NISTIR 6191

Demonstration Of Biodegradable, Environmentally Safe, Non-Toxic Fire Suppression Liquids

Daniel Madrzykowski
David W. Stroup, Editors

July 1998

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Technology Administration
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Federal Emergency Management Agency
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CHAPTER 5

CLASS A FIRE SUPPRESSION EXPERIMENTS

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CLASS A FIRE SUPPRESSION EXPERIMENTS

5.1 Wood Crib Fire Suppression Experiments

This section reports on two studies conducted at NIST on the suppression of wood crib fires and tire fires. An overview of previous research on the use of water based fire suppression agents on wood cribs and tires is provided. A burning pile of rubble or a burning pile of tires, these are examples of fuel limited fires. If a fire has an adequate supply of oxygen, the size of the fire is limited by the fuel. The primary means of suppressing a fuel limited, deep seated fire is cooling.

5.1.1 Background

Wood cribs are a widely used fuel source for fuel limited fire suppression experiments. Underwriters' Laboratories (UL) has utilized wood cribs as a standard fire for rating fire extinguisher tests for many years [1]. Research conducted by Tamanini indicates that rapid knockdown can be obtained with flows greater than 0.0065 kg/s/m^2 [2].

In 1993, the National Fire Protection Research Foundation (NFPRF) sponsored a study [3] to examine the fire suppression effectiveness of a Class A foaming agent. The type of crib used in that study was a Class 20-A, as defined in [1]. The crib is constructed of nominal 50 mm x 200 mm (2 in x 4 in) fir sticks. Each stick is 1.58 m (62.25 in) long. The crib has 10 layers each with 15 sticks evenly spaced. The cribs are ignited with 17 l (4.5 gal) of heptane in a 1.85 m^2 (20 ft^2) pan. In accordance with ANSI/UL 711, a crib of this design can be extinguished with a 125 lpm (33 gpm) straight stream of water within 60 seconds. For this test series, 57 lpm (15 gpm) flows of water and agent solution were used. Manual applications of the single agent used for the tests included a straight stream nozzle, an aspirated nozzle and compressed air foam. Three different agent solutions were used during the test series: 0.1%, 0.3%, 0.5%. Given the test design, if the agent was successful at completely extinguishing the fire it would have demonstrated twice the level of performance relative to water.

In all cases, the agent outperformed plain water by suppressing the flames within 60 seconds. Unfortunately, none of the agent applications completely extinguished the fire. In all cases the crib, reignited. Therefore this test series demonstrated an increased efficiency, less than a factor 2.

In 1994, under the sponsorship of the U.S. Army, UL conducted another series of crib tests to examine the fire suppression effectiveness of seven different Class A agents [4]. A straight stream, self aspirating nozzle was used with a 57 lpm (15 gpm) flow rate for all of the tests. The fuel load consisted of a 20 A crib, as in the previous test series. In 21 of the 24 agent tests, the agent outperformed water by knocking down the flames, but all reignited after agent application stopped. In 7 of the 21 tests, reignition occurred within 20 seconds or less. Similar to the previous UL tests, the agents demonstrated an increased efficiency less than a factor of two.

5.1.2 Experimental Procedure

A series of crib fire tests were conducted to examine the impact of the selected agents on heat release rate. Cribs for the test series were assembled from a combination of Southern pine lumber, acrylonitrile butadiene styrene (ABS) and polyvinyl chloride (PVC) sticks. Each crib consisted of 10 layers, with each layer containing seven 55.88 cm (1.8 ft) long sticks of 3.81 cm (1.5 in) x 3.81 cm (1.5 in) cross section and each successive layer laid crosswise to the previous layer (Figure 1). These cribs are similar in design to the cribs burned by Gross [5], Block [6], and Bryner et al [7]. Southern pine was selected to represent the framing lumber found in typical residential structures. The ABS sticks were selected to represent the asphaltic roofing, carpeting, and polyurethane furnishings while the PVC sticks were added to simulate the vinyl tile and PVC plumbing components from a house fire. All the cribs were assembled approximately one month before the first scheduled fire test. This allowed all the cribs to reach about the same moisture content before the first crib was burned. The moisture content of each crib ranged from 6 to 8% as measured using two different types of conductivity moisture meters. Each crib weighed between 29 and 34 kg (63.8 and 74.8 lb) of which approximately 3.2 kg (7 lb) was PVC and 2.6 kg (5.8 lb) was ABS.

An isometric view of the suppression apparatus is shown in Figure 2. As shown in the figure, nozzles were located adjacent to each of the four sides of the crib. Each nozzle was positioned approximately in the middle of the side and at a level equal to the height of the crib. The typical nozzle spray angle was between 20° and 30° for the pressures used in the test series. The nozzles were angled to provide a spray pattern covering about two-thirds of the top and three-fourths of the side facing the nozzle. Data regarding agent, number of nozzles, nozzle pressure, and total flow rate are shown in Table 1. Either two nozzles on opposite sides of the crib or four nozzles adjacent to each side were used for the tests.

5.1.3 Analysis

Heat release rate versus time for three configurations demonstrate the reproducibility of the crib fires (Figures 3 - 5). Peak heat release rates ranged from 300 to 400 kW. Total heat released from the cribs ranged from 90 to 120 MJ.

As shown by the sharp heat release rate decreases in Figures 3 and 5 after "Extinguishing Agent Applied", the four nozzle configurations using flow rates of 7.8 lpm (2.1 gpm) and 6 lpm (1.6 gpm) easily extinguished the crib fires. There was not any discernable difference between the agents or plain water. The two nozzle configuration with a flow rate of 5.4 lpm (1.4 gpm) did not extinguish the fire. Some variation in heat release rate is evident in Figure 4 after application of the extinguishing agents. From visual observations of the tests, incomplete extinguishment appeared to be due primarily to inability of the nozzles to reach all parts of the burning crib and not to any differences agent extinguishment capability.

5.1.4 Conclusions and Recommendations

The various agents used in this series of experiments did not significantly alter the performance of water in reducing the heat release rate from a wood crib fire. When the water or agent could reach the burning surface, the fire was readily extinguished. The heat release rate data does not provide any useful information for identifying any differences in the extinguishing capabilities. More research work would be required to develop these experiments into an appropriate test procedure.

5.2 Tire Fire Suppression Experiments

In the United States, more than 240 million tires are discarded each year. The national inventory of scrap tires is estimated at 3 to 4 billion [8]. Piles of burning tires are extremely difficult to extinguish. The tires shed water, the shape of the tire provides shielded areas for burning, the synthetic rubber in tires can have an auto ignition temperature as low as 200 °C [9] and tires contain steel which is heated and then is insulated by the synthetic rubber. Therefore cooling and extinguishing a pile of burning tires can be difficult.

The difficulty of fighting a tire fire has been demonstrated in the field many times. A fire in Winchester, VA consumed between 6 and 9 million tires and burned for 9 months [8]. Three million tires burned outside of Hudson, CO in 1987 [10]. In Hagersville, Ontario a fire consumed several million tires during a seventeen day period [11].

In 1990, tests were conducted at Lawrence Livermore National Laboratory to evaluate the effectiveness of liquid fire suppression agents on stacks of burning tires [12]. Twelve tires were stacked three to a layer and allowed to become fully involved in the fire. Agents were discharged from a fixed spray nozzle at 57 lpm (15 gpm). Applications were made for 1 minute and stopped. If the tires were still burning, a two minute period was allowed for fire redevelopment and another 1 minute application was made. This sequence was repeated for a third application if necessary. Plain water could not extinguish the fire. Eleven agents were tested, four of the agents including a "wetting agent" and an AFFF performed similar to water. Seven of the agents were able to suppress the fire, therefore demonstrating an effectiveness greater than water. Three of the agents used in the study, are on the 1995 U.S. Forest Service QPL [13]. These Class A agents did extinguish the fire after three applications. No replicate tests were conducted.

Another series of tire fire suppression experiments were conducted in England in 1991 [9]. The fire scenario consisted of dual mounted tires, positioned and shielded as if they were mounted on a tractor-trailer. A wide variety of water-based agents were used in the tests: flouroprotein -3%, film-forming fluoroprotein-3%, alcohol resistant film-forming flouroprotein-3%; aqueous film-forming foam-3%, alcohol resistant film-forming foam-3%, a synthetic-3%, a wetting agent-1%, and two other products identified by their trademark only. The results showed that the fire could be put out with water at approximately 50 lpm (13 gpm) in 20 seconds or less, if the firefighter was in close proximity to the fire. If the firefighter's access was limited due to safety concerns, the attack would be made from a distance. For this test series a distance of 4.1 m (13.5 ft) was chosen. From that distance, firefighters using a narrow water spray (approximately 15°) and a flowrate of 100 lpm (26.5 gpm) had an average suppression time of 152 seconds. The average was taken from four tests with results ranging from 142 s to 163 s. Since the limited access case was more challenging the remainder of the tests fires were conducted with this scenario.

Of the agents tested, the synthetic foam, applied with an aspirating nozzle, had the shortest suppression time, extinguishing the fire in 48 s or approximately three times faster than water. The synthetic foam applied with a non-aspirating nozzle, had a time to suppression of 106 s. Three replicate tests were conducted with non-aspirated and aspirated AFFF. The average time to suppression for both types of application was 93 s. The results ranged from 72 to 111 s. The wetting agent had the longest suppression time, relative to the other agents, with a time of 146 seconds. This result is similar to the results from the tests using plain water.

5.2.1 Experimental Procedure

The objective of these experiments was to demonstrate the fire suppression effectiveness of liquid supression agents on tire fires relative to plain water. The matrix of agent and application combinations used in the tire suppression experiments is shown in Table 2. The National Institute of Standards and Technology prepared a test area at the University of Maryland, Maryland Fire and Rescue Institute, Western Regional Training Center near Cumberland, MD. The area had a sand bed over a plastic liner to prevent run-off of suppression agents and tire residue (Figure 6). Nine tires, arranged as three layers of three were stacked on an expanded metal deck for each test. The average mass of tires used in each test was 74.7 kg (165 lbs). The standard deviation of the mass of the tires was ±4.6 kg (10 lb) or 6%. The tires were ignited with a diesel fuel fire contained in a 0.5 m (20 in) diameter pan 0.18 m (7 in) deep (Figure 7). 750 ml (0.2 gal) of diesel was used for each experiment. Suppression was not started until the diesel fuel had burned itself out and the tire pile was fully involved with flames. This resulted in pre-burn times ranging from 255 s to 420 s. Photographs of the tire experiments during preburn and at the start of suppression are shown in Figures 8 and 9, respectively.

The agents were all batch mixed in separate containers, pumped with a diaphragm pump and delivered via a 25 mm (1 in) internal diameter, 15.2 m (50 ft) long hoseline. The spray nozzle was an commercially available, adjustible spray nozzle set to a narrow fog pattern of approximately 15° and a flow rate of 30 lpm (8 gpm) ±0.5 lpm (0.14 gpm) of plain water. The aspirating nozzle (AN) was a commerically available, "tube type" nozzle with an internal bore of 20 mm (0.8 in). For the compressed air foam (CAF) applications, a commercially available, residential scale, compressed air foam generator was used. A 25 mm (1 in) quarter turn, ball valve was served as the nozzle.

The agents were applied manually. The same firefighter was used for all of the experiments. A few trials were conducted to determine the best test procedure, flow rate and to acclimate the firefighter to the test procedure. Based on previous tire fire studies [9], suppression was attempted from a fixed position away from the tire pile. Suppression could not be achieved using this technique due to the amount of self-shielding provided by the shape of the tire and configuration of the tire pile. As a result, the method used for experiments allows the firefighter to have unrestricted access to the tire pile during suppression.

The flow rate used for the tire fire suppression experiments was 30 lpm (8 gpm) with a variance of less than 10 %. Depending on the agent and the application, the flow rates varied from lows of 28 lpm (7.4 gpm) to highs of 31.4 lpm (8.3 gpm). Before each experiment, the flow rate was measured. This procedure involved flowing the suppression system into a 113.5 l (30 gal) container for two minutes and determining the flow rate based on mass. If a foaming agent was used, then the expansion and drainage would also be checked at this time. The expansion and drainage were measured following the procedures given in NFPA 11, Standard for Low-Expansion Foam, Appendix C [14].

The experimental procedure is as follows, after the preburn the firefighter would open the nozzle to start the flow of firefighting agent as he approached the burning tire pile. The timer recording time to suppression starts as soon as the firefighter applies agent to the tires. The firefighter aggressively knocks down the fire and begins moving around the tire pile suppressing the shielded fires inside and under the tires. When no more fire is visible, suppression is stopped and the time to suppression recorded. The tire pile remained under observation to determine if a reignition of the tire pile would occur. The period of observation was 30 minutes or 1800 seconds.

5.2.2 Results and Discussion

A total of 31 suppression experiments were conducted. Five baseline water experiments were conducted. The average time to suppression was 286 seconds with an average reignition time of 365 seconds after suppression was stopped. The results from the water spray experiments are given in Table 3. Even though the experiments are designed to be reproducible, notice that the suppression times range from 125 to 390 seconds. This could be due to slight variations in the fuel configuration as the tires burn and melt or due to variations in the firefighter's attack. These results emphasize the importance of conducting multiple experiments for a given scenario.

The results for the tire fire experiments utilizing suppression agents other than water are provided in Tables 4, 5, and 6. The results are grouped by means of application: fog nozzle or spray, air aspirating nozzle, and compressed air foam. Given the limited number of experiments with each agent for each type of application, it is difficult to determine any relative difference between the agents.

Table 4 shows the results of eight suppression experiments, two with each agent, using the spray nozzle. The foam produced by the spray nozzle was extremely wet and runny. This is indicated by the very low expansion ratios and the very fast drain times. The suppression times are reasonably consistent with an average of 88.6 s within a range of values from 70 to 115 s. There do not appear to be any discernable correlations between time to suppression or application time and the time to reignition. Applying a two-sided normal test [15] to the time to suppression results from the water and the solution spray experiments demonstrates that the mean of the solution results are statistically significantly different (less) than the mean of the plain water spray results with 95% certainty. Based on the mean values, the tests have shown that for the given flow rate of 30 lpm (8 gpm), approximately one third the amount of solution produces the same results as water, with similar rekindle times.

Table 5 shows the results of eight suppression experiments, two with each agent, using the air aspirated nozzle. The foam produced by the nozzle was still wet and runny. Again as indicated by the low expansion ratios and fast drain times. With the exception of one data point, the time to suppression results have an average of 91.6 seconds within a range very similar to the spray application experiments, 75 s to 111s. The one exception of 153 s increases the average to 99.3 s, as well as the upper limit of the range.

The compressed air foam application, fire suppression results are given in Table 6. The larger expansion ratios and the longer drain times are representative of a moderately wet foam. Four of the experiments, out a set of ten, yielded suppression times approximately 50% faster than the average for the spray and self aspirated nozzle applications. The remaining six were in a range similar to that of the previous applications. As a result the average time to suppression is only slightly lower. However, 5 of the 10 of the experiments did not reignite within the half hour observation period. More foam remained visible in and on the tires after the CAF applications than it did with the two previous applications. This may account for the increase in time to reignition.

Based on the average times between the application types and by reviewing a graph (Figure 10)of the times to suppression, it appears that for this type of fire and intimate firefighting approach, the application technique had minimal if any impact on the time to suppression. Averaging the results of all 26 experiments utilizing a foaming agent produces a mean of 87.1 s. This average time to suppression is 30% of the average time to suppression using water.

Comparing these results to the previous studies provides some insight into what properties may be important to increasing the effectiveness of liquid fire suppression agents. In the tests conducted by Johnson [9] and Hasegawa [12], the agents identified as "wetting agents" performed similar to water. The reports do not provide any details on the agents. One of the principle characteristics or advantages is the reduction of the surface tension of water to which the agent is added. This is the same advantage the synthetic-hydrocarbon based agents used in this study have. The synthetic agents in this study performed better than water, which is in agreement with the results of the two previous studies. Perhaps the detergents or emulsifiers in the synthetic agents enhance water over and above the advantage due to surface tension reduction by having a high affinity for carbon. This advantage would demonstrate itself best on a fuel such as tires which contain a high fraction of carbon.

5.3 References

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Table 1. Summary of Agent Used, Nozzle Pressures, and Total Flow Rate for Test Series

Test No.	Agent	Pressure (kPa)				Total Flow Rate (lpm)
		Nozzle 1	Nozzle 2	Nozzle 3	Nozzle 4	
1	A – 1%	248	248	Not Used	Not Used	4.8
2	B – 1%	265	265	Not Used	Not Used	5.4
3	C – 3%	290	276	Not Used	Not Used	5.4
4	D – 3%	321	321	Not Used	Not Used	5.4
5	Water	179	179	172	172	7.8
6	A – 1%	193	165	165	172	7.8
7	B – 1%	193	159	159	172	7.8
8	C – 3%	186	186	186	186	7.8
9	D – 3%	193	193	193	193	8.4
10	Water	221	221	Not Used	Not Used	4.8
11	A – 1%	103	103	103	103	6
12	Water	97	97	97	97	6
13	B – 1%	103	103	97	97	6
14	C – 3%	103	103	97	97	6
15	D – 3%	103	103	103	103	6
16	C – 3%	110	110	110	110	6
17	A – 1%	276	276	Not Used	Not Used	5.4

Table 2. Test Matrix

Suppression Agent	Application Method
Water	Spray Nozzle
Agent A 1% Solution	Spray Nozzle
Agent A 1% Solution	Aspirating Nozzle
Agent A 1% Solution	Compressed Air Foam
Agent B 1% Solution	Spray Nozzle
Agent B 1% Solution	Aspirating Nozzle
Agent B 1% Solution	Compressed Air Foam
Agent C 3% Solution	Spray Nozzle
Agent C 3% Solution	Aspirating Nozzle
Agent C 3% Solution	Compressed Air Foam
Agent D 3% Solution	Spray Nozzle
Agent D 3% Solution	Aspirating Nozzle
Agent D 3% Solution	Compressed Air Foam

Table 3. Tire Fire Suppression Results - Water Spray

Flowrate (lpm (gpm))	Time to Suppression (s)	Time to Reignition (s)
31.0 (8.2)	305	390
30.7 (8.1)	235	280
29.9 (7.9)	125	445
29.9 (7.9)	390	300
29.9 (7.9)	375	405
Average Times	286	364

Table 4. Tire Fire Suppression Results – Solution Spray Application

Agent	Flowrate (lpm (gpm))	Expansion Ratio	25% Drain Time (s)	50% Drain Time (s)	Time to Suppression (s)	Time To Reignition (s)
A	28.0 (7.4)	1.5	<60	<60	72	125
A	28.0 (7.4)	3.5	<60	<60	95	255
B	28.8 (7.6)	1.6	<60	<60	70	230
B	28.8 (7.6)	1.6	<60	<60	75	105
C	30.7 (8.1)	1.6	<60	<60	87	138
C	30.7 (8.1)	1.6	<60	<60	90	440
D	30.7 (8.1)	1.5	<60	<60	115	560
D	30.7 (8.1)	1.5	<60	<60	105	1175
Average Times					88.6	378.5

Table 5. Tire Fire Suppression Results - Aspirated Nozzle Application

Agent	Flowrate (lpm (gpm))	Expansion Ratio	25% Drain Time (s)	50% Drain Time (s)	Time to Suppression (s)	Time To Reignition (s)
A	31.1 (8.3)	4.6	<60	120	75	85
A	31.1 (8.3)	4.6	<60	124	110	70
B	31.1 (8.3)	5.4	<60	65	85	185
B	31.1 (8.3)	5.4	<60	<60	111	None
C	29.9 (7.9)	6.6	<60	80	153	None
C	29.9 (7.9)	5.5	<60	<60	80	None
D	29.5 (7.8)	4.2	<60	<60	85	130
D	29.5 (7.8)	4.4	<60	<60	95	175
Average Times					99.3	550

Note: Values of 1800 s were used in place of "None" for purposes of calculating the Time to Reignition average.

Table 6. Tire Fire Suppression Results - Compressed Air Foam Application

Agent	Flow Rate lpm (gpm)	Expansion Ratio	25% Drain Time s	50% Drain Time s	Time to Suppression s	Time To Reignition s
A	30.7 (8.1)	8.0	260	540	55	None
A	30.7 (8.1)	8.0	275	570	53	97
B	30.7 (8.1)	12.9	186	306	20	165
B	30.7 (8.1)	12.1	126	214	93	None
B	30.3 (8.0)	13.9	191	325	105	None
C	30.3 (8.0)	10.9	161	254	45	None
C	30.7 (8.1)	10.9	163	256	85	360
C	30.3 (8.0)	8.3	236	346	87	810
D	30.3 (8.0)	10.3	137	351	112	973
D	30.3 (8.0)	11.4	110	198	80	None
Average Times					73.5	1140.5

Note: Values of 1800 s were used in place of "None" for purposes of calculating the Time to Reignition average.

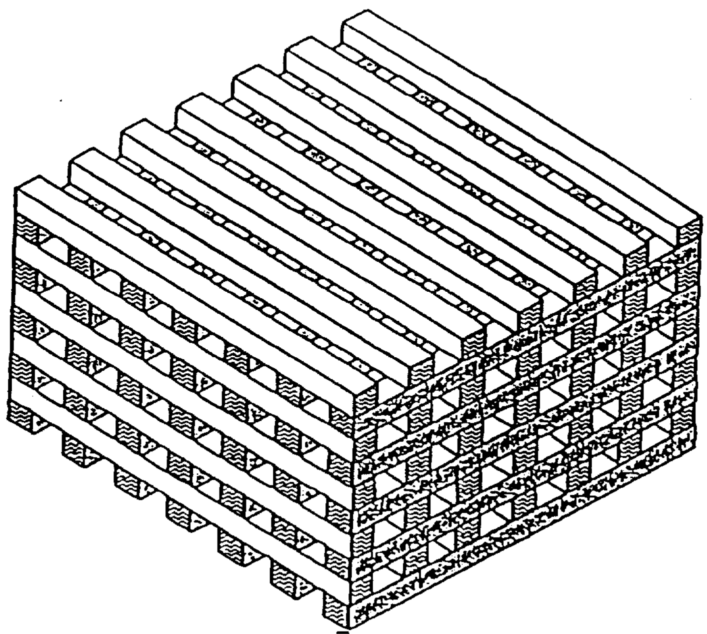

Figure 1. Diagram of crib (55.9cm X 55.9cm X 38cm high) used for suppression experiments

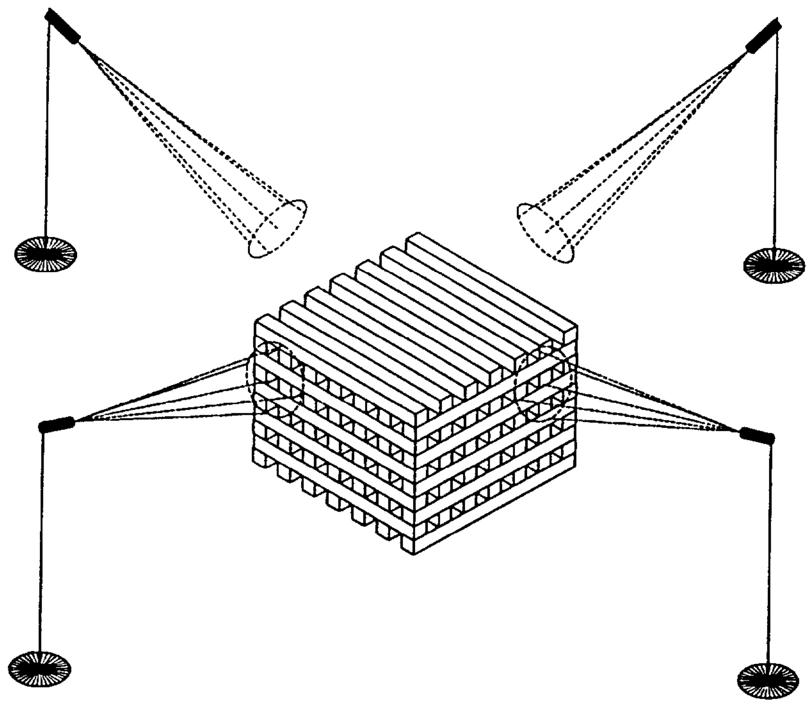

Figure 2. An Isometric view of the suppression apparatus

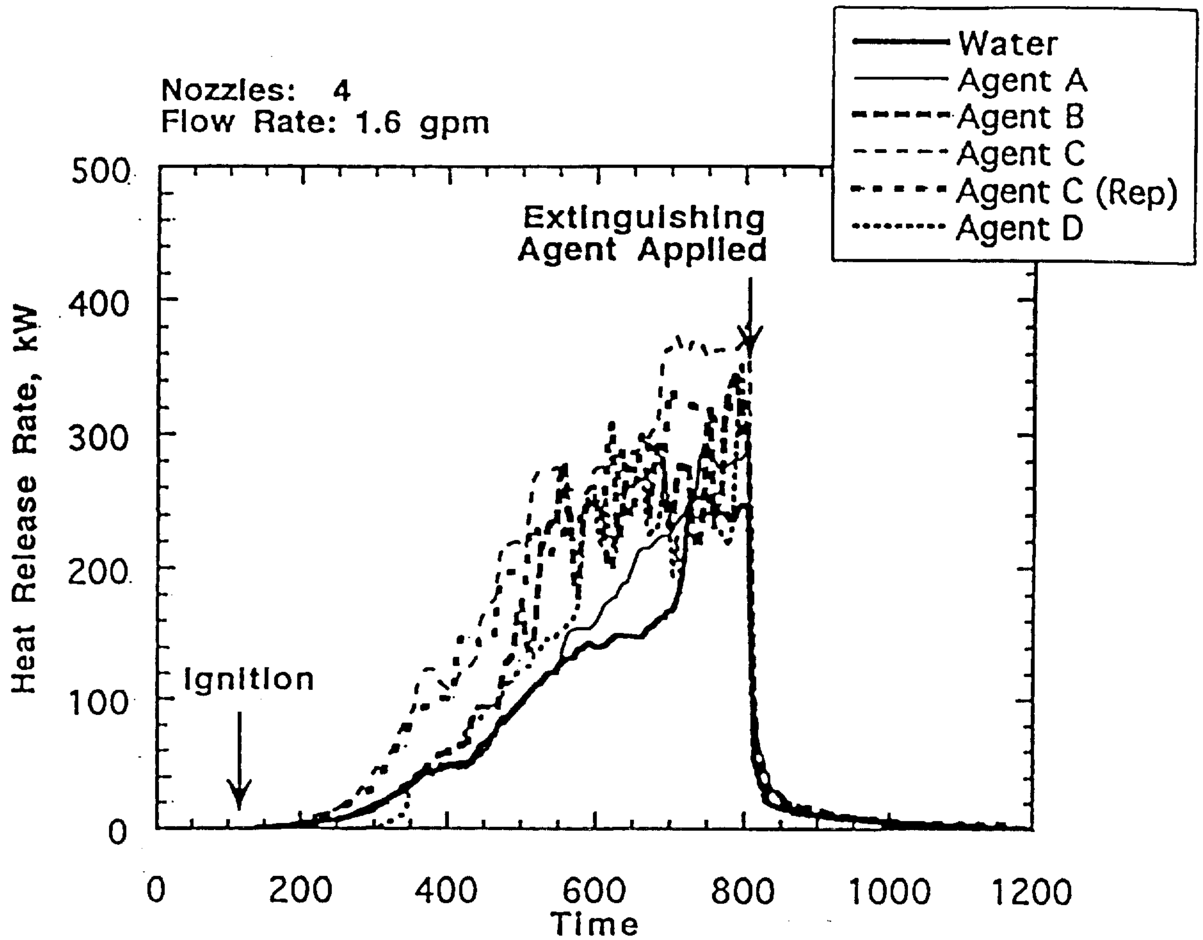

Figure 3. Heat release rate with four nozzles at 6 L/min (1.6 gpm)

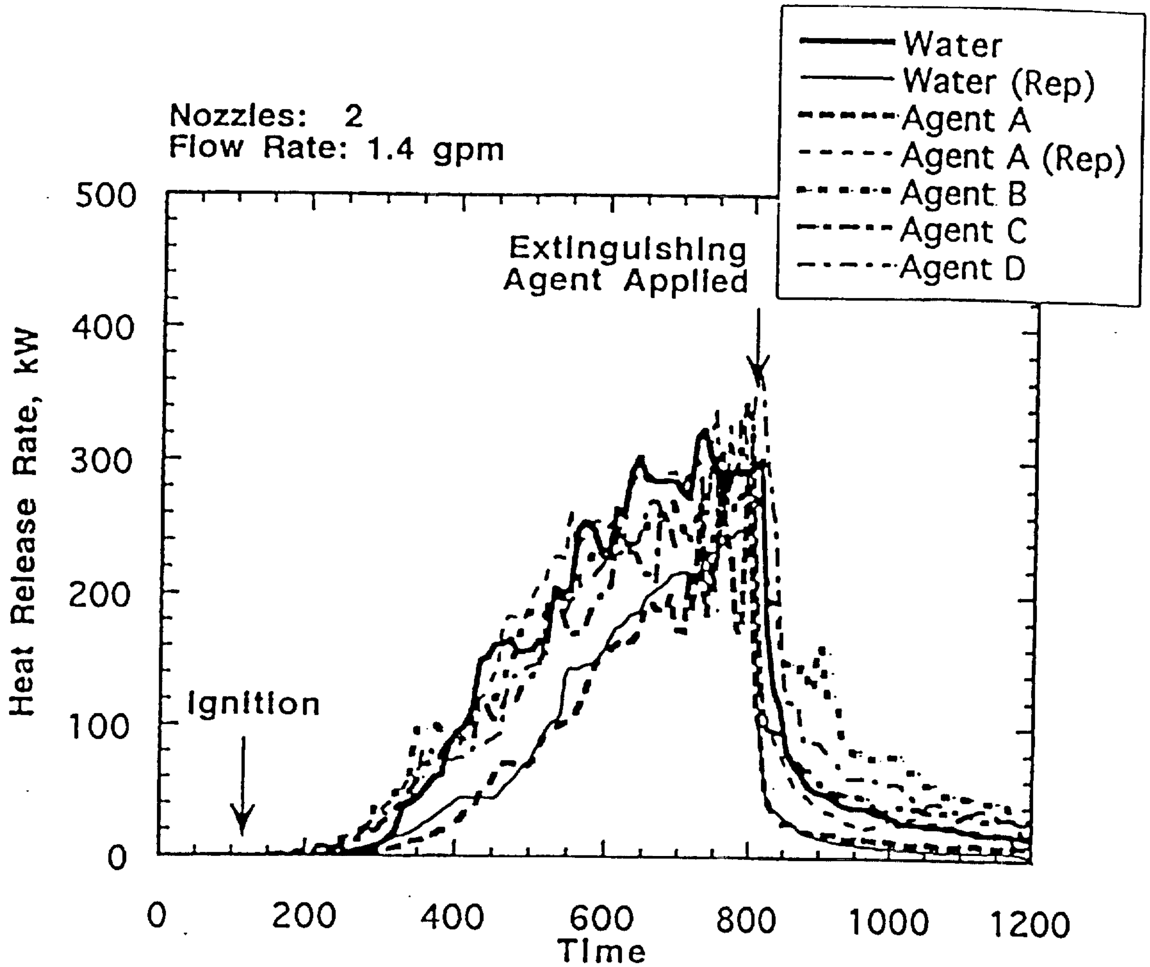

Figure 4. Heat release rate with 2 nozzles at 5.4 L/min (1.4 gpm)

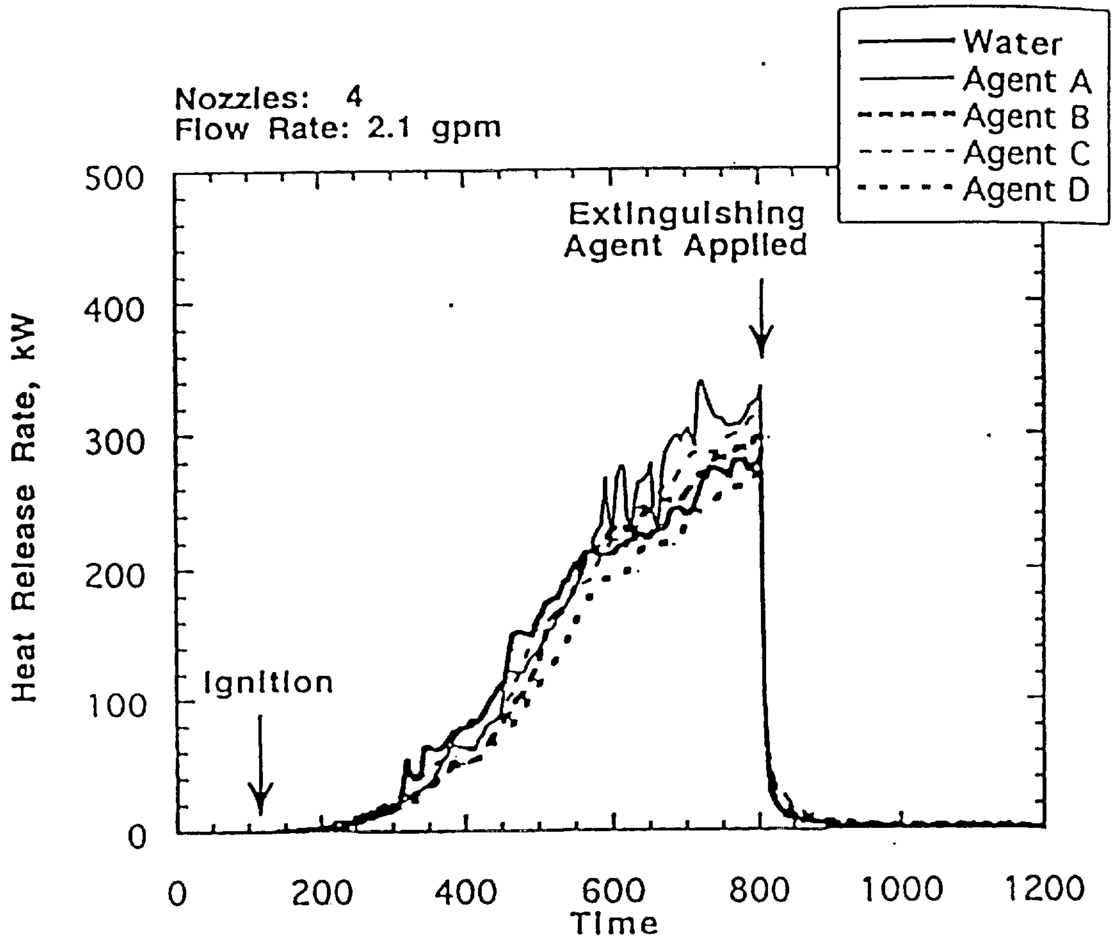

Figure 5. Heat release rate with four nozzles at 7.8 L/min (2.1 gpm)

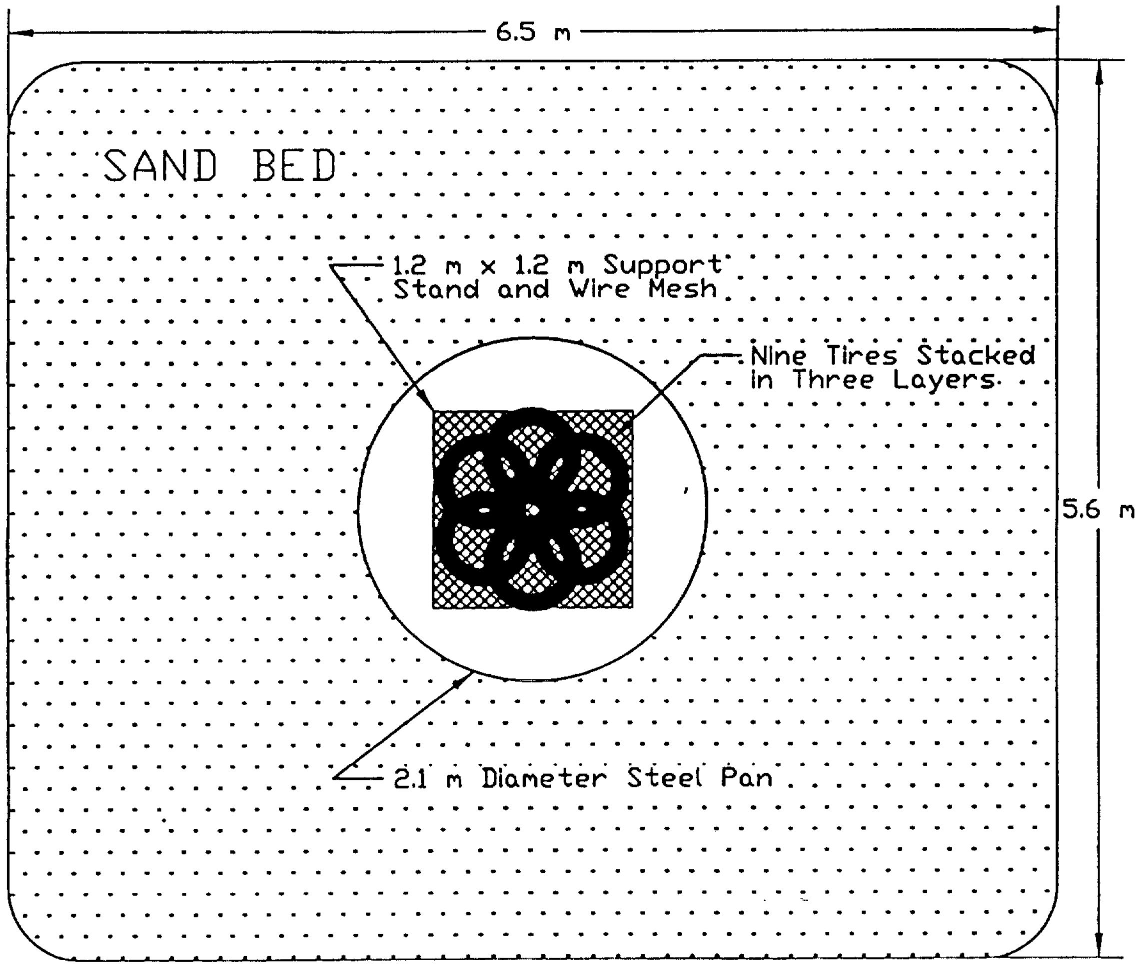

Figure 6. Plan view of tire fire suppression arrangment

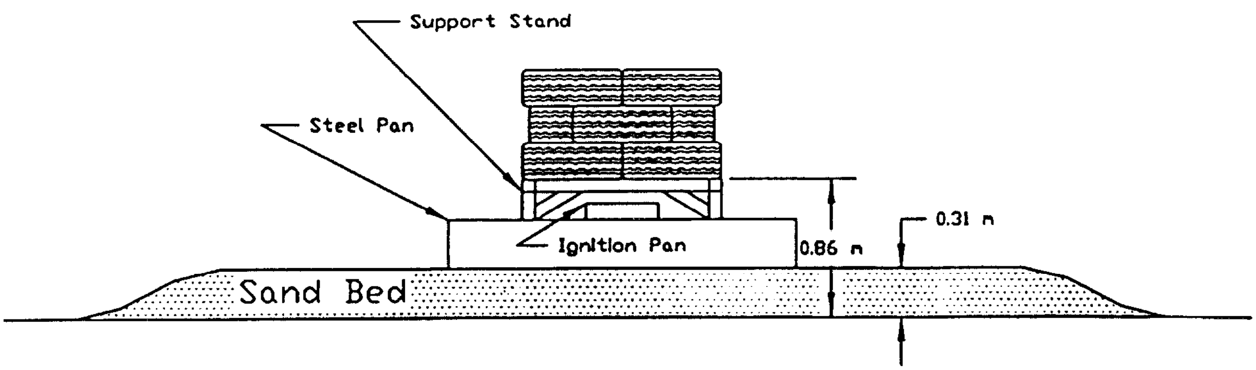

Figure 7. Elevation view of tire fire suppression experiment arrangment

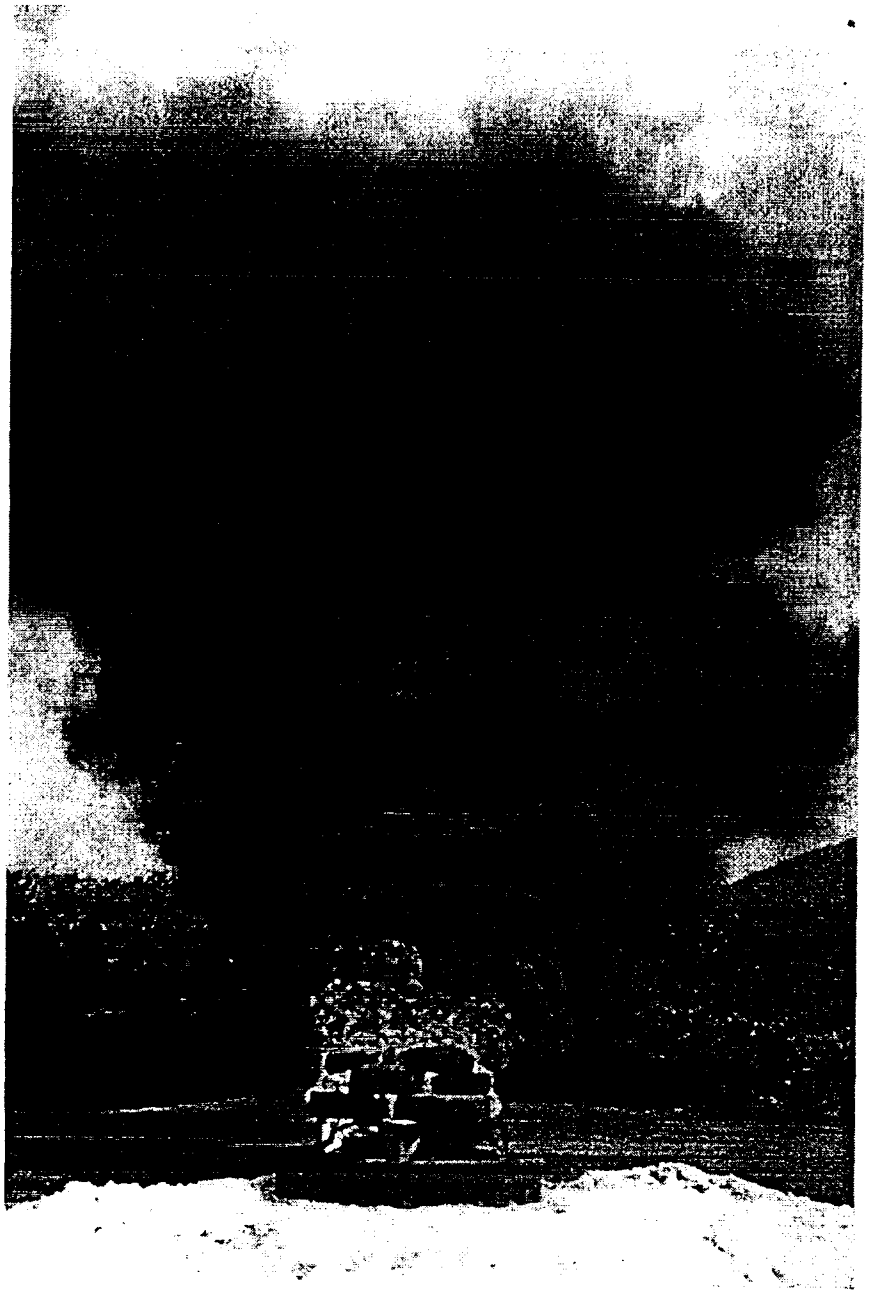

Figure 8. Tire fire before start of suppression

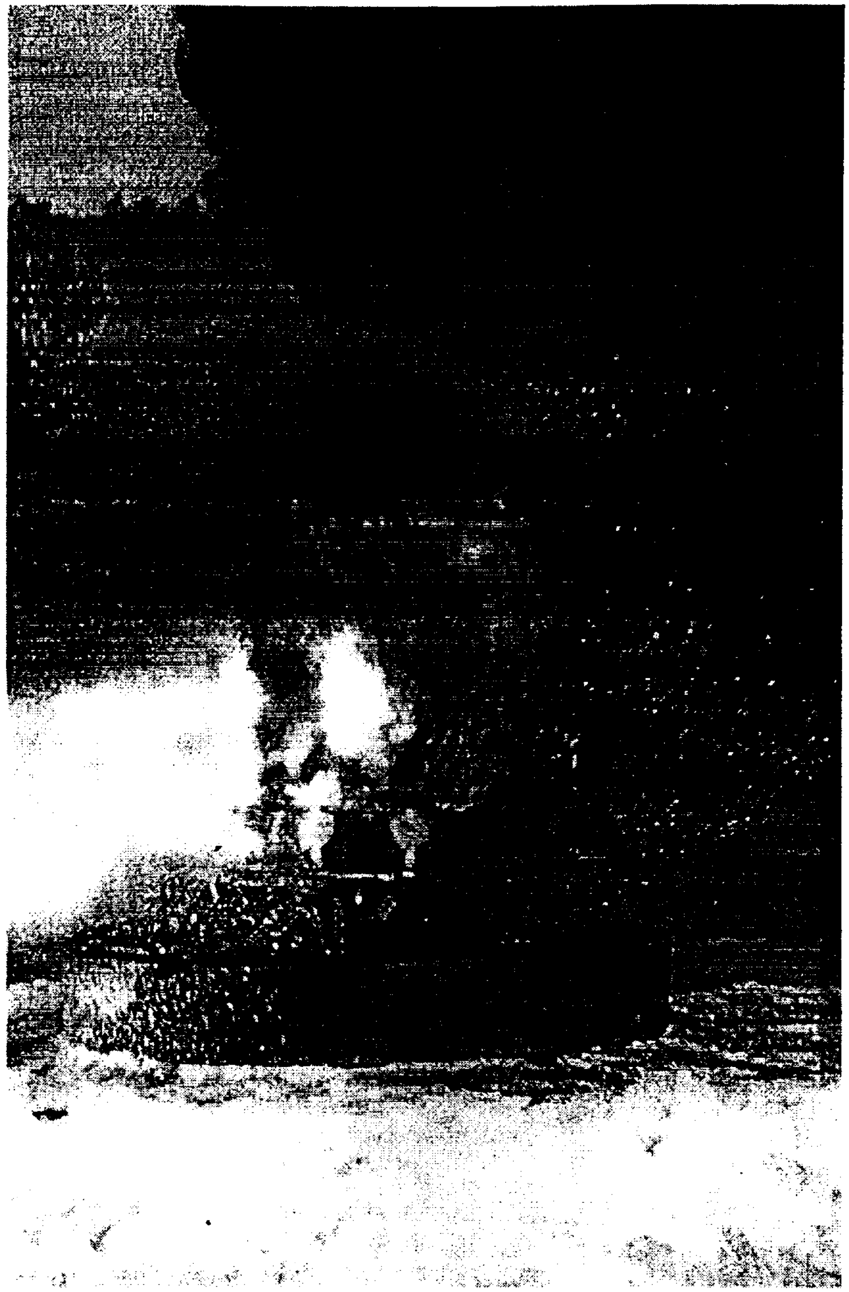

Figure 9. Tire fire at start of suppression

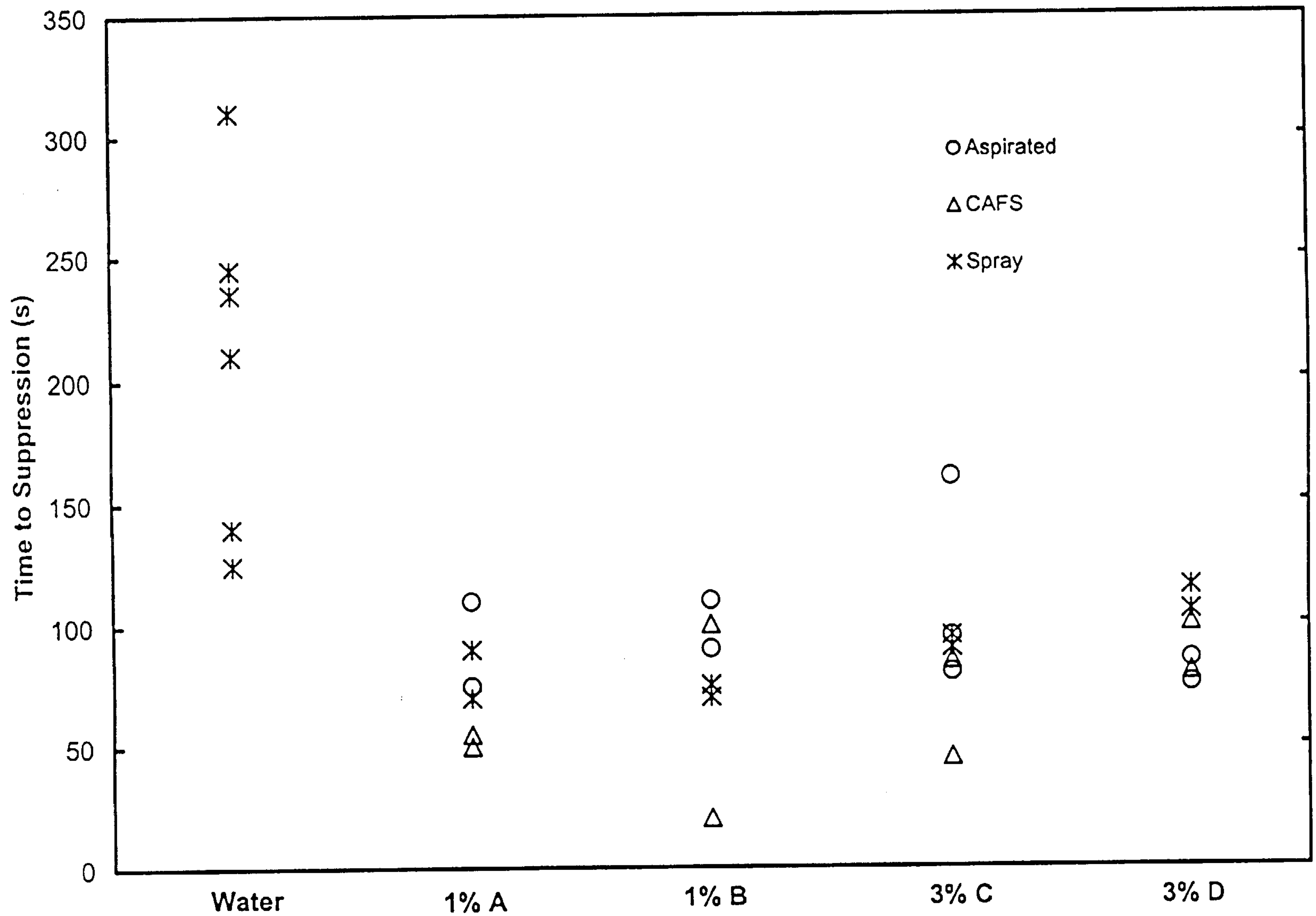

Figure 10. Fire suppression times for water and agents A, B, C, and D