White paper

A new era in ultra- and mega-class vehicle fire suppression: Assessing the latest evolution in fire safety solutions

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The power behind **your mission**

Mining, forestry, aviation and waste disposal – these are a just a few of the hundreds of industries that rely on heavy-duty industrial mobile equipment. The technology that drives these essential vehicles has evolved over the decades, as they have been called on to haul, dig, lift and move ever greater quantities of material. This progressive demand for power led to the emergence of Mega- and Ultra-class mobile equipment. The giant size of these vehicles means everything is heightened - bigger parts, more complexity, larger engines, larger quantities of fuel, higher fluid pressures and - consequently - a higher risk of fire. As the cost and danger associated with industrial vehicle fires increases, it's time to take a fresh look at the state of vehicle suppression solutions and how they can evolve even further.

This paper will explore the progression of fire suppression solutions for mobile equipment over the last 50 years and the emerging challenges that are fueling the need for innovative solutions. It will conclude by presenting exclusive testing data, highlighting the revolutionary performance of the new **ANSUL® LVS NF-40 Non-Fluorinated Liquid Suppression Agent** and its potential to protect personnel, property and operational continuity.

Back to basics: the fire tetrahedron and suppression requirements

To ignite and sustain a fire, four basic elements are required: fuel, oxygen, heat and a chemical chain reaction. This phenomenon is known as the fire tetrahedron.

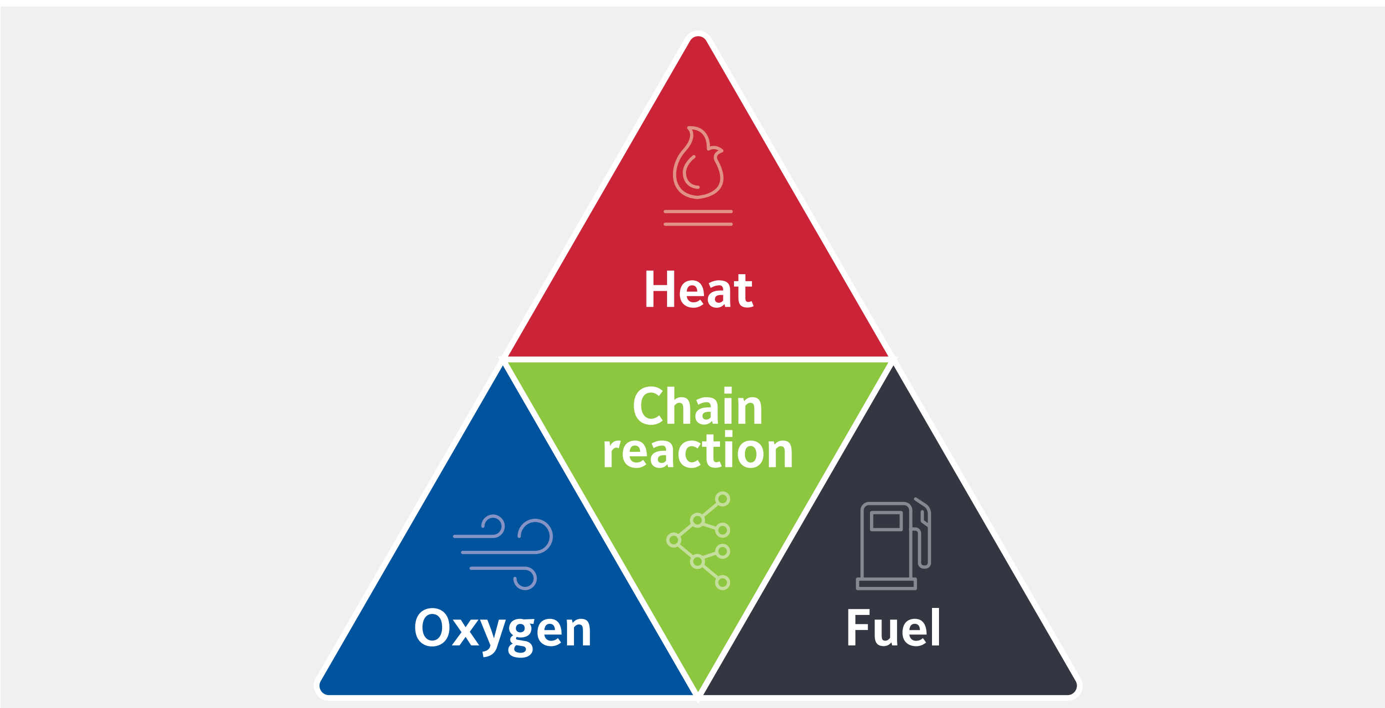

Figure 1 - Fire tetrahedron

At their most basic level, fire suppression systems work by removing one or more of these contributing elements using various mechanisms of action. If any one component of the fire tetrahedron is successfully removed, a fire cannot be sustained and will be extinguished. There are multiple types of suppression technologies used in vehicles today, and each address at least one aspect of the fire tetrahedron.

Three commonly employed vehicle fire suppression systems are:

1. **Dry chemical systems:** These systems use monoammonium phosphate, a dry chemical, to interrupt the chemical chain reaction of A, B or C class fires. They can also help mitigate the influence of heat by melting and forming a crust on top of a superheated surface, separating it from the fire's fuel source[1].

1 Refer to ANSUL® technical bulletin No.61, Document No. F-97146 for more information

2. **Liquid agent systems:** Liquid agents suppress the fire by interrupting the chemical chain reaction and providing a cooling effect. They also help minimize fire propagation by following the flow of flammable liquids to prevent reflash.
3. **Twin-agent systems** (also referred to as dual-agent systems): These systems include both dry chemical and liquid agents in a single design, employing the firefighting properties of both agents. Twin-agent designs require two completely independent storage and discharge installations for each agent, with separate tanks, nozzles, hose networks, bracketry, etc., but may share common detection and activation componentry to initiate the fire suppression agents.

While most vehicle fire suppression systems rely on the basic principles of the fire tetrahedron detailed above, over the last half-century the technology behind the industry standard has undergone some marked shifts.

The need for evolution in vehicle fire suppression systems

Dry chemical systems have been the go-to for fire protection on large, industrial vehicles since the mid-twentieth century. In the nineties, the ANSUL® Liquid Vehicle System (LVS) was introduced to complement the existing Foray®-branded dry chemical solution. The rationale behind these dual installations was to use dry chemical for rapid flame knockdown and ANSUL® LVS liquid agent to cool hot surfaces and minimize reflash potential. After thorough third-party testing, in 2011 the ANSUL® LVS system was introduced as a single-agent fire suppression system, suitable for many heavy industrial vehicle applications.

Despite the availability of an FM approved single-agent system, the National Fire Protection Association (NFPA) standards (2020 editions) still require the use of a twin-agent suppression system in Ultra- and Mega-class equipment. NFPA 120 is the Standard for Fire Prevention and Control in Coal Mines and NFPA 122 is the Standard for Fire Prevention and Control in Metal/ Nonmetal Mining and Metal Mineral Processing Facilities. The pertinent sections of these standards state, **"…for hydraulic systems containing more than 567.8 L (150 gal) in the lines, a dual agent system shall be provided."**

From costly clean up and repairs following dry chemical discharge, to the careful planning and installation needed to operate two separate systems effectively, the suppression benefits of these dual-agent configurations are matched by their accompanying complexity. As a counterpoint, ANSUL® published a position paper in 2016 outlining the case for the use of an ANSUL® LVS single-agent system on all vehicle equipment with superheated surfaces[2].

The size and scale of mining and tunneling machinery continues to grow, and mining operations continue to expand into geographies with harsh operating conditions. In addition, shifting environmental regulations regarding the use of per- and polyfluoroalkyl substances (PFAS) have led to changes in agent chemistry. All of these factors combine to highlight the limitations of and to create challenges for existing vehicle fire suppression technology. Armed with this understanding, ANSUL® fire protection engineers began work on a new, single-agent vehicle suppression solution that meets the needs of today's heavy-duty industrial vehicle operations.

In May 2022, **ANSUL® LVS NF-40 Non-Fluorinated Liquid Suppression Agent** was introduced to help meet the fire protection challenges of today's vehicles. This latest innovation delivers a stand-alone liquid agent system technology for Ultra- and Mega-class earthmovers that delivers extraordinary firefighting performance and exceeds the capabilities of historical systems. **The ANSUL® LVS NF-40 Non-Fluorinated Liquid Suppression Agent** has the additional capability of covering diesel, gasoline and most other flammable fuels to help minimize reflash potential.

2 Document No. F-2016050, 2016

Evaluating a new solution

The ANSUL® LVS NF-40 Non-Fluorinated Liquid Suppression Agent from Johnson Controls was developed to provide stand-alone fire protection in systems for the most challenging heavy equipment applications. As NFPA 120 and 122 mandate twin-agent suppression systems for vehicles with over 567.8 L [150 gal] of hydraulic fluid in their lines, ANSUL® Vehicle Systems experts set out to compare the efficacy of the new single-agent system versus some of the best single-agent and twin-agent setups currently utilized in the industry.

To evaluate the effectiveness of the new non-fluorinated solution compared to the systems currently available on the market, the ANSUL® team embarked on an extensive testing program. The base protocol chosen for these tests was the Australian vehicle standard AS-5062:2016 Indirect Fire testing scenario. This fire test is similar in nature to what is found in the FM-5970 Heavy Duty Mobile Equipment Standard, February-2022 edition.

This indirect fire test protocol requires agents to achieve the following:

- Suppress fire through a pressurized fuel spray
- Cool a superheated surface (simulating a turbocharger, manifold, etc.)
- Extinguish a fuel pool fire that could potentially be caused by fire/fuel propagation in real-world scenarios
- Prevent flame reflash

Tackling any one of these four objectives can be difficult, but this procedure incorporates all of them in a single test. In addition, what makes this test especially challenging is that the suppression agent is sprayed horizontally at the vertical (indirect) reignition plate and must, therefore, suppress and secure the pool fire by indirect coverage. To approach the challenges of today's vehicles even more accurately, this test protocol was modified in the following ways, with each modification designed to make the tests even more difficult than the current standards (Figure 2):

1. The thickness of the vertical reignition plate was increased from 0.118 inches [3 mm] to 0.25 inches [6.35 mm]. This allowed more rigidity during repeated tests and increased the overall mass of the superheated surface testing component from 24.1 lbs [10.9 kg] to 51 lbs [23.1 kg]. A larger mass requires increased cooling performance from the agent to sufficiently drop the temperature below the auto-ignition point of the fuel.
2. The pressure of the fuel spray was increased from 218 psi [1,500 kPa] to 4,000 psi [27,579 kPa] to simulate the higher pressure of the hydraulic lines commonly found on larger Ultra- and Mega-class equipment.
3. To mimic real-world applications even further, diesel fuel was replaced with a standard universal hydraulic fluid in both the fuel in-depth pool fire and the pressure spray scenarios. This minimized test-to-test variation of diesel fuel additives and decreased the autoignition temperature of the fuel spray from 850°F [454°C] down to 750°F [400°C]. The decrease makes cooling the vertical plate (representing the superheated engine surfaces) below the fuel flashpoint that much more challenging[3].
4. The pre-burn time was modified to limit the overall test heat of the vertical reignition plate (superheated surface) to around 2,000°F [1,093°C]. Rather than a two-minute pre-burn with fuel spray as prescribed by AS-5062:2016, or the one-minute pre-burn with fuel spray in the FM-5970 standard (February-2022), the overall pre-burn was kept at two minutes during these tests. The fuel spray, however, was started in the last 30 seconds of pre-burn, which allowed for a relatively consistent starting temperature.

3 Note: There are heat-resistant hydraulic fluids on the market that move the autoignition temperatures up higher than diesel fuel, but to make the testing more universal and more difficult, these heat-resistant fuels were not used.

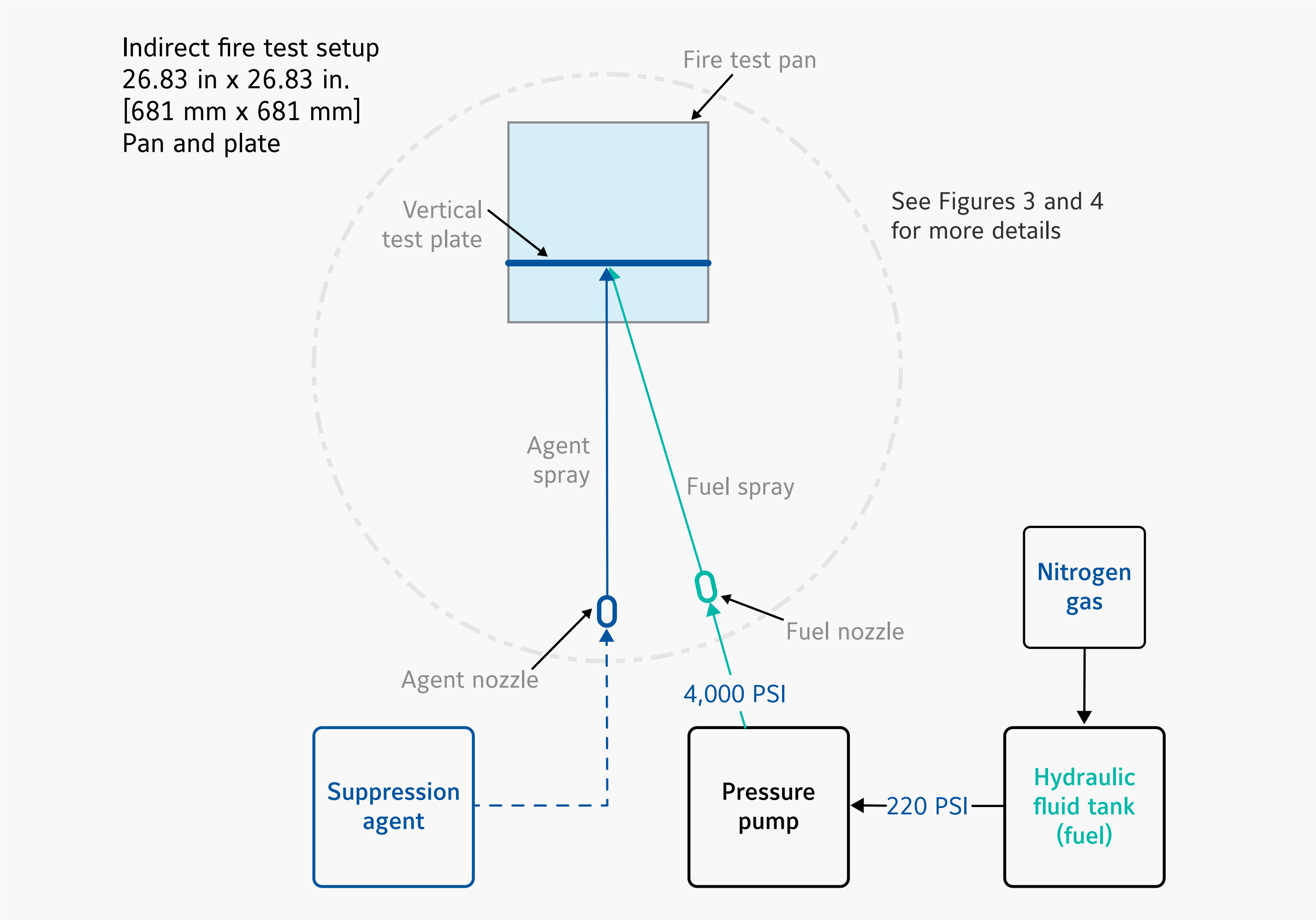

Figure 2 – Top view of test setup

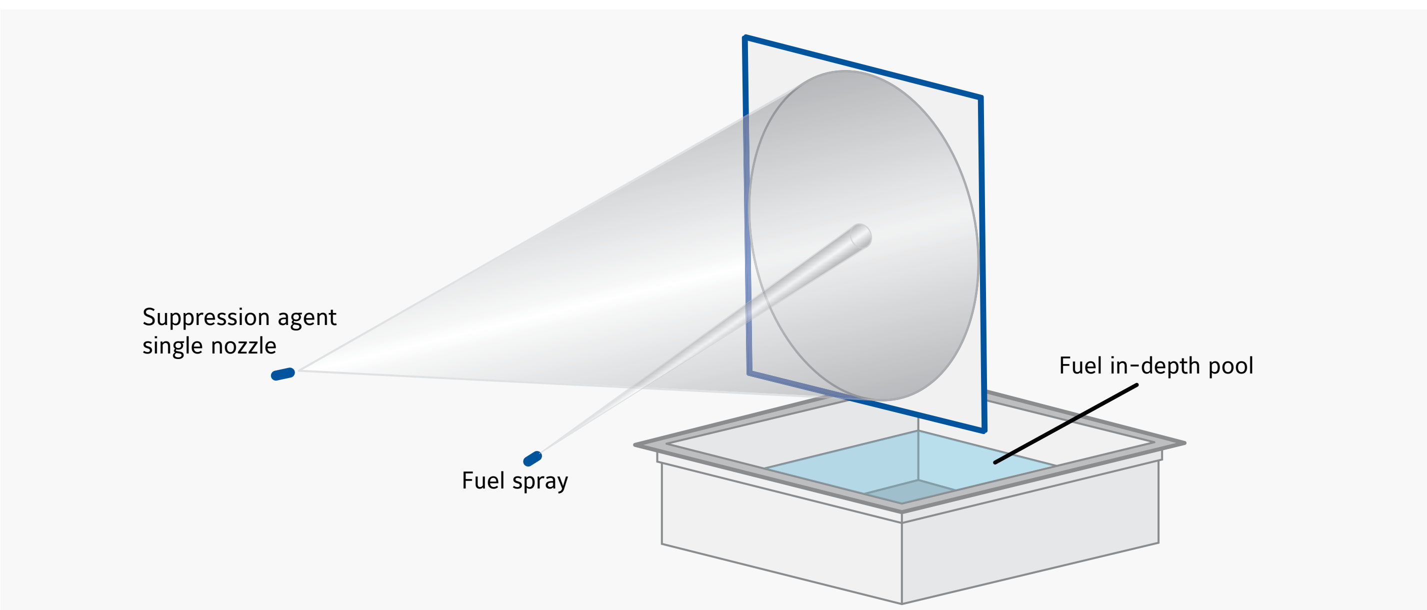

Figure 3 - Isometric view of test setup

Figure 3 shows an isometric view of the test setup. The vertical plate is positioned 3.94 inches [100 mm] above the fire test pan and a third of the distance back from the front edge. A single suppression agent nozzle is aimed horizontally at the center of the vertical plate at the maximum distance allowed per manufacturer's design/installation manual. The fuel spray is also aimed at the center of the vertical plate at 47.24 inches [1,200 mm] away, along the edge of the test pan.

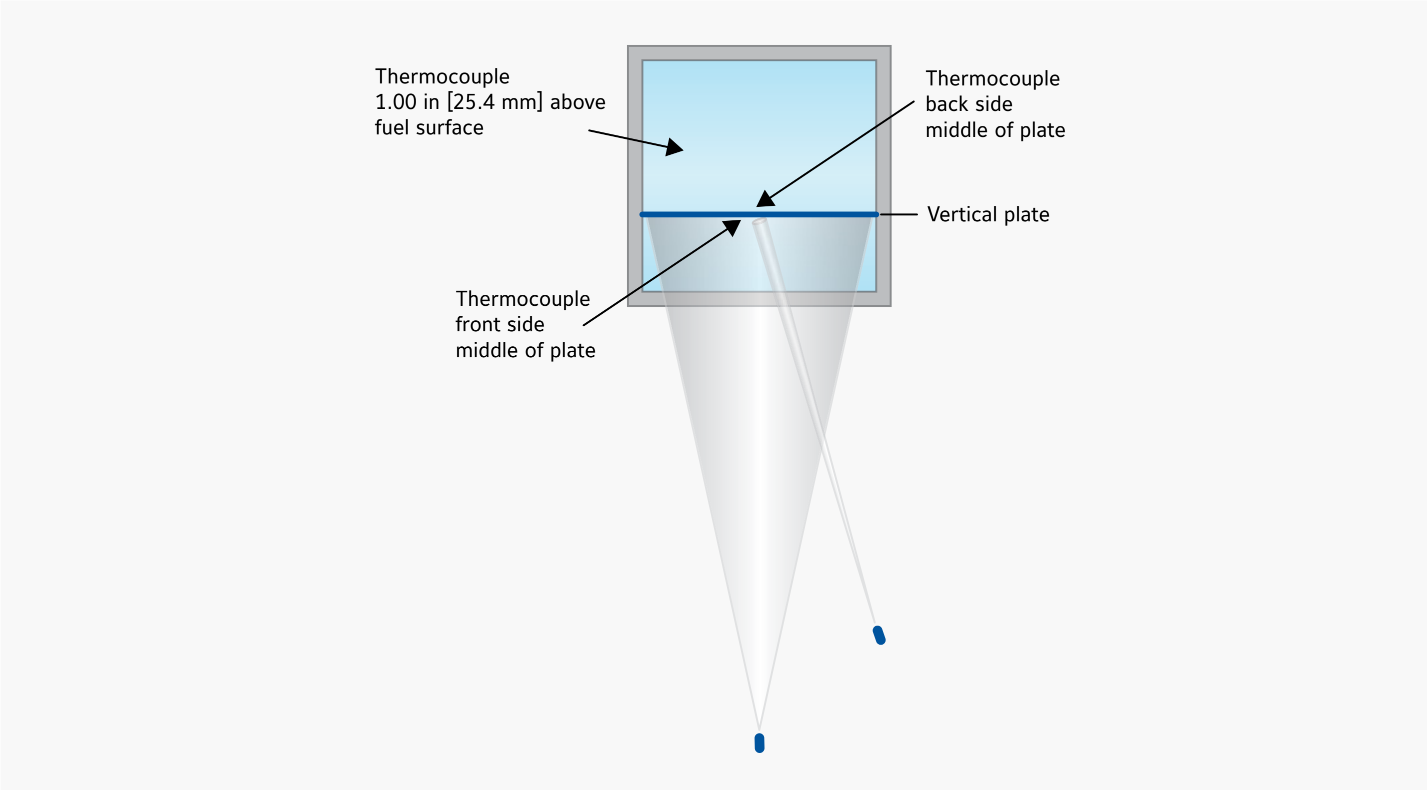

Figure 4 - Top view of test setup, thermocouple locations

Figure 4 shows a top view of the test setup with the location of the three thermocouples installed to best capture the cooling effect during each test. To get an accurate indication of total cooling, a surface-mounted thermocouple was placed on the back side of the vertical plate and another placed just above the fuel surface. This configuration provided a good assessment of how much heat was removed from the entire mass of the vertical plate (superheated surface) and from the fuel in the pan, without impinging on the suppression agent flow.

The test procedure was as follows:

1. Ignite fuel in-depth pool fire, roughly two inches of hydraulic fuel over two inches of water (50 mm fuel over 50 mm of water). (Figure 5)
2. When entire fuel pan ignites, start pre-burn clock.
3. After 90 seconds, start fuel spray. (Figure 6)
4. After 120 seconds, discharge suppression agent. (Figure 7)
5. Upon completion of suppression agent effective discharge, shut off fuel spray and then immediately restart for an additional 15 seconds. (Figure 8)
6. Shut off fuel spray; test completed. Record thermocouple data and suppression times.

Figure 5

Figure 6

Figure 7

Figure 8

This evaluation utilized five different test scenarios. Testing began with the suppression agent with the longest tenure in industrial vehicle applications, dry chemical. Next, water was tested to demonstrate both the importance of an appropriate cooling agent and that liquid agents perform differently. A twin-agent system with dry chemical and the ANSUL® Legacy LVS agent was tested next to show the performance of the industry accepted Ultra- and Mega-class protection scheme. The testing continued with a twin-agent system using the dry chemical and the new LVS NF-40 liquid agent, and lastly, the LVS NF-40 liquid agent was tested as a stand-alone system.

Individual test details are as follows:

Test #1 used Foray® dry chemical as the suppression agent (Figure 9), with a flow rate of roughly 0.6 lbs/sec [272 g/sec] through a single C-1/2 nozzle (standard cone nozzle), at a distance of 48 inches [122 cm]. There was no fire extinguishment, and the agent could not effectively cool the superheated surface. The dry chemical agent tests were attempted several times, each time reducing the starting temperatures, but all with similar results. The graph below shows that the temperature did drop slightly but only on the front side of the plate. However, the dry chemical alone could not knock down the flames, and after roughly 20 seconds, the heat and flames actually increased.

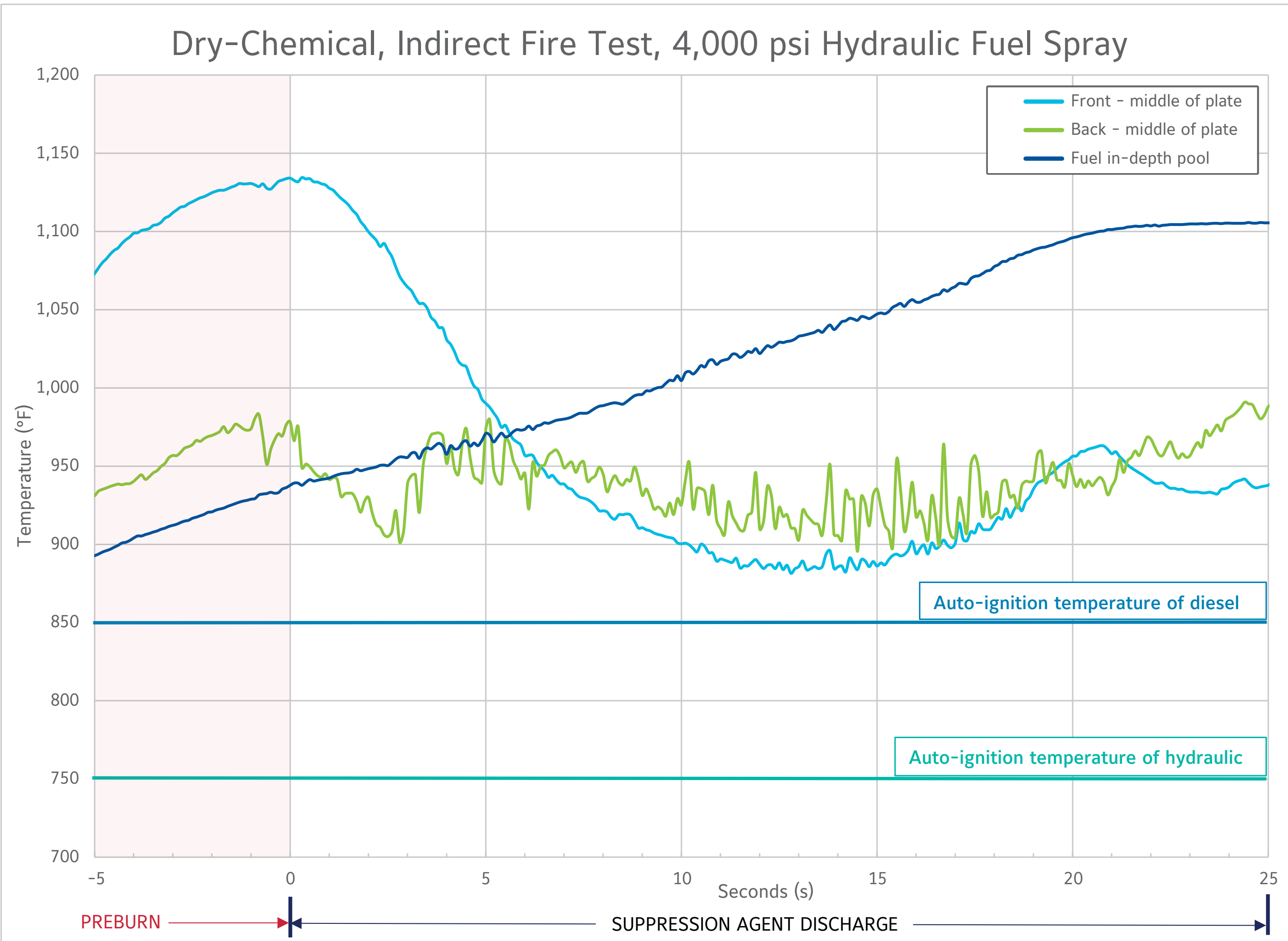

Figure 9 - Test #1, Dry chemical

Test #2 used water as the suppression agent with roughly 1.83 GPM [6.94 liters/min] at a distance of 48 inches [122 cm] (Figure 10). Water alone was not able to knock down or suppress the flames. It was also unable to sufficiently cool the superheated vertical plate and could not effectively lower the temperature of the fuel in-depth pool fire. In this particular test, the flames actually grew and became more violent rather than being controlled or diminished. The test was stopped after 25 seconds as the temperatures started to increase to dangerous levels.

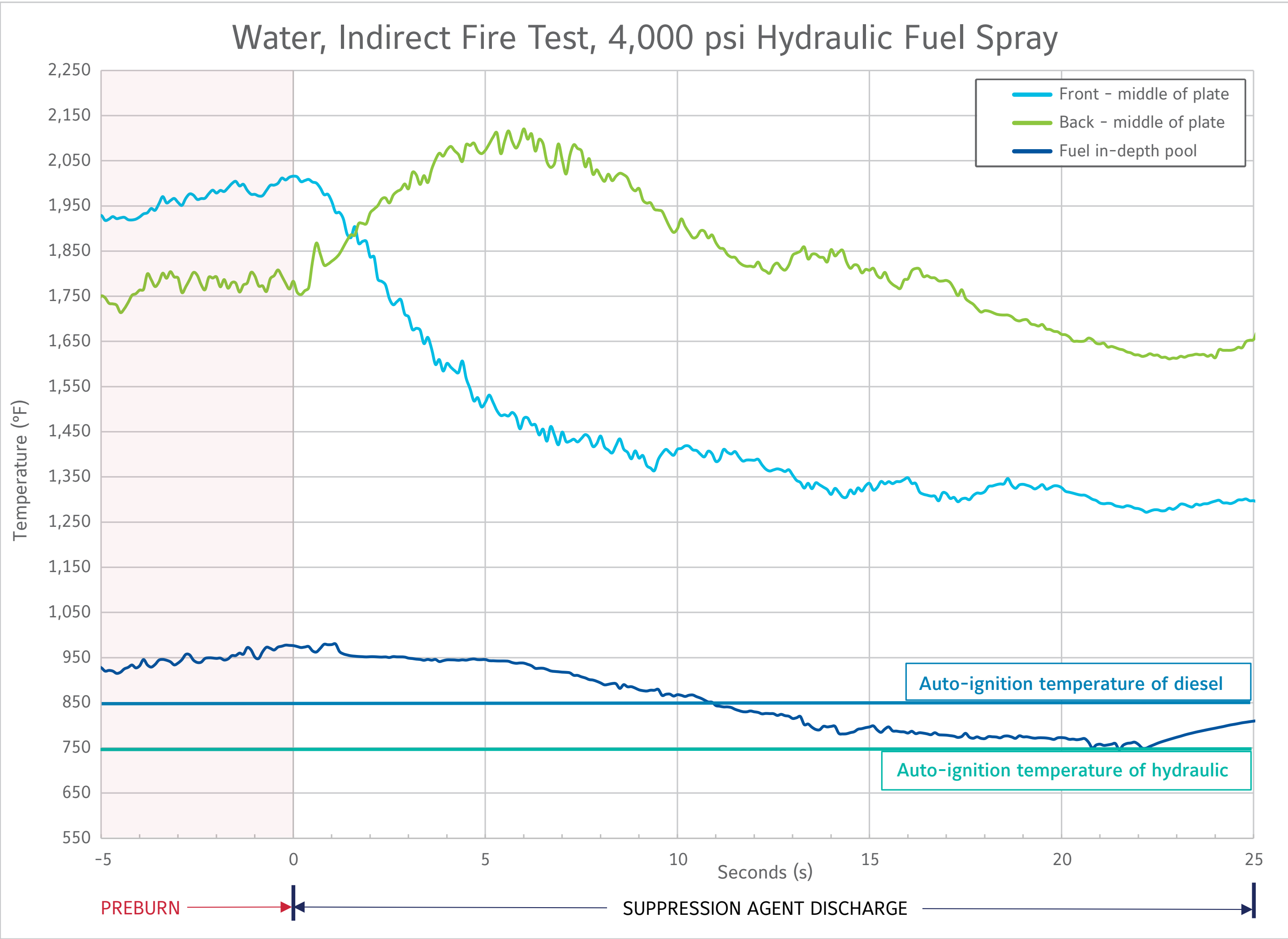

Figure 10 - Test #2, Water

Test #3 used a twin-agent system commonly found on vehicles today: Foray® dry chemical and the ANSUL® Legacy LVS liquid suppression agent (Figure 11). The flow rate used for the dry chemical agent was the same as used in Test #1, roughly 0.6 lbs/sec [272 g/sec] through a single C-1/2 nozzle (standard cone nozzle). The test consumed 1.2 gallons [4.41 L] of Legacy LVS agent at a flow rate of 1.49 GPM [5.63 liters/min] through a single LVS-9.5 nozzle. Both agents were simultaneously discharged through their specific nozzles, with each nozzle positioned 48 inches [122 cm] away and aimed at the center of the vertical plate. Total extinguishment was achieved in eight seconds, with a total effective discharge time of 25 seconds for the dry chemical and 47 seconds for the Legacy LVS agent. This test demonstrated the effectiveness of a twin-agent system on a high-pressure fire that includes a superheated surface and a fuel in-depth pool fire.

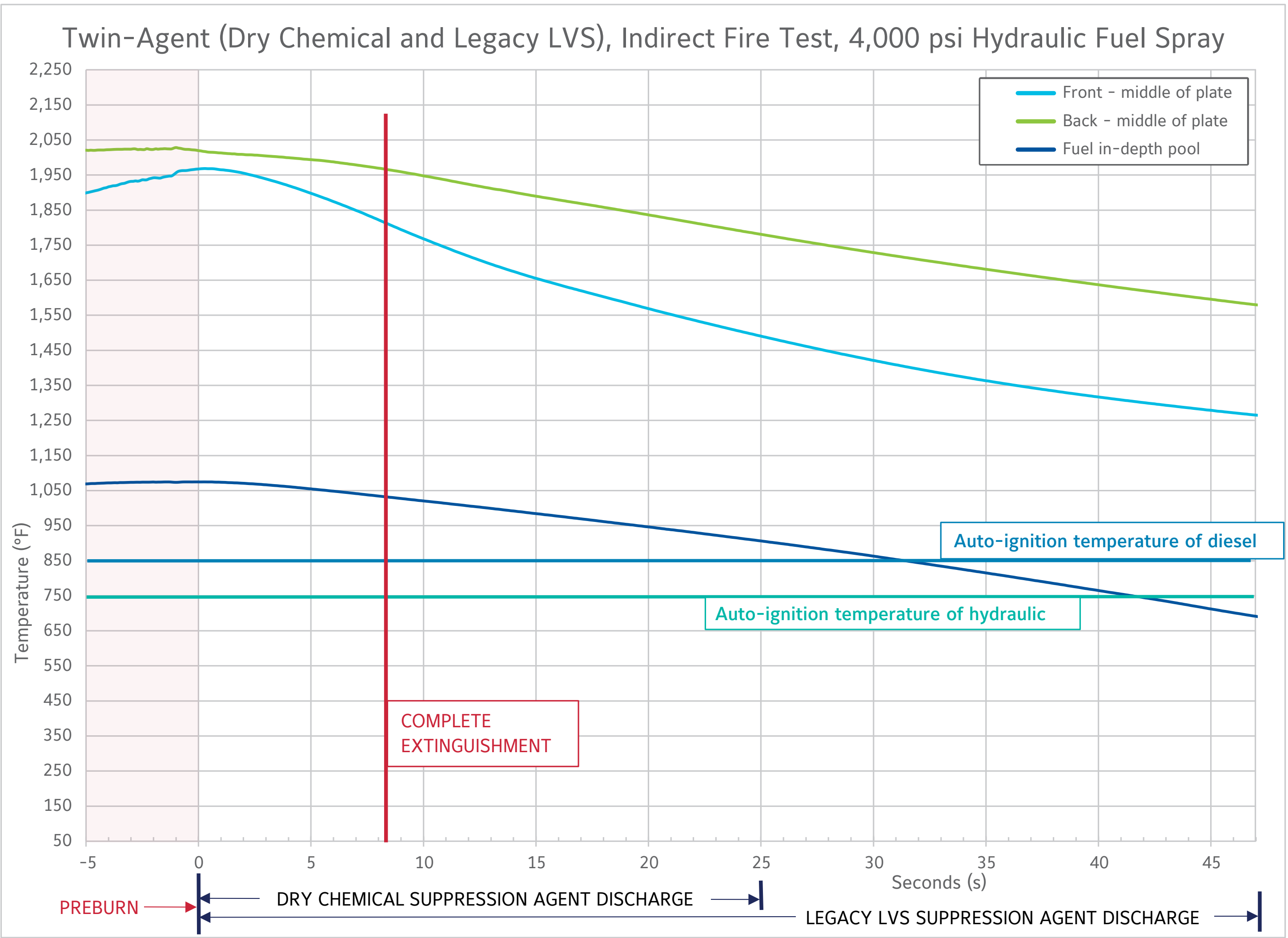

Figure 11 - Test #3, Twin-agent with dry chemical and legacy LVS liquid agent

Test #4 used another twin-agent system, this time replacing the Legacy LVS agent with the new ANSUL® LVS NF-40 agent, combined with Foray® dry chemical (Figure 12). The flow rate used for the dry chemical agent was the same as used in Test #1, roughly 0.6 lbs/sec [272 g/sec] through a single C-1/2 nozzle (standard cone nozzle). The test consumed volume 0.7 gallons [2.65 L] of the LVS NF-40 agent at a flow rate of 1.68 GPM [6.37 liters/min] through a single LVS-9.5 nozzle. Both agents were simultaneously discharged through their specific nozzles, with each nozzle positioned 48 inches [122 cm] away and aimed at the center of the vertical plate. Total extinguishment was achieved in six seconds with a total effective discharge time for both agents of 25 seconds.

An additional test was performed under this scenario setup with the agent nozzles positioned a distance of 60 inches [152 cm] away from the vertical plate with similar results.

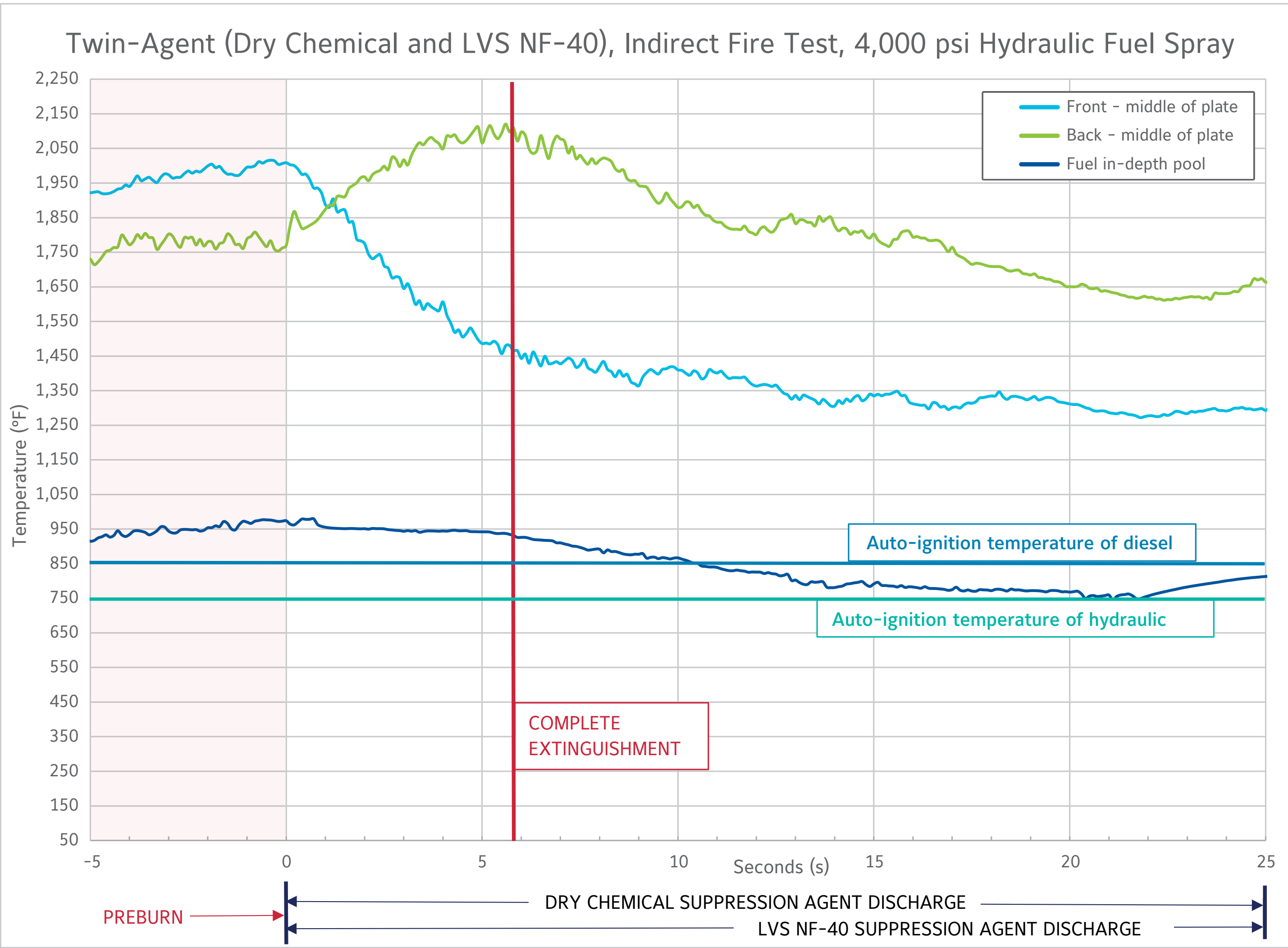

Figure 12 - Test #4, Twin-agent with dry chemical and LVS NF-40 liquid agent

Test scenarios #3 and #4 show the similarity in effectiveness of the two twin-agent discharge setups on a high-pressure fire that includes a superheated surface and a fuel in-depth pool fire. Given that the dry chemical used in Test #1 could not knock down the flames alone, these tests suggest that the addition of the Legacy LVS and the LVS NF-40 agents provided the suppression and fuel in-depth securing components.

> "During testing, dry chemical agents were shown to be unable to suppress fires when used alone, suggesting that it is the liquid component of twin-agent systems that provides flame knockdown and surface cooling."

The twin-agent testing graphs (Figure 11 and Figure 12) illustrate an interesting phenomenon. Complete suppression was achieved, but the cooling data does not rapidly drop to below the auto-ignition temperature. As mentioned, during the tests the dry chemical agent displayed the expected surface melting which formed a barrier on the vertical plate. This barrier isolated the heat of the plate from the fuel spray; however, this barrier also prevented the LVS liquid agent from efficiently removing the heat from the plate surface. The thermocouple data shows that the plate remained superheated after both agent discharges were complete. Taken together, this data suggests that the dry chemical component of twin-agent system is not only ineffective in suppressing the fire, but it can even hinder the suppression effect of the liquid agent – an important finding with significant implications for the future design of heavy vehicle fire suppression systems.

Test #5 used the ANSUL® LVS NF-40 Liquid Suppression agent as a stand-alone system (Figure 13). The test consumed 0.76 gallons [2.89 L] of agent at a flow rate of 1.57 GPM [5.99 liters/min] through a single LVS-9.5 nozzle positioned 48 inches [122 cm] away from the vertical plate. Total extinguishment was achieved in five seconds with a total effective discharge time of 29 seconds. This test demonstrates the incredible speed at which the new LVS NF-40 liquid agent can extinguish high-pressure fuel sprays and fuel in-depth pool fires, while cooling the entire mass of the plate and the fuel in-depth pan below at the same time (suppress, cool, secure).

An additional test was performed under this scenario setup with less agent, 0.70 gallons [2.66 L], and with the agent nozzle at a distance of 60 in. [152 cm] away from the vertical plate with similar results.

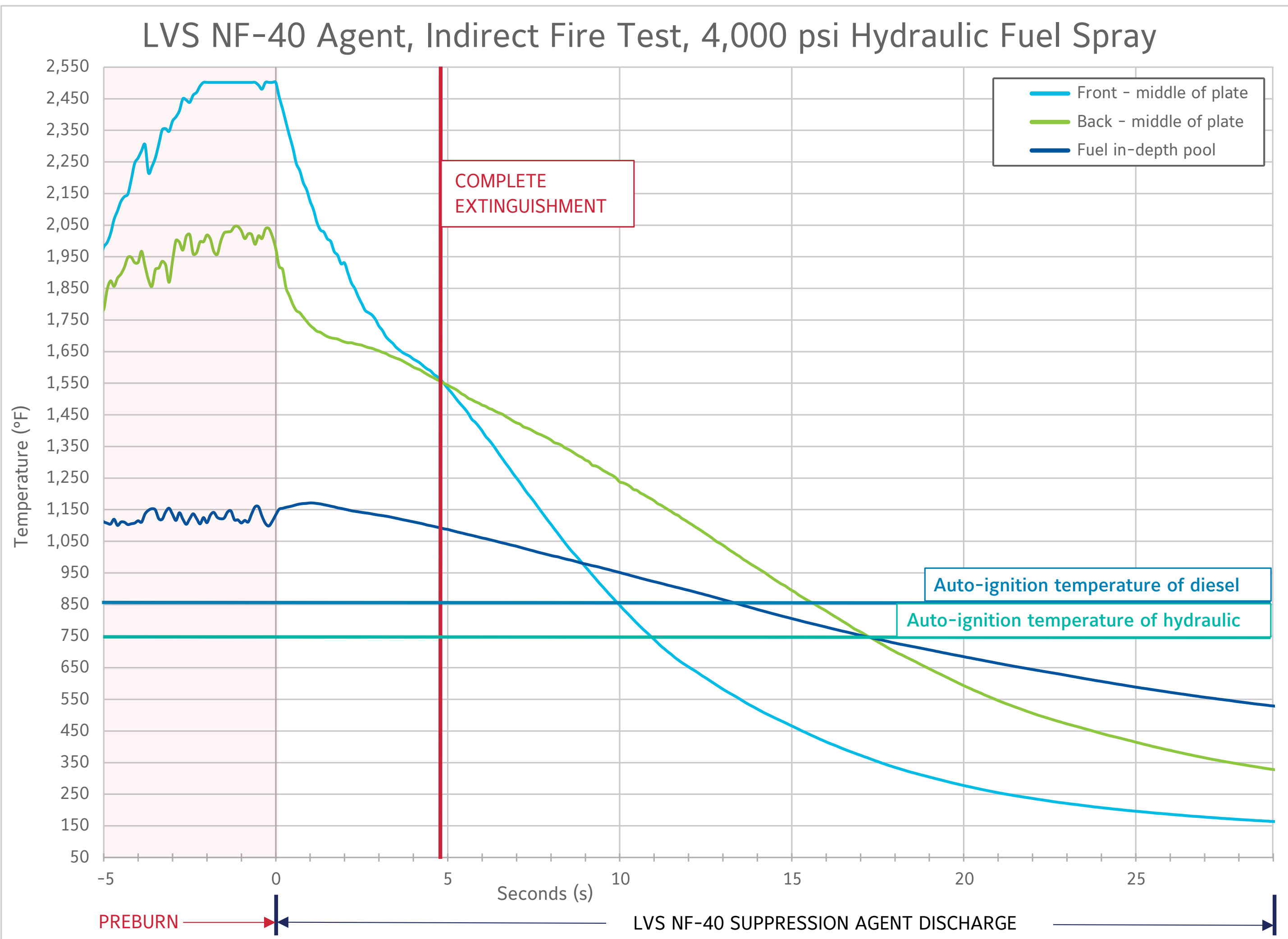

Figure 13 - Test #3, LVS NF-40

Understanding the results

The following table summarizes the performance of the various suppression systems tested by the ANSUL® Systems team.

	System Type	Quantity of Agent	Agent Nozzle Distance (in.)	Discharge Time (sec.)	Total Extinguishment Time (sec.)
Test #1	DC-Foray	15 lbs	48	25	*DNE
Test #2	Water	0.76 gal	48	25	*DNE
Test #3	Twin Legacy LVS	1.16 gal	48	47	8
	Twin DC-Foray	15 lbs	48	25	
Test #4	Twin LVS NF-40	0.70 gal	48	25	6
	Twin DC-Foray	15 lbs	48	25	
Test #5	LVS NF-40	0.76 gal	48	29	4-5
	LVS NF-40	0.70 gal	60	25	4-5

*DNE = Did not extinguish

Figure 14 - Testing summary

Key conclusions from the tests include:

1. A stand-alone ANUSL® LVS NF-40 agent extinguished the flames faster than all other systems tested. It removed heat more quickly from the entire superheated hazard mass (front and back surfaces) while also securing the fuel in-depth pan from reflash.

2. A twin-agent system demonstrated effective fire suppression. In a twin-agent system the dry chemical appears to isolate the heat from the fuel spray, and the liquid agent extinguishes the flames and secures the pool fire. The surfaces are shown to remain superheated at the conclusion of the agent discharge.

   Both the ANSUL® Legacy LVS and the new ANSUL® LVS NF-40 agents exhibited similar flame suppression, flow rates and cooling capabilities in a twin-agent installation. However, the system equipped with LVS NF-40 agent used roughly 35 to 40 percent less agent and shortened the discharge time by 18 to 22 seconds while achieving the same results.

3. Water alone did not demonstrate effective fire protection for most vehicle applications. In Test #2 it failed to control and suppress flame spread and provided only minimal surface cooling, making it unsuitable for heavy-duty vehicle fire protection.

4. Dry chemical agents alone were minimally effective against high-pressure fuel fires and did not provide sufficient cooling for large, superheated surfaces.

Conclusion

The field of vehicle fire suppression is entering an exciting phase. Twin-agent systems have helped to successfully protect heavy industrial vehicles for decades and are still required in some applications to meet NFPA-120 and 122. However, the new **ANSUL® LVS NF-40 Non-Fluorinated Liquid Suppression Agent** offers a higher performing, more cost effective, less complicated solution for fire protection on Ultra- and Mega-class equipment compared to twin-agent systems. This innovative biodegradable and freeze-protected agent offers heavy industries an effective stand-alone fire suppression system option for even the most challenging equipment applications.

With the release of the new LVS NF-40 liquid agent, the vehicle industry now has a stand-alone option with a single agent, that was not previously available for use on Ultra- and Mega-class equipment. This latest technology advances our understanding of fire suppression and utilizes these new insights to deliver the most effective vehicle systems solution for protecting personnel, property and operational continuity.

References:

1. Document No. F-2016050, https://files.hvacnavigator.com/p/F-2016050.pdf

2. Document No. F-97146, https://files.hvacnavigator.com/p/F-97146.pdf

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