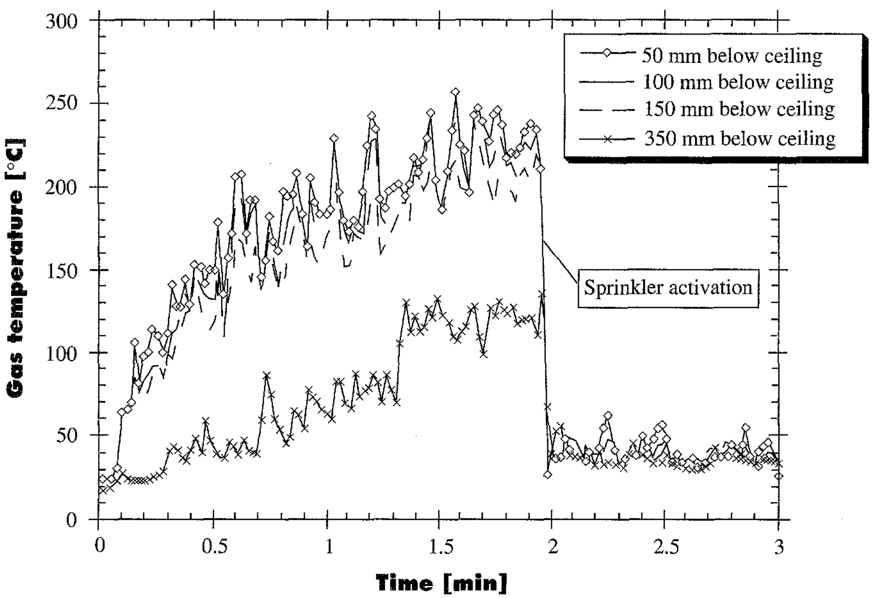

Figure 3. Gas temperature as a function of height. The fire source was 1.5 m from the sprinkler, and a tea bag was used to cover the sprinkler (ϕ 8 mm).

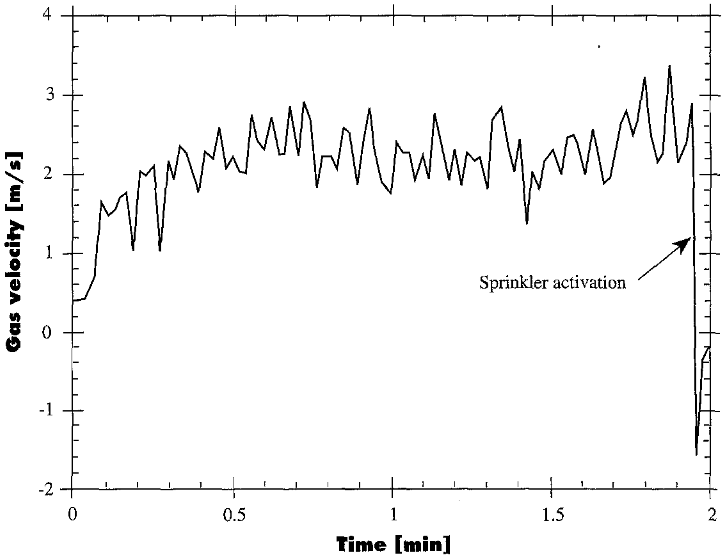

Figure 4. The gas velocity at the instrument station. The fire source was 1.5 m from the sprinkler, and a tea bag was used to cover the sprinkler (ϕ8 mm).

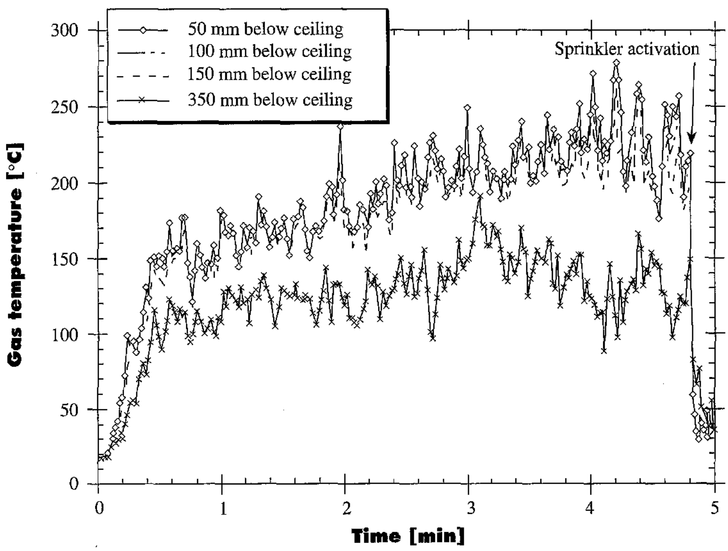

Figure 5. Gas temperature as a function of height. The fire source was 2.8 m from the sprinkler, and a tea bag was used to cover the sprinkler (ϕ8 mm).

In Figure 7, the temperature both inside and outside the tea bag covering is shown (Test 16). The fire source was 1.5 m from the sprinkler, and the thermocouples used were of Type K with a diameter of 0.25 mm. The temperature inside the bag was about 90°C when the sprinkler responded. The heat transfer to the glass bulb inside the covering was probably dominated by natural convection.

Discussion of Results of Large-Scale Tests

The covers delayed the response of the sprinkler considerably, in most cases by a factor of two to five. As an example, the response time for the ϕ 8 mm sprinkler was increased by 182% at a distance of 2.8 m from the fire and by 146% at 1.5 m when covered. Corresponding values for the ϕ 3 mm sprinkler were 498% and 230%, respectively.

The ϕ 3 mm sprinkler responded considerably faster than the ϕ 8 mm sprinkler when covered with a bag. The gas temperature inside the covering was found to be considerably lower than outside for some of the bags tested. The gas temperature inside the bags at sprinkler response varied, depending on the type of covering material. To give an example of the order of magnitude, the temperature was about 160°C for the plastic bags, about 120°C for the paper bags, and about 90°C for the tea bags. The gas temperature outside the covering material at sprinkler response was about 210°C. The heat transfer to the heat-sensitive element apparently differs, depending on the type of cover.

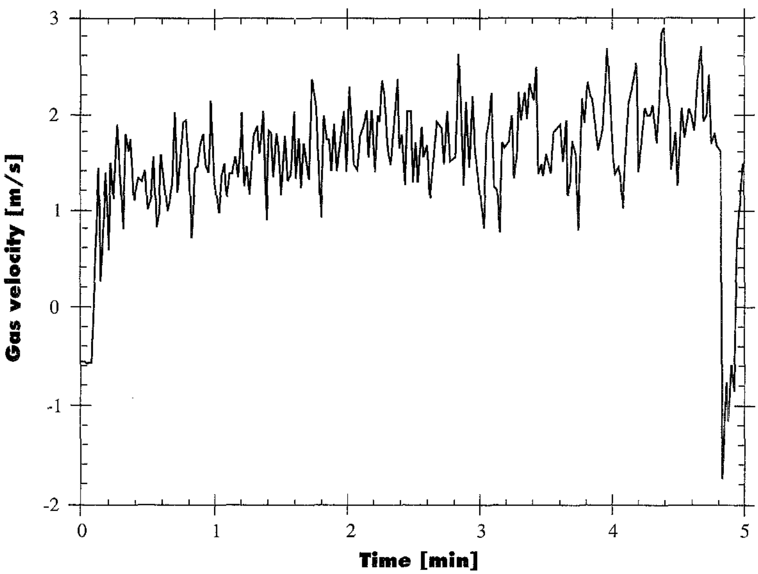

Figure 6. The gas velocity at the instrument station. The fire source was 2.8 m from the sprinkler, and a tea bag was used to cover the sprinkler (ϕ 8 mm).

It was also found that the accumulated paint on the heat-sensitive element affected the response time but not nearly as much as the covers did. The normalized response times for the ϕ 3 mm and the ϕ 8 mm sprinklers are shown in Figure 8. The response time is normalized to the response time without paint or coverings.

The covers did not burn off during the tests despite the fact that they were located relatively close to the flame tip. The plastic bags shrank to the sprinkler frame and influenced the spray pattern. The vertical flame was deflected by the ceiling, and the horizontal flame tip pulsed between 0.5 m to 1.0 m from the sprinkler when the sprinkler was 1.5 m from the fire source.

Paint covering both the glass bulb and the frame acted as a glue. As a consequence, the glass envelope and the release button became glued to the frame in some cases. In some of the fire tests, the spray pattern of the sprinkler was therefore affected considerably. In these tests, the sprinklers were tested with minimum water pressure, 0.5 bar. In one test (Test 21) in which the spray pattern was affected, the water pressure was increased from 0.5 bar to 3.4 bar. As a result, the release button and the glass envelope were washed completely away. For thicker paint layers, the bulb and the button might not be washed away. For paint layers thicker than those tested, the spray pattern will probably also be influenced by the paint on the sprinkler deflector.

In Test 19, a nitrate string was bent around a tea bag covering a ϕ 3 mm sprinkler 1.5 m from the fire source. The nitrate string ignited after 31 seconds, and the sprinkler

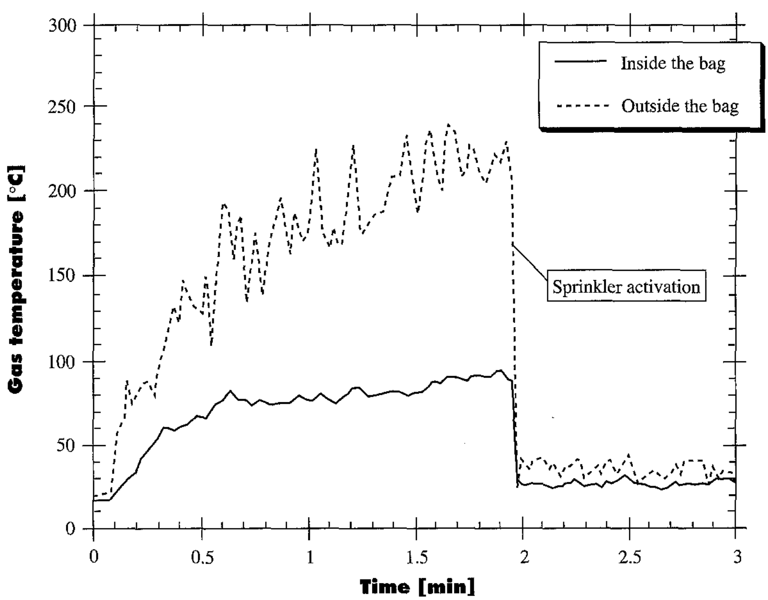

Figure 7. The gas temperature inside and outside a tea bag covering a sprinkler. The sprinkler was 1.5 m from the fire source.

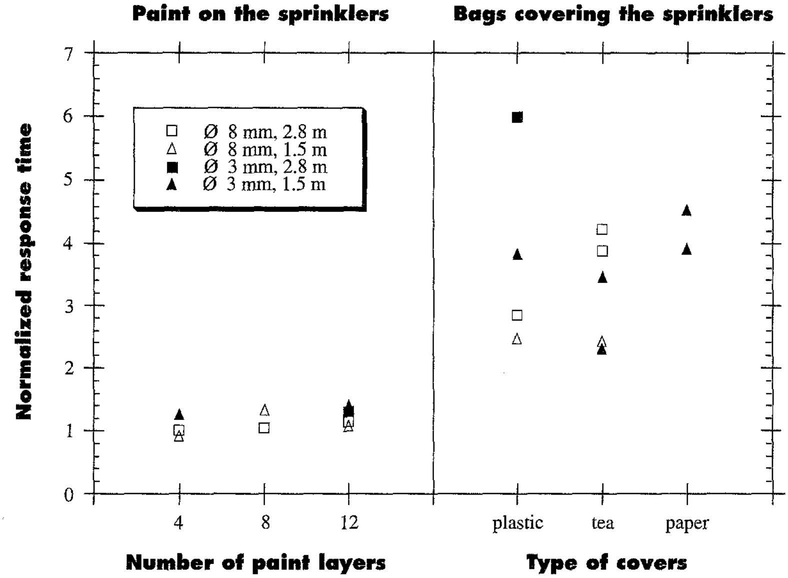

Figure 8. The normalized response time for the ϕ3 mm and ϕ8 mm sprinklers. The response time is normalized to the response time without paint or covers. The left-hand side of the graph represents painted sprinklers and the right-hand side sprinklers tested with covers. The sprinklers were tested at 1.5 m and 2.8 m from the fire, respectively.

responded after 33.2 seconds. When the sprinkler was tested with only a tea bag, the response time was 48.7 seconds.

As mentioned earlier, the covers delayed the sprinkler response considerably. This is, of course, a major disadvantage as it can influence the ability of the sprinkler to suppress or control the fire. However, the other choice–to let the paint accumulate on the heat-sensitive element–can have greater disadvantages as it can affect both the spray pattern and the response time. It is also very expensive to regularly replace paint-covered sprinklers. Therefore, a possible choice is to use a cover, which burns off at low gas temperatures (between 100°C to 200°C) but which is, at the same time, very robust. This would mean that the sprinkler would respond faster and that the problem of the paint acting as a glue would not arise. Materials such as the plastic film tested showed positive results, but it is probably not robust enough to be used in industrial installations. The use of a nitrate string also gave positive results. Further investigation of alternative materials or methods with which sprinklers may be covered is desirable.

Conclusions

It was found that the tested covering materials delayed sprinkler response considerably, by a factor of two to five in most cases. The covers did not burn off during the test, despite the fact that they were located relatively close to the flames.

The gas temperature inside the covers over the sprinkler was found to be considerably lower than the temperature outside. At sprinkler response, it varied depending on the type of material used.

The quick response sprinkler still responded faster when covered than the standard response sprinkler did when covered. With covers, the quick response sprinkler operated about one and a half to two and a half times faster than the standard response sprinkler.

It was found that the accumulated paint on the heat-sensitive element affected the response time but not nearly as much as the sprinkler covers did. In order of magnitude, the delay was about 10 times greater when the sprinklers were covered than it was when the sprinklers had paint on them.

Materials that burn off at low gas temperatures (but are, at the same time, very robust) are probably the most appropriate for use as sprinkler covers. Further investigation is desirable.

Other problems were encountered. The paint sometimes glued the glass bulbs and the release button to the frame at 0.5 bar operating pressure. In some of the fire tests, the spray pattern of the sprinkler was affected considerably. At 3.4 bar operating pressure, this phenomenon disappeared. This indicates that, at higher operating pressures than the minimum operating pressure, this problem may become less important. Another problem was that the plastic bags wrinkled around the sprinkler frame and influenced the spray pattern when the sprinkler operated.

The influence of different numbers of paint layers on the response time of a sprinkler was more definite in the wind tunnel tests than it was in the large-scale tests.

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