Evaluation of Water Additives for Fire Control and Vapor Mitigation – Two and Three Dimensional Class B Fire Tests

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Background

Various water additives are available in today's marketplace that claim to provide advantageous performance characteristics for fire control and vapor mitigation. Of particular interest are additives that report to provide superior fire suppression capabilities through emulsification or encapsulation. A scientific assessment of these various additives is lacking, and the fire protection community would benefit from an evaluation of the various available water additives for fire control and vapor mitigation. This paper reports on FPRF-sponsored testing of these agents, performed by JENSEN HUGHES at the Underwriters' Laboratories facility in Northbrook, Illinois.

Prior to testing, a comprehensive evaluation was performed to clarify the benefits of using water with additives for fire suppression versus water without additives. It was found that potential users of water additives have performance criteria for most scenarios of interest, as established by NFPA 18A. The Sponsors and Technical Panel agreed that a Class B scenario was of most interest. It was desired to use a test scenario that could be associated with real-life conditions, not just as a scaled down scenario.

Representative water additive agents were tested against Class B fire threats which provided a generic, comparative analysis between water and water additives. The three fire scenarios used in this test series were: (1) a two-dimensional (2D) pool fire, (2) a three-dimensional (3D) Class B flowing fuel fire, and (3) a three-dimensional Class B flowing fuel fire within a two-dimensional pool fire. Diesel was used as the fuel for all tests; the flashpoint of the diesel fuel was between 136–138 ºF. Water and three representative additives were applied from a sprinkler array using a modified UL 162 suppression test approach. The performance enhancement associated with the additives was evaluated by comparison with water alone.

Agents

The Technical Panel decided to evaluate water additives agents which: 1) had supposedly different extinguishing characteristics compared to more traditional foaming agents, e.g., emulsifiers or encapsulators, 2) were already listed as UL wetting agents, and, 3) were not already UL listed as Foam Liquid Concentrates. Three agents and water were evaluated in this test series. All three agents met the criteria established by the Technical Panel. They were tested "blind," without identifying the manufacturer, and were designated as Agents A, B, and C. The concentrations used for testing were 3% for Agent A, 0.5% for Agent B, and 6% for Agent C. The extinguishing characteristics of Agent A were described by the manufacturer as those which could rapidly cool the fire and surrounding structures, encapsulating fuel, and interrupting the free radical chain reaction. Agent B was described as absorbing the energy of the fire, cooling the fuel, blanketing the fuel to eliminate oxygen, and rendering Class B fuels non-flammable. Agent C was described as encapsulating the oxygen molecules to starve the fire, chemically shearing hydrocarbon strings to render the fuel inert, and acting as a scrubber, knocking smoke and soot to the ground.

Set-up and Procedures

The Class B pool fire area was 50 ft^2 (7.07 ft on a side); the height of the pan was 1.0 ft. For every test, the pan was filled with water such that the freeboard height (i.e., the height between the top lip of the pan and the top of the fuel) was 8.0 in. A small amount of heptane on top of the diesel was used as an accelerant to increase flame spread across the pool during ignition. For the 2D fire scenario, the application of the water with additive was started 30 seconds after full involvement of the 2D pool fire. Full-involvement was between 15 and 30 seconds.

A relatively "standard" cascade array used in other similar tests was used as the three-dimensional Class B fire. It consisted of five inclined trays mounted above a 3.25 ft square pan. The fuel was discharged onto the top tray and flowed down that tray to the tray below which was inclined in the opposite direction. The fuel flowed successively down each of the inclined trays. The bottom pan had a notch cut in the front of the pan to facilitate the flow of the fuel to a larger containment pan. The fuel cascade is shown in Figure 1. For the 3D only fire scenario, the ignition fuel in the cascade pan was first ignited. One minute after full-involvement of the pan, the fuel flow to the cascade was initiated and set to 2 gpm. Thirty seconds after full-involvement of the cascade, the application of the water with additive was started.

For the 2D and 3D fire scenario, the ignition fuel in the cascade pan was first ignited. One minute after full-involvement of the cascade pan, the 2D pan was ignited and the fuel flow to the cascade was initiated and set to 2 gpm. In general, forty-five seconds after full-involvement of the 2D pan, the application of the water with additive was started.

Figure 1 – Fuel cascade.

A modified UL 162 sprinkler test was used to apply agent (see Figure 2). The parameters were:

- Test pan – 50 ft^2 (7.07 ft x 7.07 ft)
- Nozzle height – 15 ft to centerline of piping
- Sprinkler grid – 4 sprinklers located near the corners of the pan
- Cascade apparatus – centered in 50 ft^2 test pan

This approach provided a sprinkler test design closely resembling an actual installation. Application rates were 0.16, 0.22, 0.30, and 0.45 gpm/ft^2. The application rate was varied by adjusting the spacing of the sprinklers and the total flowrate though the system. An initial sprinkler spacing of 10 ft x 10 ft was used which is associated with an ordinary hazard application rate of 0.30 gpm/ft^2. This is a design rate found in many existing facilities of interest such as fossil fuel power generation facilities.

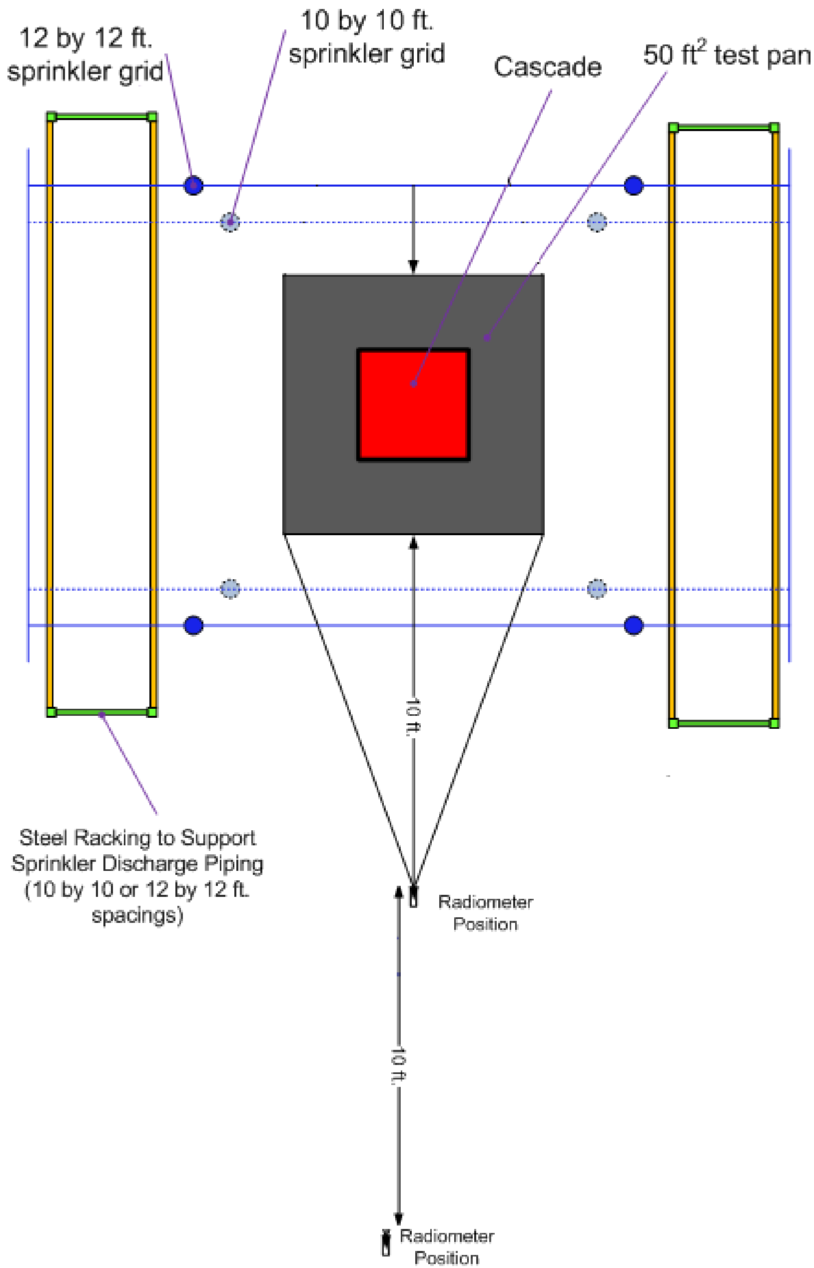

Figure 2 – Test layout plan view.

Thermocouples, heat flux gauges, video cameras, and infrared cameras recorded the test data. Flame height was determined using video footage and a flame height indicator (ladder) in the same plane as the centerline of the fuel pan. It was half way between the pan and the sprinkler piping support rack in order to calibrate video footage. Rungs on the indicator were 2.0 ft apart with the bottom most rung 9.75 ft above the floor. Two heat flux gauges were placed outside of the 2D fuel pan to measure radiative heat flux from the fire. These measurements were used to assess the degree of fire knockdown by the agents.

Measures of Performance and Overall Results

Performance in these tests was evaluated based on fire suppression and cooling. No attempt was made to define the physio-chemical properties of any particular agent, such as encapsulation. Rather, the comparison was based on quantifiable fire-cooling, suppression, and extinguishment measures as follows:

<u>*90% Control Time (Visually Assessed)*</u>

2D – 90% of pan area extinguished
3D – (a) no trays burning, fire just in cascade pan; or, (b) if bottom cascade pan extinguished, fire on just one tray
2D and 3D – both the 2D and 3D criteria achieved

<u>*Extinguishment Time (Visually Determined)*</u>

Extinguishment time was the time between when the agent discharge began and:

2D – complete extinguishment of the 2D pan
3D – complete extinguishment of the 3D cascade, cascade pan, and any fire which may have spread to the 2D pan
2D and 3D – complete extinguishment of 3D cascade, cascade pan, and 2D pan

<u>*Flame Height and Heat Flux Reductions*</u>

A value of 90% reduction in flame height was established as a de facto measure of fire control. Flame height was measured every 5 seconds after ignition. Values of 60, 90, and 99% reduction in heat flux established when the fire was reduced by a moderate amount, a controlled state, and almost extinguished, respectively.

Results

A total of 19 tests were conducted; four water only tests and five tests of each water additive. The following general testing approach was used:

1. 2D fire alone, application rate of 0.30 gpm/ft^2
2. 3D fire alone at application rate of 0.30 gpm/ft^2
3. 2D+3D fire at application rate of 0.30 gpm/ft^2
4. 2D fire alone, application rate of 0.16 gpm/ft^2
5. 2D, 3D, or 2D+3D at application rate of 0.22 gpm/ft^2 depending on prior results.

For the water only tests, only the 2D and 3D fires alone were conducted; application rates of 0.3 and 0.45 gpm/ft^2 were used for each scenario. Table 1 lists the tests conducted and results.

Table 1 – Test Matrix and Results.

Test	Fire Scenario	Agent	Sprinkler Application Rate (gpm/ft^2)	Extinguished?	Time to 90% Control (sec)	Time to Extinguishment (sec)	Time to 90% Flame Height Reduction (sec)	Time to 90% Reduction in Heat Flux – 10ft (sec)
1	2D	Water	0.3	No	480	NA	510	191
2	2D	Water	0.45	Yes	85	153	35	23
3	2D	A	0.3	Yes	131	157	80	17
6	2D	A	0.16	No	NA	NA	NA	40
7	2D	A	0.22	Yes	180	243	215	19
8	2D	B	0.3	Yes	39	50	50	18
11	2D	B	0.16	Yes	95	98	100	23
15	2D	C	0.3	Yes	22	29	29	16
18	2D	C	0.16	Yes	43	62	29	29
13	3D	Water	0.3	No	NA	NA	NA	222
14	3D	Water	0.45	No	NA	NA	314	44
4	3D	A	0.3	No	NA[1]	NA	NA	42
9	3D	B	0.3	Yes	264	274	160	49
16	3D	C	0.3	No	275	NA	150	52
19	3D	C	0.22	No	NA	NA	365	252
5	2D+3D	A	0.3	No	NA	NA	NA	129
10	2D+3D	B	0.3	Yes	320	329	70	69
12	2D+3D	B	0.22	No	NA	NA	458	88
17	2D+3D	C	0.3	Yes	185	197	196[2]	81

NA – Not achieved
1 – 90% control was almost achieved at the end of the test
2 – Interpolated

Results – 2D Fire Scenario

All three agents and water were tested with the 2D pan fire at an application rate of 0.3 gpm/ft^2. All three agents were able to extinguish the fire at the 0.3 gpm/ft^2 application rate, with water only able to achieve 90% control after an extended discharge period. For the range of application rates, the agents, from quickest to slowest in terms of knocking down the fire, were consistently Agent C, Agent B, Agent A, and water. All three agents were significantly quicker than water at controlling the fire and reducing flame height by 90%. The times to 90% reduction in heat flux were comparable for all three agents and water at the application rate of 0.3 gpm/ft^2. For 90% control, Agent A was approximately 3 times quicker and Agent C was 21 times quicker than water. For time to 90% reduction in flame height, all three agents were at least 6 times quicker than water.

Water was able to extinguish the 2D pan fire at a higher rate of 0.45 gpm/ft^2 in a time period comparable to what the other agents achieved at the application rate of 0.30 gpm/ft^2. Agents B and C were the most effective in that they were able to extinguish the 2D pan fire at application rates of 0.16 gpm/ft^2. Agent A was effective at a slightly higher application rate of 0.22 gpm/ft^2.

Results – 3D Fire Scenario

All three agents and water were tested with the 3D fire at an application rate of 0.3 gpm/ft^2. Only Agent B (Test 9) was able to fully extinguish the 3D fire scenario at an application rate of 0.3 gpm/ft^2 in 274 seconds (90% control in 264 seconds). Agent C (Test 16) was able to achieve 90% control of the 3D fire in 275 seconds. Based on the 90% control and 90% heat flux reduction times, the performance of Agents B and C was comparable. Agent A and water were unable to control the fire, but were able to reduce the heat flux by 90%. However, water was able to achieve a 90% reduction in heat flux about five times slower than Agent A.

Water was also tested at the higher application rate of 0.45 gpm/ft^2. Even at this higher rate, water was unable to control the fire. The times to 90% reduction in heat flux for the higher water application rate (0.45 gpm/ft^2) was approximately equal to the 90% reduction in heat flux times for the other agents at 0.3 gpm/ft^2. Agent C was the only additive to be tested twice; it was unable to extinguish or control the fire at the lower application rate (0.22 gpm/ft^2). The times to 90% heat flux and flame height reduction were approximately twice as long for the 0.22 gpm/ft^2 application rate versus the 0.3 gpm/ft^2 application rate.

Results – 2D+3D Fire Scenario

Only the three water additives were tested with the 2D+3D fire scenario; water was not tested with this fire scenario as it had not been successful in either the 2D or 3D fire scenarios at an application rate of 0.3 gpm/ft^2. All agents were tested at an application rate of 0.3 gpm/ft^2. Both Agents B (Test 9) and C (Test 17) were able to fully extinguish the 2D+3D fire scenario at an application rate of 0.3 gpm/ft^2; Agent A was unable to control the fire. Agent C was able to extinguish and control this fire scenario approximately 2 minutes faster than Agent B. However, based on the 90% flame height and heat flux reduction times, the performance of Agent B was moderately better than Agent C. Test 17 appears to be an anomaly for Agent C given that this agent was unable to extinguish the 3D fire scenario (Test 16).

Agent B was also tested at 0.22 gpm/ft^2. It was unable to extinguish or control the fire at this lower application rate. The time to 90% flame height reduction was approximately 6 times longer for the 0.22 gpm/ft^2 application rate versus the 0.3 gpm/ft^2 application rate; the times to 90% heat flux reduction were approximately equal.

Additional Discussion and Analysis

At the application rates tested, water was found only to be effective on the 2D pan fires. Water required the highest application rate of 0.45 gpm/ft^2 for extinguishment, although the test at 0.3 gpm/ft^2 met the 90% control measure of performance. Given that the 2D pan fire was extinguished by water in under 3 minutes, it is possible that an application rate between 0.3 and 0.45 gpm/ft^2 could have also caused complete extinguishment during a longer discharge period. However, such fine adjustment of the application rates was not within the scope of this test program.

Agent A extinguished the 2D pan fires at the application rates tested. Agent A was tested with the 2D pan at application rates of 0.3, 0.22, and 0.16 gpm/ft^2; it extinguished the pan fires with the two higher application rates; it did not meet the 90% control measure of performance at the lowest application rate. Agent A was tested with the 3D and the 2D+3D at application rates of 0.3 gpm/ft^2 without meeting the 90% control measure of performance. Based on observations of the 3D and 2D+3D tests with Agent A, a higher application rate or, perhaps, a higher concentration, might contribute to improved performance. The 3% concentration was recommended for testing by the manufacturer; the UL wetting agent listing for Class B fires is 6%. Agent A produced a thin layer which floated atop the fuel layer after the test.

Agent B was the only water additive to successfully extinguish all three fire scenarios even though it had the lowest concentration (0.5% compared to 3% and 6% for agents A and C, respectively). Agent B successfully extinguished the 2D pan at the lowest application rate of 0.16 gpm/ft^2 and the 3D and 2D+3D scenarios at an application rate of 0.3 gpm/ft^2. Agent B was unsuccessful at extinguishing or controlling the 2D+3D scenario at an application rate of 0.22 gpm/ft^2. Agent B produced a moderately thick layer which floated atop the fuel layer after the test.

Agent C successfully extinguished the 2D pan at the lowest application rate of 0.16 gpm/ft^2 and the 2D+3D scenario at an application rate of 0.3 gpm/ft^2. Despite successfully extinguishing the 2D+3D fire scenario, Agent C was unsuccessful at extinguishing the 3D scenario at application rates of 0.22 and 0.3 gpm/ft^2 although it was able to meet the 90% control measure of performance with the higher application rate. It is unclear what may have caused this as the 3D fire would be considered easier to extinguish than the 2D+3D fires combined. The 3D cascade is an inherently difficult fire to suppress due to its many shielded surfaces. Agent C produced a rather thick layer which floated atop the fuel layer after the test.

Conclusions

1. The test scenarios provided an acceptable means to compare water to water additives.

2. The 2D fire was extinguished by all agents. An application rate of 0.45 gpm/ft^2 was required for water to achieve total extinguishment, which is greater than the 0.25 gpm/ft^2 baseline referenced in NFPA 850 for boiler front oil fires. Water additives were effective at application rates of 0.3 gpm/ft^2 and lower.

    a. NFPA 850 should consider increasing the minimum water application rate for protection of fuel oil hazards.

    b. The use of these results for turbine lubricating oils hazards may not be appropriate, since higher flashpoint fluids were not tested. Also, these tests did not include unconfined spills or spray fires.

3. Water failed to extinguish the 3D and 2D+3D fire scenarios. Two of the three water additives extinguished fires which included the 3D scenario.

4. Generally, the water additives provided quicker reductions in the thermal threat of the fires compared to water. From an overall performance standpoint, water additives were superior to plain water.

5. Performance differences were observed between the three water additives tested. This might be attributable to physio-chemical properties of a particular agent, or agent concentration. These factors were not evaluated. All water additives created a residual emulsification or foam layer which was evident at the conclusion of the test.

6. The fire scenarios used are not considered worst case, but do represent real-life conditions which might occur where there are Class B hazards. For comparative purposes, the scenarios demonstrated performance differences between water and water additives.

7. If the test apparatus and scenarios are considered for adoption for standards making/listing of water additives:

    a. Minor modifications should be made to the setup, as documented in the full report;

    b. A maximum time to achieve the performance metric should be established. A range of performance metrics were analyzed: 90% visual control, extinguishment, and 60/90/99% thermal threat reductions. One or more of these could be used in a performance standard adopted for assessing water additives; and

    c. Tests should be conducted with a greater floor-to-sprinkler height where installations having heights greater than 15 ft are anticipated. Alternately, an increased application rate than that established for 15 ft high performance could be used as a safety factor for any increased height installation.

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