Wet Chemical Fire Extinguishing System for Extreme Low-Temperature Vehicle Applications

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Abstract

Fire extinguishing systems used on industrial vehicles operating at extremely low temperatures have historically relied on dry chemical extinguishing agents. This is largely due to the fact that wet chemical agents typically freeze at temperatures well above the low ambient temperatures at which these vehicles are commonly used, as low as -65 °F (-54 °C). Generally, there are two main drawbacks to using only dry chemicals on vehicle fires. First is the limitation of dry chemicals as cooling agents for hot surfaces that can act as ignition sources (e.g. exhaust manifold). Secondly, dry chemical agents have no ability to prevent a liquid fuel from being reignited once discharge is completed. A foaming wet chemical agent could offer hot surface cooling and re-ignition protection; however, the challenges of high liquid viscosity and agent freezing at low temperatures have prevented use of wet chemical agents in low temperature vehicle applications as a primary means of extinguishing fires. A new foaming wet chemical agent, Aquagreen XT™ (patent pending), has been developed by Kidde Fire Systems that seeks to address both of these concerns. Aquagreen XT™ remains liquid at storage temperatures below -65 °F (-54 °C) while maintaining reasonable viscosity at -40 °F (-40 °C), the lowest approved use temperature. Unlike many low-temperature wet chemical agents, this agent does not rely on the use of added ethylene glycol or propylene glycol as the freeze point depressant. Rather, the successful control of freezing point depression and low-temperature viscosity is achieved using a multi-component salt mixture. The salt mixture allows the total salt concentration to remain relatively low while achieving a much lower freezing point than any single salt could attain on its own. The lower overall salt concentration is an important factor in maintaining reasonable values of low-temperature viscosity. As temperature decreases, the viscosity of a wet agent will increase which can substantially hinder the performance of a fire protection system. This new agent has undergone rigorous flow and fire extinguishing testing to validate its fire-fighting efficacy at temperatures down to -40 °F (-40 °C). Aquagreen XT™ is approved for use by FM Global as either a primary or secondary fire-extinguishing medium for industrial vehicles operating at low temperatures down to -40 °F (-40 °C). This paper discusses the properties and features of a new readily biodegradable foaming wet chemical agent as well as its fire extinguishing performance characteristics. It also describes the fire and flow testing conducted to ensure performance throughout its operating temperature range of -40 °F (-40 °C) to 200 °F (93 °C). Kidde Fire

Systems' testing of Aquagreen XT™ was modeled after the requirements given in *Australian Standard for Fire protection for Mobile and Transportable Equipment,* AS 5062-2006. Based on the lack of a U.S. standard for testing of wet chemicals as a primary extinguishing agent on industrial vehicles, Australian Standard AS 5062-2006 could serve as a basis or model in developing a new U.S. standard for this type of testing.

Introduction

There are many challenges in protecting industrial vehicles due to the hazards and complexity of the machinery itself as well as the harsh environments the fire protection equipment and agent must endure until called upon to extinguish a fire. The forestry, mining, steel, agriculture, and waste management sectors all utilize vehicles that can typically be found in remote areas that may or may not be in harsh environments. Forestry industry operations, for example, could reach temperatures well below freezing, perhaps even down to -65 °F (-54 °C), while the steel industry sees the other extreme with vehicles operating in furnaces experiencing temperatures well above 200 °F (93 °C). These industries depend upon their vehicles to remain operational as the success of their business relies upon it. Consequently, any fire protection agent expected to protect these mobile hazards must meet stringent requirements. These include, but are not limited to, the agent must be able to flow well and extinguish a fire across a wide range of temperatures from extremely low temperatures to relatively high temperatures and allow for storage at temperatures as low as -65 °F (-54 °C). The agent also must be able to handle both Class A and Class B fires. Another point of consideration is environmental impact: the vehicles operate outdoors releasing the agent directly into the local ecosystem if the fire protection system is discharged. This is a concern today and is expected to become more significant in the future, making it important to have a non-hazardous environmentally friendly agent.

Currently the primary means of fire extinguishing on these types of vehicles is by application of ABC dry chemical. ABC dry chemical is generally regarded in the fire-fighting industry as an effective extinguishing agent for both Class A and Class B fires and offers a wide operating temperature range, typically -65 °F (-51 °C) to 200 °F (93 °C). However, the use of a vehicle extinguishing system comprised solely of a dry chemical agent has two important drawbacks. Dry chemical agents are unable to effectively cool hot-surface ignition sources thereby leaving the vehicle vulnerable to re-ignition once the agent has finished discharging. Secondly, dry chemicals cannot secure a Class B fire hazard (i.e. pooled combustible liquid such as hydraulic fluid) in order to prevent its re-flash in the presence of an ignition source. These two drawbacks are generally accepted in the fire-fighting industry as limitations when using dry chemical agents. In order to deal with the risk of re-ignition some vehicles have a dual system in place consisting of an initial discharge of ABC dry chemical to knockdown and extinguish the fire followed by a secondary discharge of a freeze-protected wet chemical to either cool hot surfaces, secure the fuel, or both. The freeze-protected wet chemical typically utilizes propylene glycol as the freezing point depressant. While propylene glycol antifreeze solutions prevent the agent from freezing, there are distinct disadvantages in using these solutions as additives in an aqueous fire-extinguishing agent. An aqueous agent that employs propylene glycol for freeze protection becomes quite viscous as the fluid temperature dips below freezing 32 °F (0 °C). The increased viscosity reduces the flow rate of agent through distribution hose or pipe, which can lead to difficulty obtaining adequate atomization pressure at the nozzle. The failure to achieve proper atomization during discharge can reduce the fire extinguishing effectiveness of the agent. High concentrations of propylene glycol are needed to obtain low freezing points, which consequently reduce the overall water content within the agent. This can affect how well the agent performs thermodynamically when cooling the hot surfaces and fuel. The ideal antifreeze would help contribute to the fire fighting performance, limit the viscosity increase, and help to maintain a greater water concentration; all of which are very difficult to accomplish at extremely low temperatures. Currently, due to limited performance of wet chemical agents at low temperatures, most vehicle fire protection relies heavily on dry chemical systems to work efficiently to knockdown and extinguish a fire. Unfortunately, the vehicle is still at risk for re-ignition at the temperatures below which wet chemicals can operate effectively.

Based on research conducted by Kidde Fire Systems, a foaming wet chemical agent that can handle the temperature extremes without using a glycol based freeze depressant has been developed and fire tested at temperatures down to -40 °F (-40 °C). In testing, the wet chemical, Aquagreen XT™ developed by Kidde Fire Systems, remains liquid at temperatures down to -65 °F (-54 °C). The agent's low freezing point is due to the use of a multi-component salt solution. Multiple salts within the solution enable the freeze point depression while at the same time limiting the total overall salt concentration. By limiting the overall salt concentration the resulting viscosity of the solution at low temperatures was reduced significantly. Aquagreen XT™ was flow tested in multiple extinguishing system configurations to provide a pre-engineered system with maximum design limits. The fire test procedures were based on the requirements of Australian Standard AS 5062-2006 including fire tests that simulate both spray and pool fires. The fire tests also incorporate direct and indirect agent exposure to the fire. This paper describes the wet chemical agent and freeze protection system as well as the flow and fire tests completed to ensure fire protection at temperatures down to -40 °F (-40 °C).

Wet Chemical Agent

Within the fire protection industry there is a good understanding of how wet chemicals and foams extinguish Class A and Class B fires at ambient temperatures, but these agents are limited by the low temperature restrictions imposed by the operating conditions of many industrial vehicles where temperatures may be well below 32 °F (0 °C). Most wet agents have a freeze-protected version available in which ethylene or propylene glycol is utilized as the freeze point depressant. A problem with using glycols as the freeze point depressant is that they are viscous and can decrease the fire fighting performance of the agent. When trying to obtain freeze points below -40 °F (-40 °C) the solution could require upwards of a 50% concentration of propylene glycol according to published freeze point depression curves.[2] Therefore, the highly favorable thermodynamic properties of water are replaced with that of propylene glycol. Two key factors were taken into consideration when investigating new methods of freeze protection for a foaming agent: the importance of obtaining an extremely low freezing point and maintaining a relatively low viscosity at low temperatures. Both of these factors are addressed in more detail in later sections of this paper.

Freeze Point Depression

Achieving a significant depression of freeze point in an aqueous fire extinguishing agent is complicated by the limited number of suitable antifreeze chemicals available. Alcohols and ketones of a low carbon number offer freeze protection, however, the toxicity of many of these organic compounds, as well as their flammability, limits their use in fire protection agents. Some liquids that can be utilized as freeze point depressants, with relatively low risk due to flammability and toxicity, are glycols. Glycols, while they offer adequate freeze protection tend to diminish the fire fighting performance of the agent due to decreased water content and lead to increased viscosity at lower temperatures. Another known option to reduce an agent's freezing point is the introduction of electrolytes. The electrolytes typically used for freeze point depression in the fire protection industry consist of the salts of sodium and potassium, as these ions have proven effective in fire extinguishment. Single salt solutions have been used in foaming agents previously, but finding a salt that is compatible with the surfactant system can be difficult. In order to obtain the extremely low freeze point desired for vehicle applications, the salt concentration must be upwards of 50% for most single salt solutions based on published freeze point depression curves.[2] These high concentrations can introduce complications at low temperatures in regards to viscosity and fire fighting efficacy. In order to address the negative characteristics of using an agent containing high salt concentrations, it was determined that a multiple component salt solution could be beneficial as a freeze point depressant system. For reasons that are complex, multiple-component salt solutions require lower temperatures to achieve solidification. Using this method, a much lower freezing point was achieved, while at the same time limiting the overall salt concentrations.

Aquagreen XT™ utilizes multiple salts to achieve its extremely low freezing point. The salts act together to inhibit the formation of a crystalline lattice structure until much lower temperatures are reached. These salts were selected based upon their low contribution to the final solution viscosity, fire fighting performance, and high specific heats. To determine the best combination of salts, a test matrix was developed to evaluate the overall salt concentration and the proportions of the salts involved. Each mixture's freezing point was then determined by slowly reducing the solution's temperature until ice crystal formation was observed. During testing it was noted that as the salt concentrations increased the solution became unstable causing precipitates to form. The precipitates were formed due to the interaction between the salt and the surfactant system employed. This study revealed that the salt solution freezing point was a function of the ratio of the salts and the total salt concentration. Through this study salt solutions were discovered that had freezing points below -70 °F (-57 °C).

Viscosity

The viscosity of an aqueous solution increases as the temperature decreases. As viscosity increases the flow resistance increases with a net effect of reducing flow rate to and pressure at the nozzles. Further, the presence of foam-forming surfactants will have an effect on the increase in solution viscosity as solution temperature is reduced. If the aqueous agent becomes too viscous the quality of the atomized spray exiting the nozzles could be significantly impaired. The inability to properly atomize can severely reduce the fire-fighting efficacy of an aqueous agent. Thus, the selection of the types and concentrations of salts, and other additives, in an aqueous agent must be done with care to minimize solution viscosity, particularly at low operating temperatures, if fire-extinguishing performance is to be maintained. Viscosity data for solutions of both propylene glycol and ethylene glycol with freezing points of -40 °F (-40 °C) are reproduced[3] in Figure 1 along with viscosity data obtained for Aquagreen XT™ with a freezing point below -65 °F (-54 °C). Based on Kidde Fire Systems' testing, Aquagreen XT™ maintains a lower viscosity than propylene glycol at temperatures below 10 °F (-12 °C) as seen in Figure 1. If the graph for Aquagreen XT™ were extended, the viscosity could be less than that for ethylene glycol at temperatures below -25 °F (-32 °C).

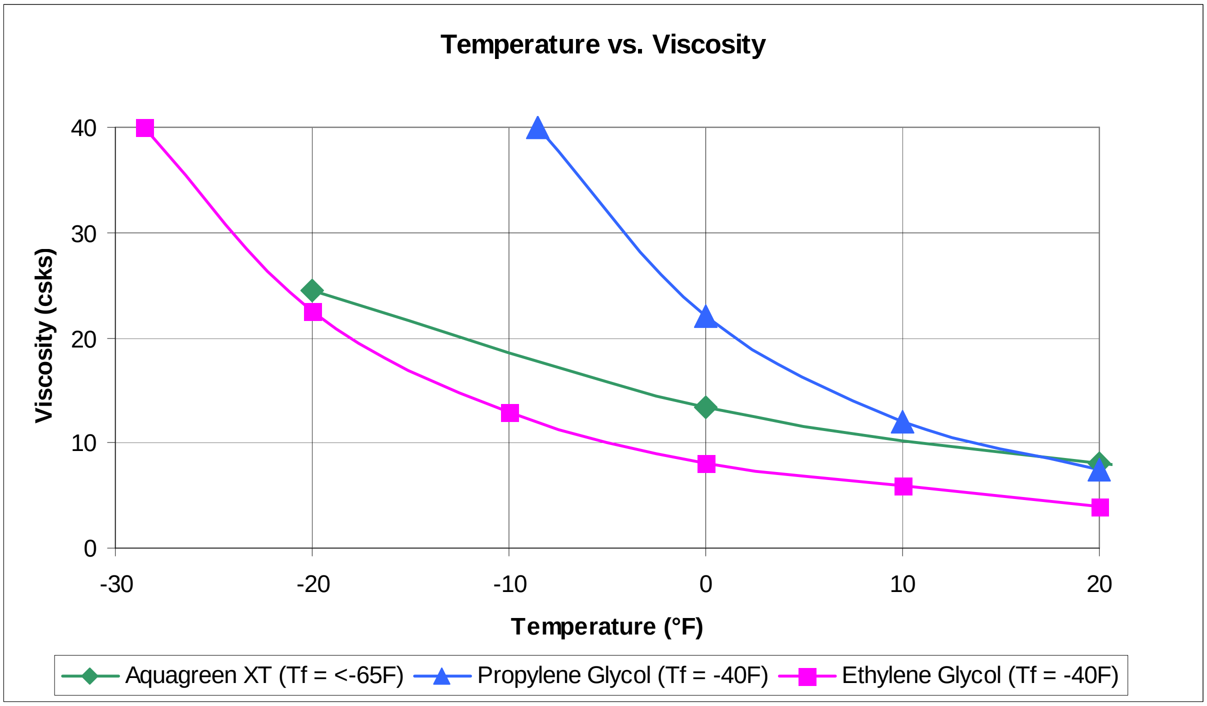

Figure 1 Viscosity data for various freeze-protected solutions

Flow Testing

The purpose of flow testing was to determine the limits of design for a fire extinguishing system within the parameter space that includes: agent quantity, number of flow branch lines, hose diameters, hose lengths, minimum and maximum system temperature, and nozzle location. Hose and nozzle networks were tested in un-balanced and balanced configurations. The hose distribution systems were designed for ease of installation, offering many options to the installer. This was accomplished by setting system limits which include: number of nozzles per branch, maximum hose volume, maximum equivalent feet from cylinder to most remote nozzle, and maximum equivalent feet from most remote nozzle to most remote nozzle. Flow testing was conducted using industry standard pressure transducers installed throughout the discharge hose network to measure the pressure change during system discharge. The data acquisition system provided for a determination of flow performance throughout the hose network thereby identifying specific areas of possible flow restriction. This test process was useful in optimizing the discharge hose system to assure effective nozzle performance. See Figures 2 and 3 below for an example of system pressures, the data collected during flow testing, and a typical hose distribution network.

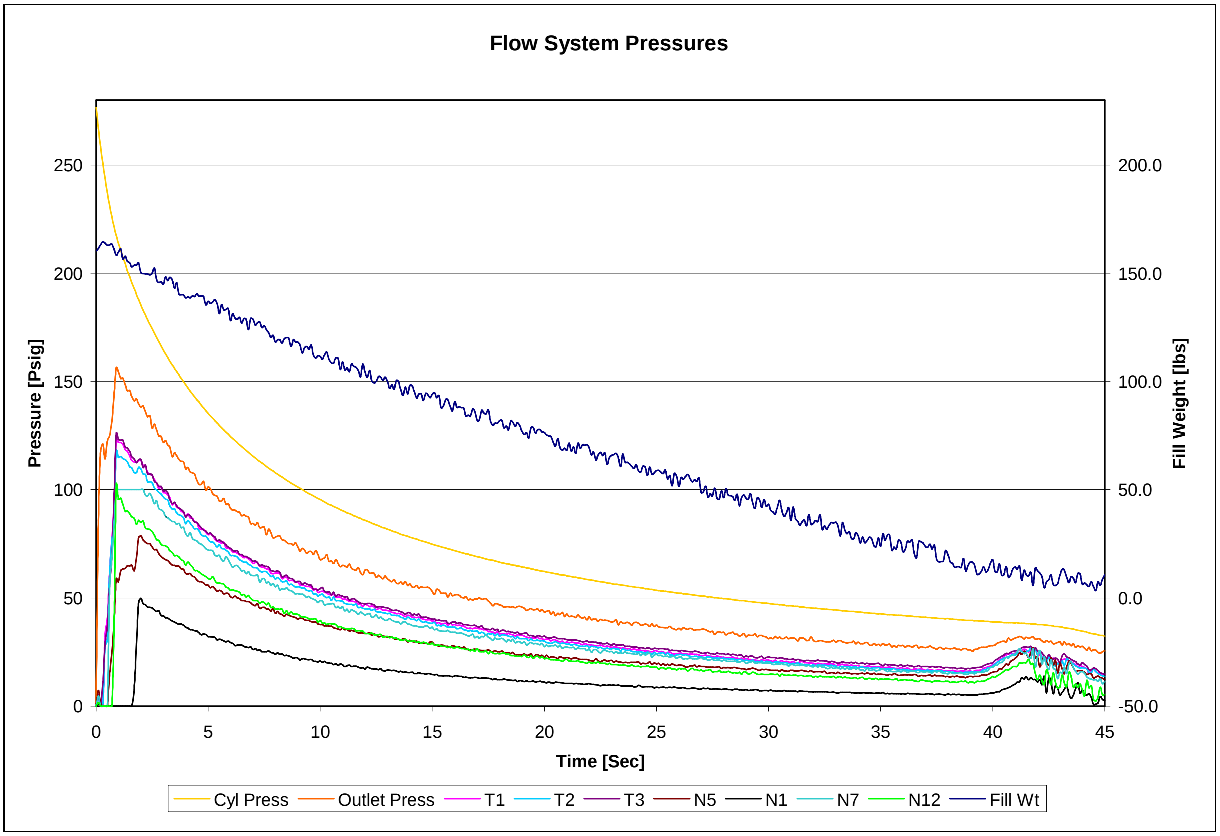

Figure 2 Flow system pressures

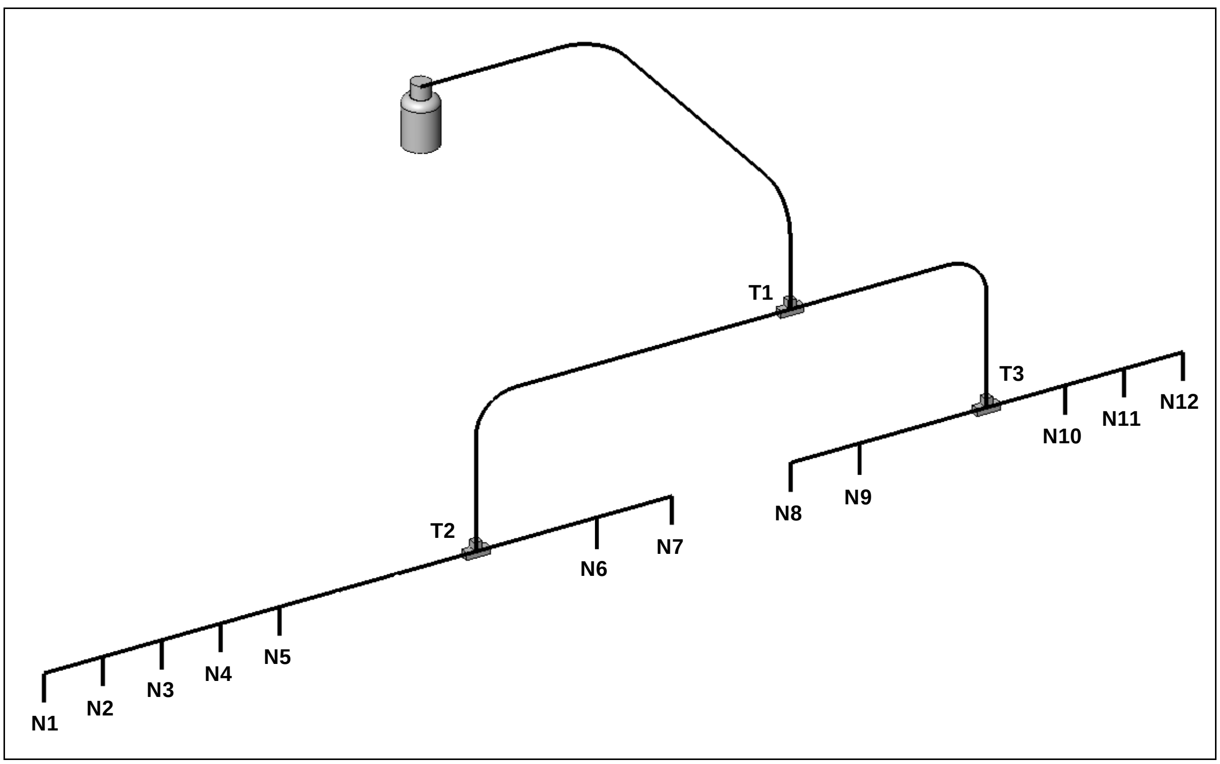

Figure 3 Typical hose distribution network

Multiple flow tests were conducted initially at low temperatures to evaluate the performance of the system and to collect some baseline data. Cylinders and agent were conditioned at the test temperature in an environmental chamber. Experimentation was conducted at multiple temperatures and nozzle designs to optimize agent atomization at the nozzle. A preliminary nozzle design with a standard cone shaped spray pattern and minimum temperature of -40 °F (-40 °C) were specified for the remaining fire and flow tests.

Fire Testing

No universally accepted standard currently exists in the United States for testing the feasibility of using a wet chemical as the primary means of extinguishing fires on vehicles. Other areas of the world, in particular Australia, have introduced standards to test foam and wet chemical systems on vehicles. Australian standard AS 5062-2006 *Fire Protection for Mobile and Transportable Equipment* was used by Kidde Fire Systems as the primary source for developing the test plan to determine if a wet chemical agent effectively extinguishes fires on vehicles. The tests were completed at both ambient temperatures as well as at the extreme low temperature of -40 °F (-40 °C). The Australian Standard specifies two fire tests: direct application and indirect application fuel spill extinguishment and re-ignition tests. The first test demonstrates the agent's ability to extinguish a diesel pan fire when applied directly onto the fire and fuel source as well as secure flammable vapors from re-ignition by a diesel spray fire. The second test demonstrates the agent's ability to extinguish (and secure) an obscured diesel pan fire when applied indirectly as well as cool a super-heated steel baffle to a temperature that would prevent re-ignition from a continuous diesel spray. Each test is described in detail below and the corresponding results and conclusions are discussed.

In designing the mechanical aspects of the Kidde Sentinel fire extinguishing system for vehicles, three critical performance factors were addressed: agent atomization, agent area coverage, and nozzle flow rate. Numerous parameters exist that can affect these three areas of focus, many of which can be inter-related. These include nozzle design, nozzle aim, nozzle location, cylinder pressure, agent fill quantity, operating temperature range, and flow system restrictions. Most of these variables could be adjusted to obtain different results. In designing the Kidde Sentinel vehicle system many of the variables were held constant allowing only the agent atomization, agent area coverage, and nozzle flow rate to be changed. These critical areas were selected based on what the desire of the market was perceived to be and were used to obtain optimal system performance.

Direct Application Fuel Spill Extinguishment and Re-ignition Test

This fire test simulates a realistic situation where a pressurized line on a vehicle carrying combustible fluid bursts and consequently sprays combustible fluid across a pool fire located near the vehicle. The test requires the agent to be able to extinguish the pan fire and secure the fuel against the heat and flames of the spray fire in order to prevent re-ignition. The fire test setup included the agent extinguishing system, a diesel spray system, and two pans, a smaller pan for igniting the diesel spray with dimensions of 12 in (305 mm) by 12 in (305 mm) and a larger test pan with dimensions of 27 in (686 mm) by 27 in (686 mm). All of the components were set up as illustrated in Figure 4. The diesel spray system consisted of a 6.5 gal (24.6 L) cylinder filled with 3.2 gal (12 L) of diesel fuel and pressurized to 220 psig (15 bar). This cylinder was connected with a hose to a 0.039 in (1 mm) orifice spray nozzle. The purpose of the smaller pan fire was simply to ignite the diesel spray. The protocol does not require the smaller pan fire to be extinguished by the agent during the test. The second larger pan, which was appropriately sized to the nozzle spray coverage at the manufacturer's maximum nozzle height, was placed on the ground in line with the small pan 47.25 in (1200 mm) from the diesel spray nozzle. This pan contained the test fire that must be extinguished with no re-ignition during the test. The fire test pan was 8 in (203 mm) deep and was filled with 2 in (50.8 mm) of water followed by 2 in (50.8 mm) of diesel fuel. The smaller ignitor pan was 4 in (102 mm) deep and was filled with 1 in (25.4 mm) of water followed by 1 in (25.4 mm) of diesel fuel. A small quantity of heptane was added to each pan to facilitate ignition. The agent nozzle was located at the maximum mounting distance for full spray coverage over the center of the larger test pan. During each test, a two-minute pre-burn was used. At one minute forty-five seconds into the test the diesel spray was initiated and the extinguishing system was discharged at the two minute mark. After completion of the agent discharge the diesel spray was allowed to continue for thirty seconds to allow the spray fire to heat up the agent-covered fuel. If the agent extinguished the larger pan fire and prevented re-ignition from the overhead spray fire for at least thirty seconds after completion of agent discharge, the fire test was successful. If re-ignition occurred, the test was considered a failure.

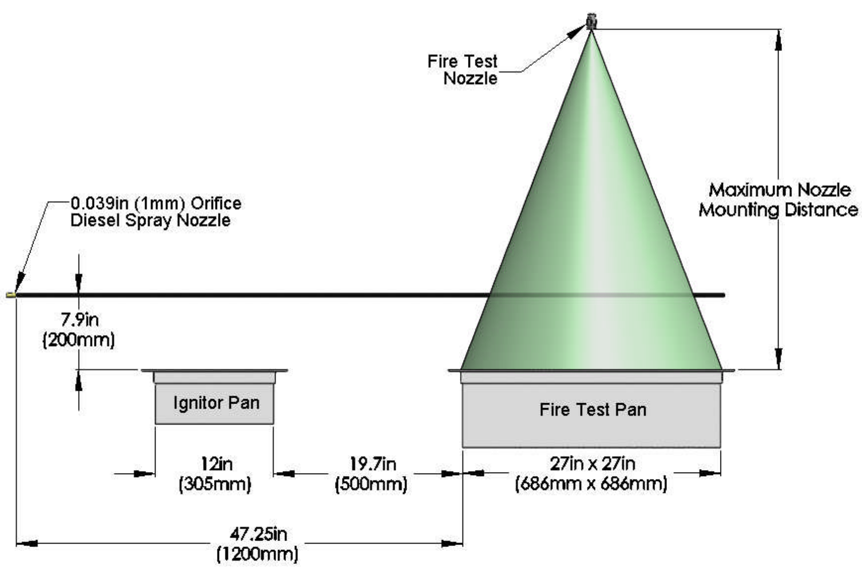

Figure 4 Direct application fire test setup

In-direct Application Fuel Spill Extinguishment and Re-ignition Test

This fire test was used to demonstrate the agent's cooling capability and its effectiveness at extinguishing an obscured fire. In this test, the agent is required to extinguish an obscured pan fire and cool the baffle plate sufficiently to prevent ignition of a diesel spray on the plate after the fire is extinguished. The baffle test setup utilized an agent extinguishing system, diesel spray system, fire test pan, and a 1/8 in (3 mm) steel plate baffle. All of the components were set up as illustrated in Figures 5 and 6. The agent nozzle was placed horizontally aimed at the center of the baffle which in this case was 25.5 in (648 mm) above the ground and located at the maximum mounting distance from the baffle for full spray coverage. The steel baffle was located a third of the fire test pan width from the edge of the pan closest to the agent discharge nozzle which in this case was 9 in (229 mm) as seen in the top view of the test setup in Figure 6. It was positioned 4 in (102 mm) above the top of the pan and had a size and shape equal to that of the fire test pan. The fire test pan was filled with 2 in (50.8 mm) of water and 2 in (50.8 mm) of diesel. A small amount of heptane was added to the pan for easier ignition. During each test, a two-minute pre-burn was used. The diesel spray was initiated at the same time as the pan fire ignition and the system was discharged at the two-minute mark. The diesel spray was shut off when the agent discharge was completed. The diesel spray was turned on again for fifteen seconds. If the agent extinguished the pan fire and the diesel spray did not ignite when impinging upon the hot steel baffle, the fire test was considered successful. If the fire was re-ignited because the baffle was not cooled sufficiently, the test was considered a failure.

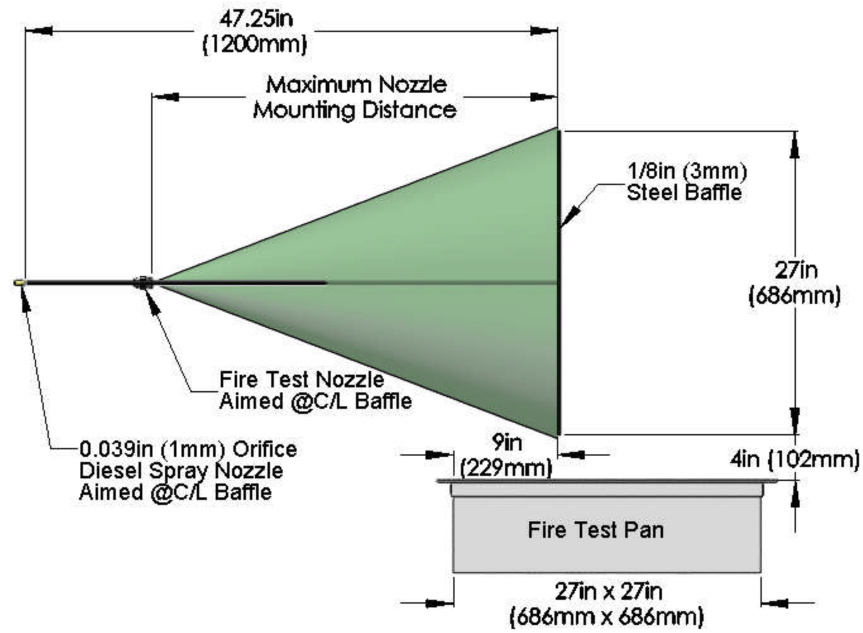

Figure 5 In-direct application fire test with baffle (side view)

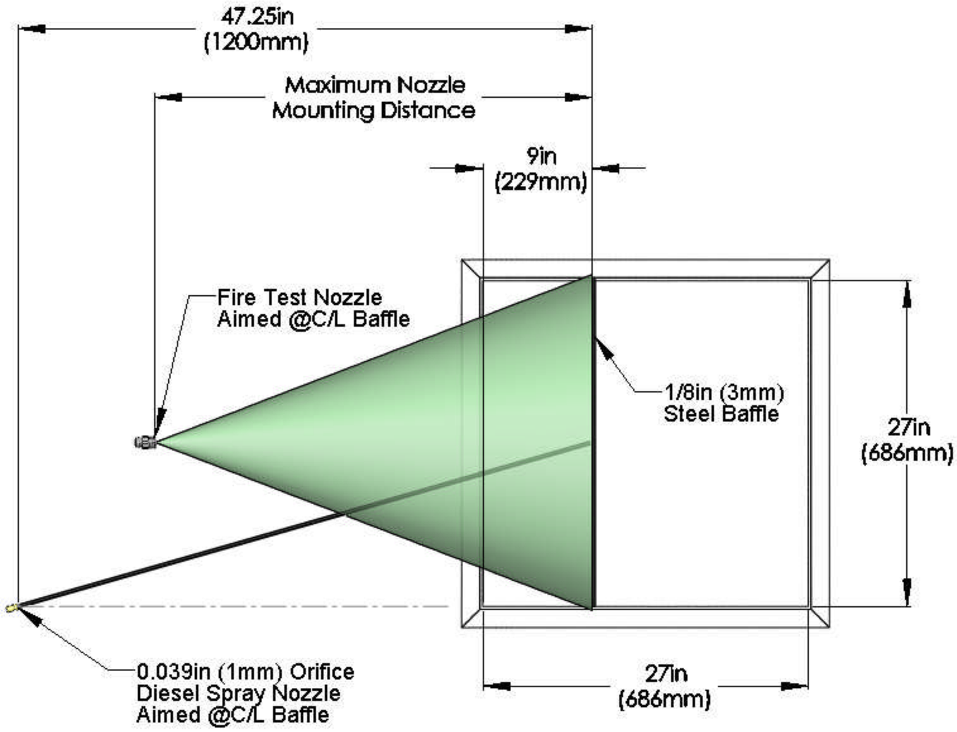

Figure 6 In-direct application fire test with baffle (top view)

During testing and experimentation with critical parameters such as agent atomization, area coverage, and flow rate, it was discovered that when testing the agent at low temperatures, proper atomization of the viscous liquid needed to occur long enough during the initial discharge to suppress and extinguish the test fire. If the agent was not atomized adequately, due to either low nozzle pressure or high viscosity, the fire was suppressed but not extinguished. This could occur in a system where the nozzle flow rate was higher but due to the large droplet size, would not be effective at extinguishing the test fire. Usually in this instance when the agent was at a very low temperature, significantly increasing its viscosity, the agent would initially discharge with a weak spray pattern with large droplets and quickly decay to a stream of agent as the droplets joined back together.

The final mechanical aspects that were incorporated into the fire extinguishing system attempted to balance proper spray area coverage over an operating temperature range that permits proper atomization of the agent and an adequate discharge rate that can quickly suppress and extinguish the fire, and then secure any free-standing fuel that may be present on a vehicle. As a validation test for the final system, two large diesel engines were placed end-to-end with a mock-up engine compartment built around them. A fire test pan was placed underneath each engine and a diesel spray nozzle was situated such that it sprayed onto the engine after being heated for two minutes by the pan fires. The effectiveness of the fire extinguishing system was validated in three successive tests in the mock-up arrangement.

Conclusions

Vehicle fire protection at low temperatures has largely relied on ABC dry chemical protection due to the limited fire fighting performance of wet chemical agents because of freezing and increased viscosity. The implementation of a multi-component salt solution in combination with a surfactant system has led to the development of a new wet chemical agent, Aquagreen XT™, that, under tests conducted by Kidde Fire Systems, can withstand temperature down to -65 °F (-54 °C) and extinguish fires down to -40 °F (-40 °C). The agent has undergone testing pursuant to standards established under the Australian Standard for *Fire Protection of Mobile and Transportable Equipment*, AS 5062-2006, including both flow and fire to evaluate its performance throughout its operating range. The Australian Standard, AS 5062-2006, could serve as a model in developing a new U.S. standard for testing wet chemicals as a primary extinguishing agent on industrial vehicles.

References

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