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Automatic Fire Extinguishing Systems (AFES) Obscuration Testing

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14. ABSTRACT
Since phase out of mainstream ozone depleting substances, such as halon 1301 (bromotrifluoromethane), the US Army (USA) has relied on hydrofluorocarbons (HFC) for many of its fire suppression applications. However, due to concern over the high global warming potentials (GWP) of HFCs, their production is being limited. Therefore, the Army initiated a research program to evaluate potential environmentally-friendly, low-GWP chemicals as candidate fire extinguishing agents for use in automatic fire extinguishing systems (AFES) that protect the crew of Army vehicles against fire and explosions caused by combat threats. This report summarizes obscuration effects of a potential alternative agent. Specifically, we present obscuration measurements associated with discharge of a proprietary finely ground sodium bicarbonate dry chemical, compared to legacy fire extinguishing gaseous agents halon 1301 and HFC227-BC (heptafluoropropane mixed with sodium bicarbonate dry chemical powder). We observed prolonged obscuration in the crew compartment after a discharge of the fine grind sodium bicarbonate compared to legacy agents. There are currently no Army criteria for obscuration effects in combat vehicle crew compartments. Our results indicate that such criteria may be needed to fully evaluate more environmentally-friendly fire protection agents.

15. SUBJECT TERMS
Fire Protection, Obscuration, Extinguisher, Fuel Fires, Environmental, Low Global Warming Potential

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TEST REPORT

Automatic Fire Extinguishing Systems (AFES) Obscuration Testing

1.0 Executive Summary

Since the cease of production of high ozone depleting substances such as halon 1301 (bromotrifluoromethane), the US Army (USA) has relied on hydrofluorocarbon (HFC) extinguishing agents for many of its fire suppression applications. However, production of HFCs is being phased down due to their high global warming potentials (GWP). Therefore, the Army initiated a research program to evaluate potential environmentally-friendly, low-GWP chemicals as candidate fire extinguishing agents for use in automatic fire extinguishing systems (AFES) that protect the crew of Army vehicles against fire and explosions caused by combat threats. The current effort is a continuation of research conducted for ground and aviation weapon systems [1]. This report summarizes obscuration effects of a potential alternative agent. Specifically, we present obscuration measurements KSA, a proprietary finely ground sodium bicarbonate dry chemical, compared to legacy fire extinguishing gaseous agents: halon 1301 and HFC227-BC (heptafluoropropane mixed with sodium bicarbonate dry chemical powder). KSA was developed as a potential replacement for halon 1301 in civil aviation fire protection systems. We observed prolonged obscuration in the crew compartment after a discharge of KSA, significantly longer than obscuration due to legacy agents. There are currently no Army criteria for obscuration effects in combat vehicle crew compartments. Our results indicate that such criteria may be needed to evaluate more environmentally friendly fire protection agents.

2.0 Introduction

The Army relies on halon 1301 (bromotrifluoromethane), HFC-227ea (heptafluoropropane), HFC-125 (pentafluoroethane), dry chemical (sodium or potassium bicarbonate based), carbon dioxide, and water mixed with a freeze point reduction additive (potassium acetate) to provide fire protection for its ground and aviation weapon systems. However, halon 1301 and HFC227-BC (HFC-227ea mixed with 5% to 10% sodium bicarbonate dry chemical by weight) are the only agents approved for use in automatic fire extinguishing systems that protect the crew compartments of ground vehicles. Due to international agreement, production of halon 1301 was eliminated in 1994 because of its high ozone depletion potential via the Montreal Protocol on Substances that Deplete the Ozone Layer [2]. Since then, the Army has transitioned to HFCs or other alternatives, such as sodium bicarbonate dry chemical, for all new vehicles. On 15 October 2016, Parties to the Montreal Protocol adopted the "Kigali Amendment" [3]. While this amendment does not restrict the use of HFCs, it calls for the gradual reduction of their consumption (production + imports – exports – destruction). The phasedown schedule for the US started with a 10-percent reduction in 2019 and culminates in an 85-percent reduction in consumption by 2036 (Appendix A). As a result, alternative low-GWP chemicals for fire suppression will likely be needed.

In response, the Army established the Low-GWP Alternative Fire Suppressants program. The focus of this effort is to evaluate the feasibility of commercially available and emerging chemicals to replace high-GWP fire suppression agents in its weapon systems [1, 4, 5]. To be considered a viable alternative to HFC227-BC, which is the Army's replacement for halon 1301 in vehicle crew AFES, the candidate must meet unique military requirements including the "Selected Crew Casualty Requirements" (Appendix B) that allow personnel to stay within the protected space for at least 5 minutes after fire suppression. Previous testing of Low-GWP alternative agents [4] identified KSA, a proprietary finely ground sodium bicarbonate dry chemical, as a fire suppression agent which exhibited enough potential to recommend continued investigation. In addition to fire suppression performance, continued investigation must include an assessment of the effect of a KSA discharge on crew safety (i.e. inhalation toxicity), and operational effects. In this effort, we examined the visual obscuration that the vehicle crew would experience after a discharge, with attention to operational issues, specifically visibility of control indicators, and egress capability. Obscuration due to the discharge of any dry chemical is expected to be more severe than with the currently fielded gaseous agents (although there is some dry chemical in HFC227-BC, and both can produce fog when discharged). However, there is currently no criteria for obscuration that is applicable to the crew compartment of an armored ground vehicle. Hence, a goal of the tests described herein, in addition to direct, comparative obscuration measurements, is to develop a basis for the development of quantitative obscuration criteria.

The testing consisted of discharging deployed fire suppression agents, halon 1301 and HFC227-BC, and the potential alternate agent, KSA, within chambers instrumented to measure the percentage of incident light that is transmitted through the test chamber. The transmittance is then used to calculate the optical extinction coefficient over time for each agent. The optical extinction coefficient, a measure of light absorption per unit distance (/m), is calculated (Appendix C) based on the measured transmittance, and the length of discharged agent which the laser has traveled through (path length). The transmittances of the various agents were measured versus time using a laser/detector system. In addition, video of a test target (United States Air Force 1951) was recorded for each AFES discharge event by two cameras—one inside and one outside of the test chamber.

Generally, the worst-case scenario for obscuration due to an AFES discharge within an Army ground vehicle is when all hatches are closed and ventilation is off. Therefore, in the tests described in this report, the chamber ventilation system was closed, and special attention was made to seal the chambers.

Ambient relative humidity and the temperature inside the test chambers were recorded, to determine whether the formation of fog was possible due to the drop in temperature which is a normal aspect of a high-speed AFES discharge.

The assessment of obscuration effects after an AFES discharges inside an actual Army vehicle crew compartment, where agent concentrations can vary significantly, were not included in these tests. The obscuration effects at temperature and humidity extremes were not measured in these tests.

This testing was conducted by the Army Ground Vehicle Systems Center's (GVSC) Fire Protection and Electronic Defeat Technologies teams. Testing was performed at the GVSC Fire Lab in Selfridge Air National Guard Base, MI.

3.0 Measurement Methods

As shown in Fig. 1 and 2, the tests were conducted within a 2.27 meter wide (7.45 feet), 2.22 meter long (7.28 feet), and 1.24 meter tall (4.07 feet) metal chamber. A removable wall was constructed, splitting the chamber in half, yielding a 1.14 meter (3.74 feet) path length. Thus, optical attenuation measurements through two different path lengths were possible. This served two purposes. First, the shorter path was desired in case the degree of attenuation in the full path length of the chamber exceeded the dynamic range of the optical detectors. Second, at least to first order, the optical extinction coefficient (a quantity associated with the degree of obscuration) should be independent of path length, so comparing the data from two otherwise identical AFES discharges through the two different path lengths served as a sanity check for linear behavior, as well as an indicator of variables in the test conditions. A laser beam was directed through two holes in the chamber walls. The transmitted laser power was measured, and extinction coefficient calculated, as a function of time during and after each AFES discharge. Two extinguisher mounts were located on the wall closest to the laser source. Each extinguisher was outfitted with a single nozzle and rotated to disperse the agent towards the center of the chamber. A GoPro camera was mounted within the chamber, 0.61 meters (2.00 feet) away from the test target, to give a visual indication of the level of obscuration created within the chamber after AFES discharge. A second video camera was mounted outside the chamber, with a distance of 2.22 meters (7.28 feet) between the window and the test target. A thermocouple was instrumented on each side of the chamber, to measure temperature changes due to the extinguisher discharge. A release switch was used to discharge the extinguishers.

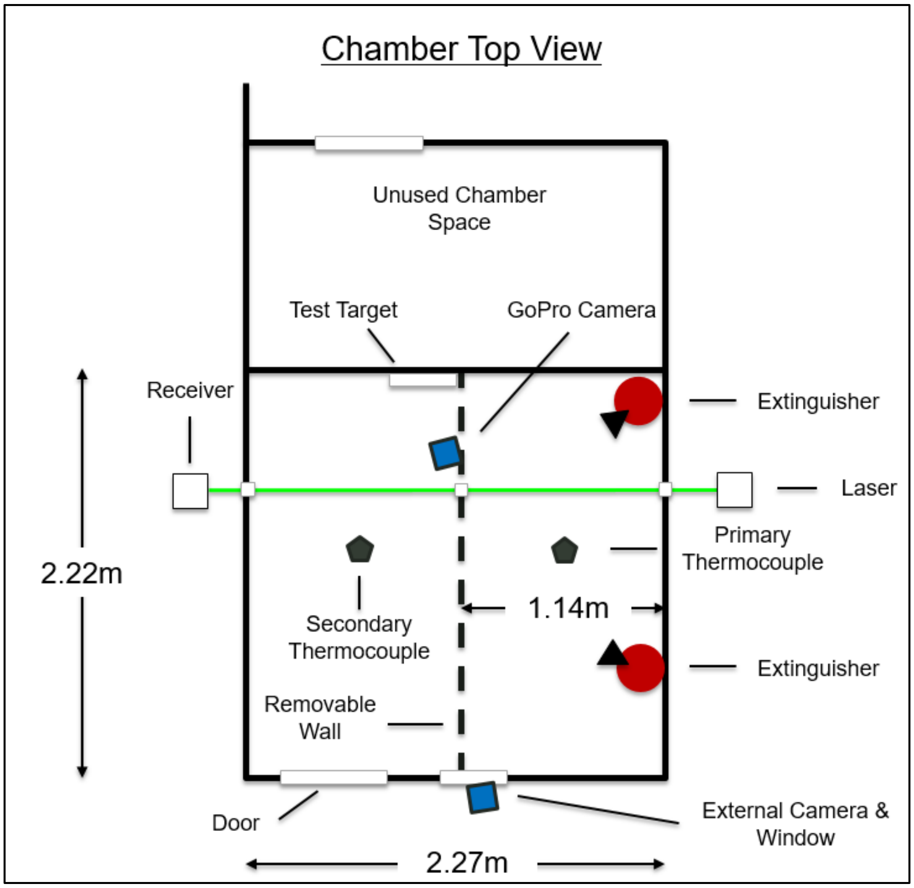

Figure 1: Top view diagram of instrumented test chamber

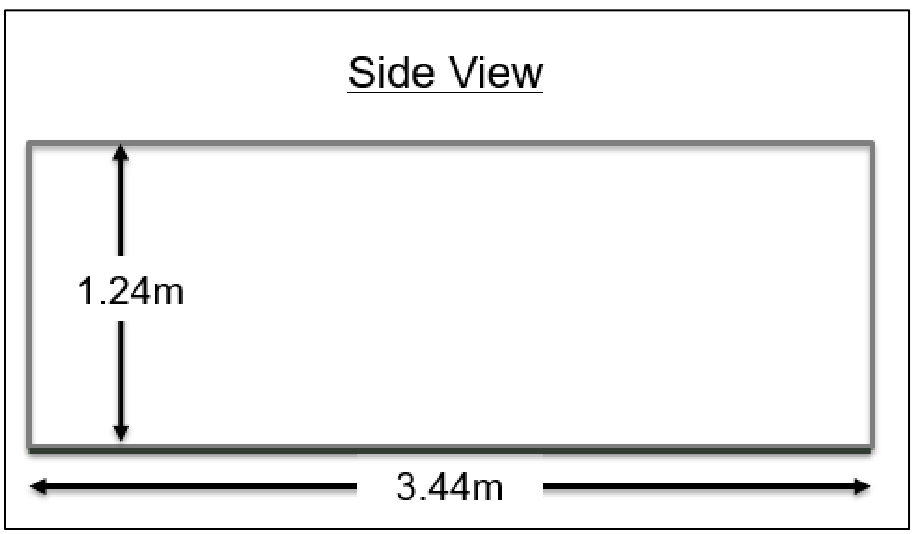

Figure 2: Side view diagram of test chamber

Figure 3: GoPro, test target, and removable wall frame within chamber

Figure 4: Extinguisher mount and removable wall

Figure 5: Second extinguisher mount, standard definition camera, and window

Figure 6: Mounted extinguisher

Two optical breadboards were set up on tripods on either side of the AFES test chamber, physically separated from the chamber to minimize any movement of the breadboards (and consequently the laser beam) that could result from an AFES discharge. A diode-pumped, solid-state, continuous-wave laser with an emission wavelength of 532 nm and nominal output power of 40 mW was used as the light source. On the laser breadboard, an optical wedge was used to direct a Fresnel reflection to a silicon detector which gave a reference signal for the input laser power. On the receiver breadboard on the output side of the chamber, a silicon detector was used to measure the transmitted laser power. Baffle tubes and cloth covers were used on the detectors to minimize interference from background lights. A notch filter was used on the transmitted power detector, but not on the reference detector, as the transmittance of the interference filter varied significantly with angle. The internal wall was erected with a hole aligned to the same laser path for the shorter chamber path length, so that the positions of the laser source and transmitted power detector were maintained. (See Figs. 7 to 9.)

The normalized laser transmittance through the chamber was measured as a function of time before, during, and after each AFES discharge. The nominal data collection duration for each event was 5 minutes. However, for events that took a longer time to clear, an additional 5 minutes of transmittance data were recorded. Normalized transmittance was calculated as:

$$\mathrm{T(t)} = \frac{\mathrm{P_B(t)}}{\mathrm{P_A(t)}} \Big/ \left[\frac{\mathrm{P_B}}{\mathrm{P_A}}\right]_{\mathrm{initial}}$$

where P_A was the reading of the reference input power detector and P_B was the reading of the transmitted power detector. (Taking the ratio with respect to the reference detector takes account of potential fluctuations in laser output power.)

When an AFES agent is discharged, the air in the chamber is filled with gas molecules and/or dry powder particles. Gas molecules and aerosol particles can both absorb and scatter light. The combination of absorption and scattering effects are represented by an optical extinction (or attenuation) coefficient. The optical extinction coefficient describes the attenuation of light as a function of atmospheric particle concentration, through a given path length, as given by the Beer-Lambert Law, which can be written as:

$$\mathrm{T(t)} = \mathrm{e}^{-\alpha(\mathrm{t})\mathrm{x}}$$

where T is the transmittance of light through the medium, α is the extinction coefficient, and x is the path length. While the Beer-Lambert Law technically does not fully hold for cases involving very high concentrations or for particles in which scattering accounts for a significant portion of the attenuation, it is used in this case as a first order approximation of visual obscuration. An exact solution would require full radiative transfer modeling, but a simple Beer-Lambert law approximation is sufficient for the insights desired from this study.

The optical extinction coefficient can be determined from the transmittance and the path length as follows:

$$\alpha(t) = \frac{-\ln(T(t))}{x}$$

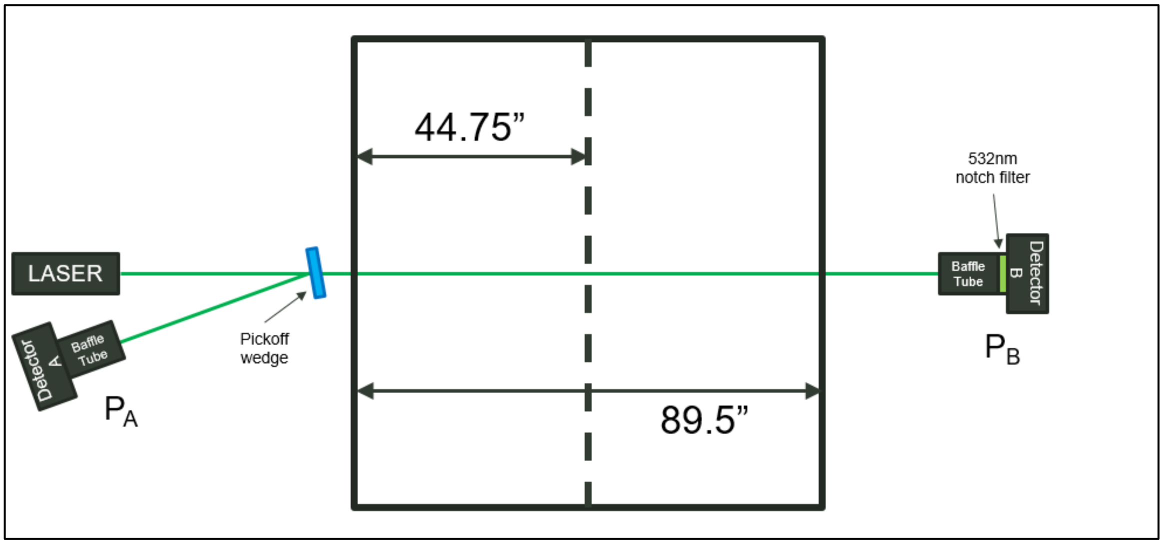

Figure 7: Optical measurement setup

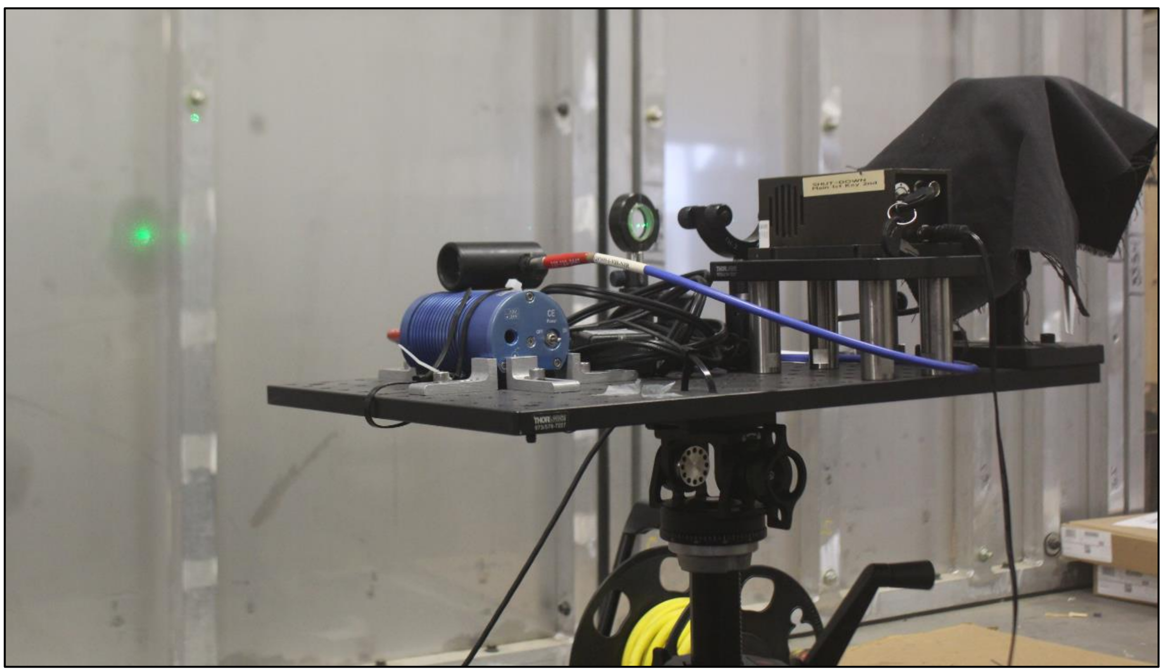

Figure 8: Laser source breadboard

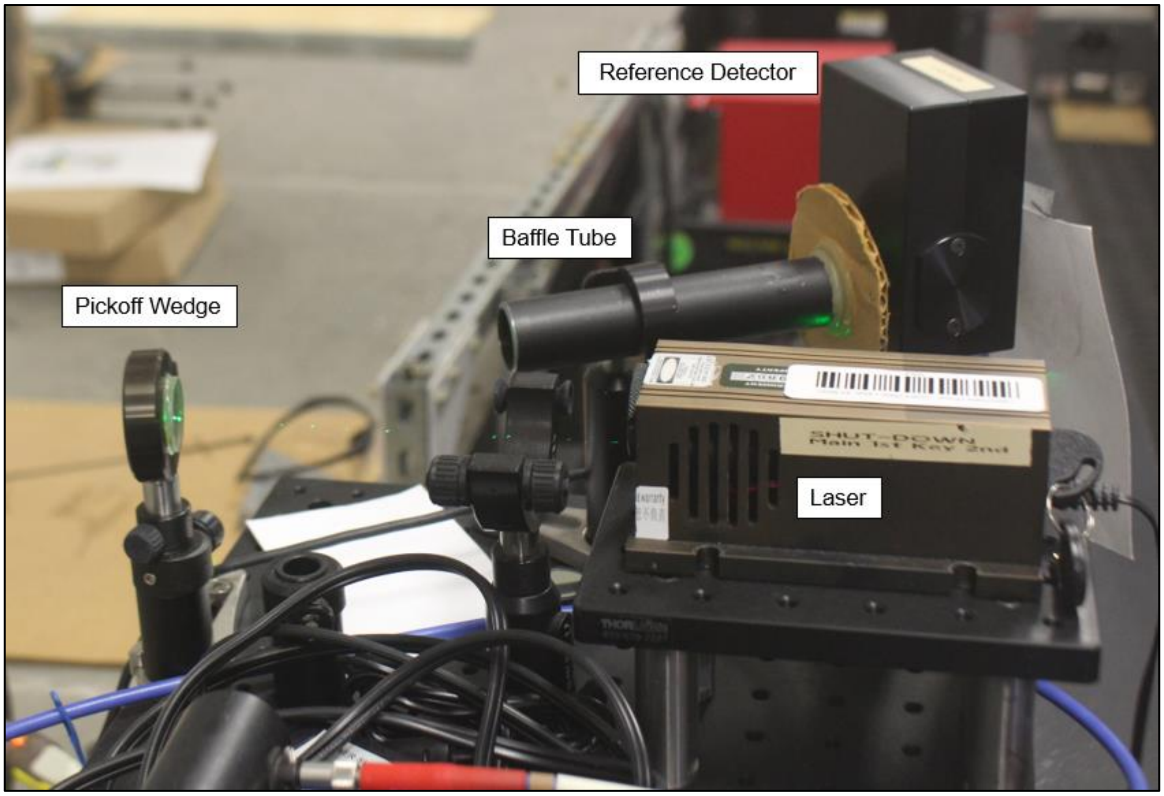

Figure 9: Close up of laser source breadboard

The halon 1301 and HFC227-BC agent concentrations used represented currently fielded AFES systems. The highest KSA concentration that was used in past performance evaluations [4] was used. Test and calibration shots were completed, using pure nitrogen in the extinguishers, to ensure the equipment and chamber were operating properly.

4.0 Results

After verification of the test setup and method using nitrogen discharges, a total of eight trials were completed, using a combination of three different extinguishing agents at two different path lengths, as listed in Table 1 and described below.

Table 1. Test Matrix

Test Number	Path Length	Agent	Notes
1	1.14m	Halon	
2	1.14m	HFC227-BC	Possible fog formation
3	1.14m	KSA	
4	1.14m	Halon	Residual KSA powder affected results
5	2.27m	Halon	Fidelity of data in question
6	2.27m	HFC227-BC	Fidelity of data in question
7	N/A	N/A	N/A
8	2.27m	KSA	

Using the footage from the GoPro and external standard definition cameras, the team established two subjective, ad-hoc benchmark extinction coefficients, which were used to benchmark the obscuration effects of the different agents. The first benchmark is an optical extinction coefficient of 4.8 which represents marginal visibility for close-in activity, such as monitoring a display, and is illustrated in Fig. 10. The number below the agent and time stamp is the optical extinction coefficient calculated from the measured transmittance. The other pictures show the obscuration caused by the agents at the same time frames. The final row of pictures shows the results after 300 seconds. Note that in the KSA tests the dry chemical coated most of the surfaces within the chamber, including the GoPro lens and chamber window. As such, it was not possible to assess the obscuration effect of the KSA within the chamber via video footage. Future testing would benefit from the development of a method to keep the optical surfaces clean in the presence of suspended dry chemical.

Figure 10: GoPro camera view over time

The second benchmark is illustrated in Fig. 11 and uses an optical extinction coefficient of 2.0 to represent the minimum visibility criteria for longer distances such as those associated with vehicle egress. The other pictures show the obscuration caused by the agents at the same time frames. The final row of pictures shows the results after 300 seconds.

Figure 11: External camera view over time

Fig. 12 shows the transmittance and extinction coefficient vs. time behavior of all agents through the 1.14 m path on a linear scale. All the plots start with a transmittance of 1 before the AFES agent is released. Three seconds after data collection began, the agent is released and the transmittance plummets nearly instantaneously as the chamber is filled with agent. As the air in the chamber clears due to leakage and settling of the agent, the transmittance gradually climbs back up. Halon 1301 and HFC227-BC have a transmittance recovery behavior that seems to have two time constants: a quick initial recovery in less than a minute and a longer recovery that extends over several minutes. Halon 1301 recovers to near-zero obscuration within a few minutes. HFC227-BC recovers quickly but has a slight long-lived haze possibly due to the finer BC particles. KSA took much longer to clear; it was approximately 25% recovered after 5 minutes, whereas halon 1301 and HFC227-BC were recovered to over 90% transmittance well before 5 minutes.

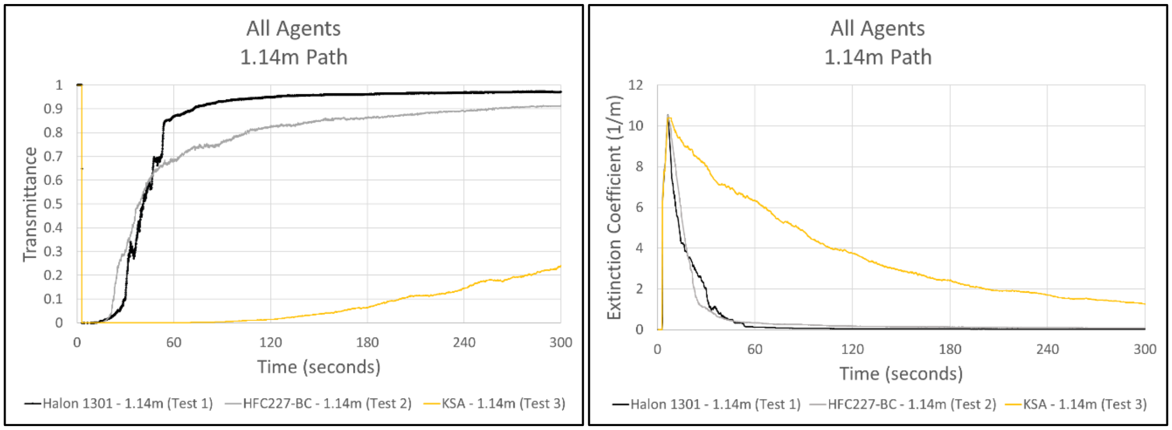

Figure 12: All agents, 1.14m path results

Fig. 13 re-plots Fig. 12 on a logarithmic scale. On a log scale, the behaviors of halon 1301 and HFC227-BC look similar, with slight differences in the shapes of the initial fast recovery slopes. Due to the turbulent nature of the agent release, some shot-to-shot differences in these profiles are likely to be expected, even for the same agent under the same conditions. As noted above, KSA has a much longer transmittance recovery than the other two agents. On the logarithmic scale, the contrast between the single-exponential rise of KSA vs. the double-exponential rise of halon 1301 and HFC227-BC is more apparent than on the linear scale.

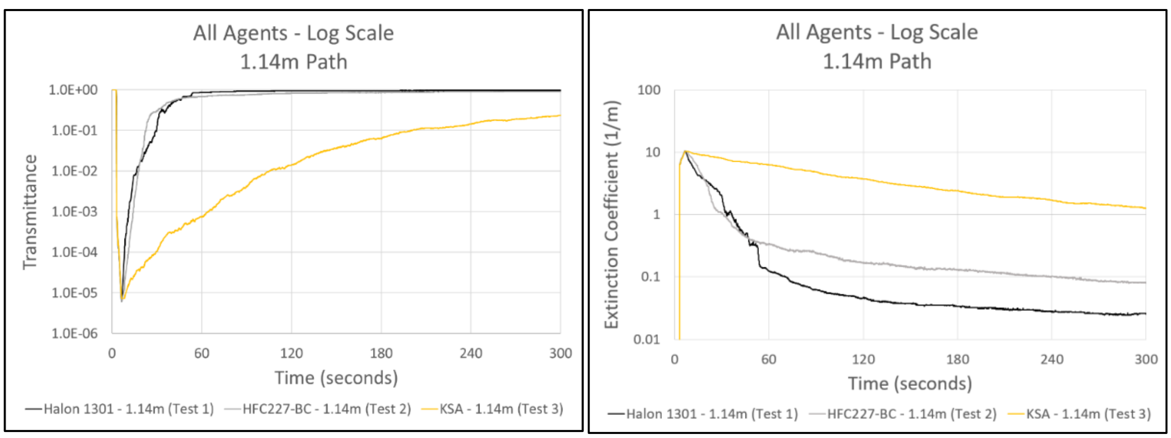

Figure 13: All agents, 1.14m path log scale results

Fig. 14 shows the measured transmittance through a cloud of KSA for the two path lengths used in this study. The gaps in the plots are due to the time required to reset the laser data-recording device, as the data were recorded in 5-minute intervals.

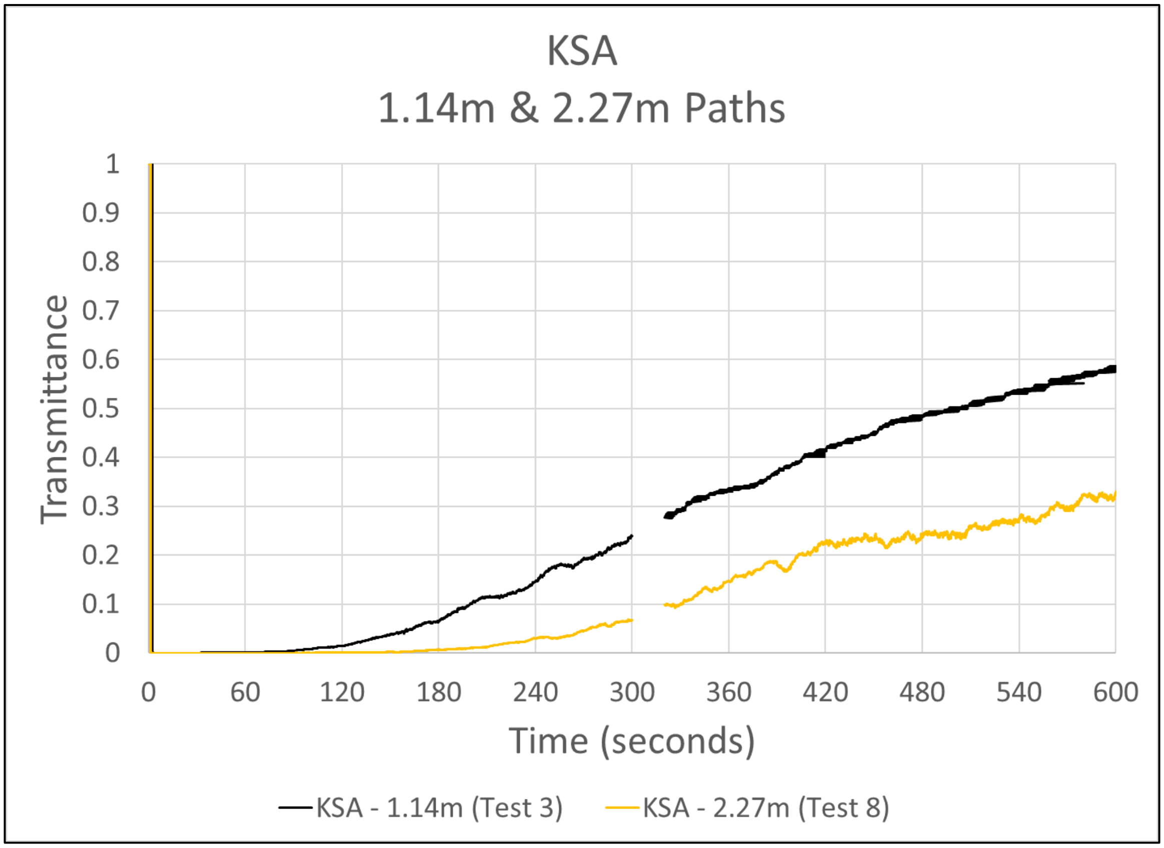

Figure 14: KSA transmittance results

We do not show other results from the long-path 2.27 m tests because we are not confident of the fidelity of the results. Concerns regarding the validity of our long-path test results include increased and inconsistent obscuration for halon 1301 and HFC227-BC which may be due to:

- contamination of the test chamber with dry chemical,
- fog formation in some cases due to different ambient conditions (e.g., relative humidity and temperature in the lab), and
- temporal discrepancies due to the automatic gain control of the laser system.

Subsequent obscuration tests will address the above issues.

Table 2 summarizes the resulting time for each agent test to reach its resulting baselines. KSA takes about 7 to 10 times longer to recover to the same obscuration level as halon 1301 and HFC227-BC.

Table 2: Extinction Coefficient Results

Property	Test 1	Test 2	Test 3
Agent	Halon 1301	HFC227-BC	KSA
Recovery Time (sec) to α = 4.8 /m	10.6	13.2	87.4
Recovery Time (sec) to α = 2.0 /m	26.9	19.8	198.4
α (/m) @ 300 sec	0.0	0.1	1.3

A possible explanation for some of the obscuration effects observed in the halon and HFC227-BC discharges is the formation of water condensate after discharge, essentially fog. The release of the highly pressurized liquid agent from the extinguishers into an ambient temperature well above the agent's boiling point results in a rapid decrease of temperature within the test chamber as the liquid agent evaporates into gas and dissolved nitrogen comes out of solution. In the tests with HFC227-BC, the temperature within the chamber reduced far enough to go below the projected dew point of the air within the chamber as shown in Fig. 15 and 16 below. The temperature of the test chamber for all other agent tests did not fall below the estimated dew point. The dew points are calculated per Appendix C.

The temperature drop observed due to the halon discharges were similar to the HFC227-BC ones shown in Fig. 15 and 16. By contrast, Fig. 17 shows the temperature change during a KSA discharge. As expected, the drop in temperature of essentially a nitrogen discharge is much smaller than that due to a low-boiling point refrigerant.

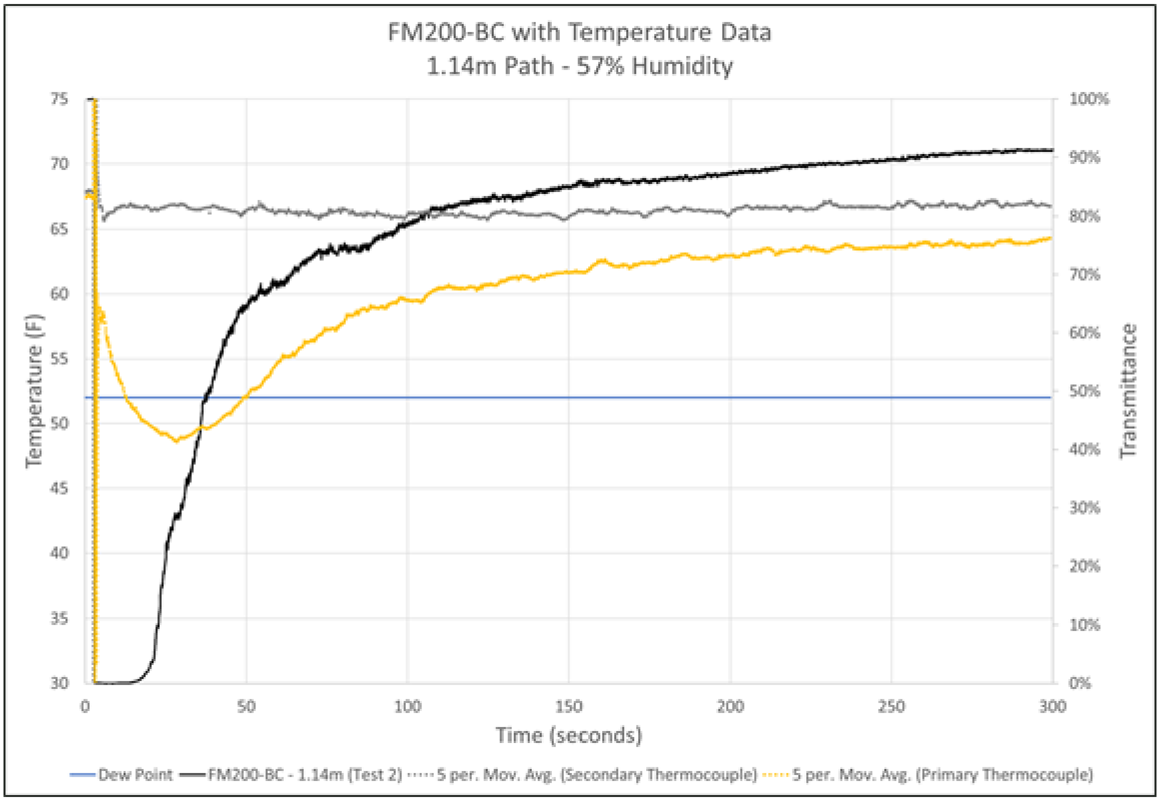

Figure 15: HFC227-BC, 1.14 m path, test temperature data and dew point

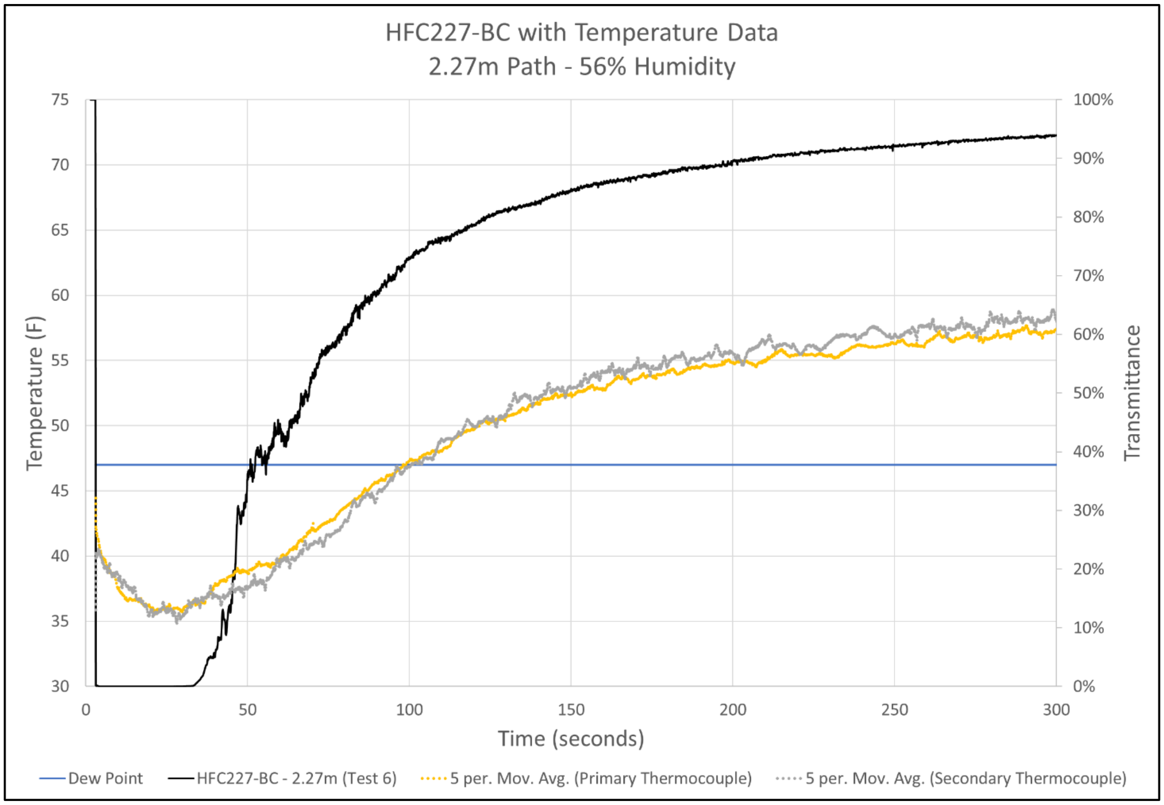

Figure 16: HFC227-BC, 2.27m path, test temperature data and dew point

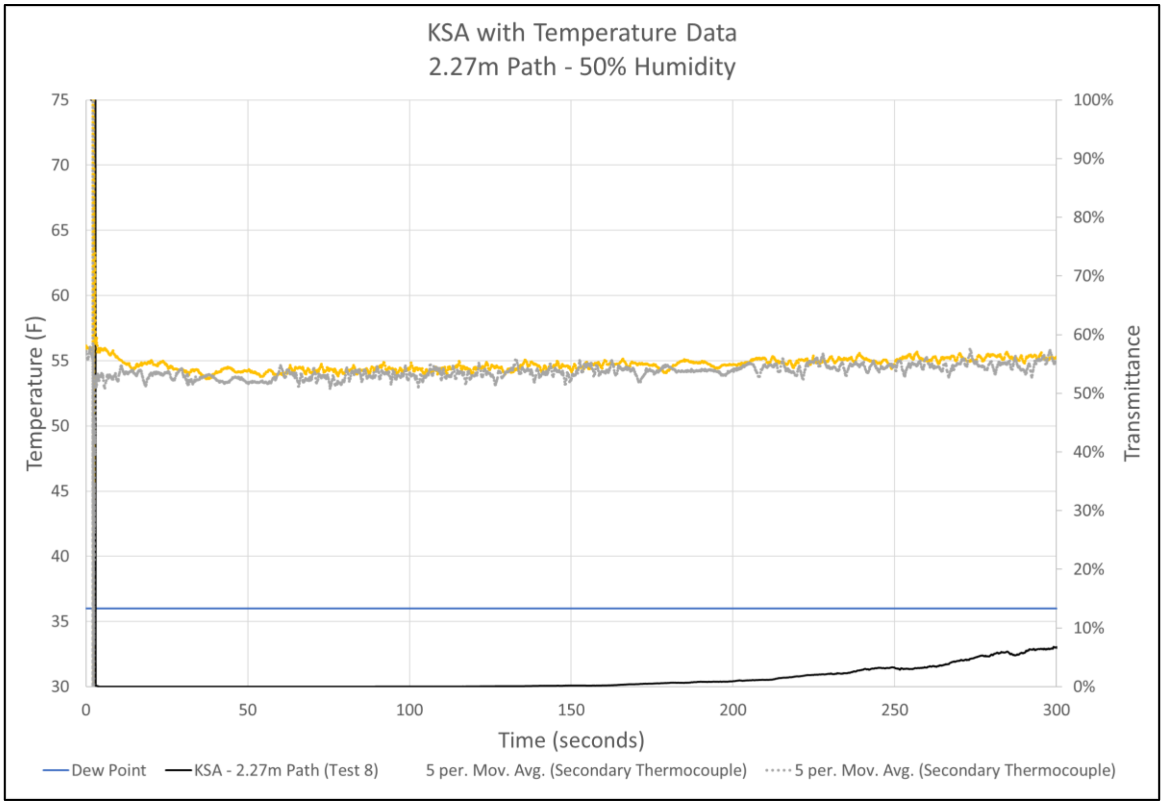

Figure 17: KSA, 2.27m path, test temperature data and dew point

5.0 Conclusion and Recommendations

The analysis of these test results came to this primary conclusion:

1. KSA required 7 to 10 times longer than legacy AFES agents to reduce obscuration to extinction coefficients of 4.8 and 2.0 /m. These values were adopted as ad-hoc benchmark extinction coefficients representing marginal visibility of close-in activity (monitoring a display) and longer distance activity (vehicle egress) respectively.

Our recommendations for future investigations related to the obscuration resulting from an AFES discharge into a ground vehicle crew compartment are as follows:

1. Establish obscuration criteria for possible use as a requirement for AFES that protect army ground vehicles

2. Investigate obscuration effects of KSA over time in ventilated and unventilated chambers, to quantify the effects of vehicle air via ventilation systems on the duration of significant obscuration.

3. Measure obscuration of HFC227-BC using various dry chemical additives.

4. Measure obscuration of HFC227-BC and halon 1301 at temperature and humidity extremes.

5. Improve the accuracy and repeatability of the test method.

Appendix A. Kigali Amendment HFC Phasedown Schedule

On 15 Oct 2016, Parties to the Montreal Protocol adopted the "Kigali Amendment" that adds HFCs to the Montreal Protocol and gradually reduces their consumption (production + imports - exports - destruction)

	Article 5 Group 1	Article 5 Group 2	Article 2
Baseline	2020-2022	2024-2026	2011-2013
Formula	Average HFC consumption	Average HFC consumption	Average HFC consumption
HCFC	65% of baseline	65% of baseline	15% of baseline*
Freeze	2024	2028	Not applicable
1st step	2029 – 10% Reduction	2032 – 10% Reduction	2019 – 10% Reduction
2nd step	2035 – 30%	2037 – 20%	2024 – 40%
3rd step	2040 – 50%	2042 – 30%	2029 – 70%
4th step	None	None	2034 – 80%
Plateau	2045 – 80%	2047 – 85%	2036 – 85%

* For Belarus, Russian Federation, Kazakhstan, Tajikistan, Uzbekistan 25% HCFC component of baseline and different initial two steps (1) 5% reduction in 2020 and (2) 35% reduction in 2025

Group 1: Article 5 parties not part of Group 2
Group 2: GCC, India, Iran, Iraq, Pakistan

Appendix B. Crew Casualty Criteria

Parameter	Requirement
Fire Suppression	Extinguish all flames without reflash
Skin Burns[a]	Less than second degree burns (<2400°F-s over 10 sec or heat flux < 3.9 cal/cm^2)
Toxic Gases[a]	Acid Gases (HF + HBr + 2·COF2) < 746 ppm-min (5 min dose) Other toxic gases (eg, CO2, CO, NOX, HCN) are also measured
Oxygen[b]	Levels at breathing locations of at least 16%
Overpressure[b,c]	Lung damage <11.6 psi; Ear damage ≤ 4 psi
Discharge Impulse Noise[d]	No hearing protection limit: <140 dBP Single hearing protection limit: <165 dBP
Discharge Forces[e]	Not to exceed 8 g averaged over 30 milliseconds
Agent[f]	Concentration within occupational safety limits
Fragmentation[g,h]	Ejected non-agent particles <300 micrometers Non-Shatterable Cylinders (NONSHAT)

a) Ripple, Gary and Mundie, Thomas, "Medical Evaluation of Nonfragment Injury Effects in Armored Vehicle Live Fire Tests," Walter Reed Army Institute of Research, September 1989.

b) Swanson, Dennis, "Fire Survivability Parameters for Combat Vehicle Crewmen," Department of the Army, Office of the Surgeon General, 20 February 1987.

c) Rice, W. A., "Noise Specification for Automatic Fire Extinguishing Systems (AFES)," Dept. of the Army Memorandum, 14 Nov 2013.

d) "Hearing Conservation Program," US Army Pamphlet 40-501, January 2015; similar criteria are found in "Design Criteria Noise Limits," MIL-STD-1474, 1997.

e) Extrapolated from the 57 N-m limit given in reference (a).

f) Lowest Observed Adverse Effects Level per "NFPA 2001 Standard on Clean Agent Fire Extinguishing Systems," (HFC-227ea) and "NFPA 12A Standard on Halon 1301 Fire Extinguishing Systems," National Fire Protection Association (NFPA).

g) Section 3.4.1.3 in "VALVE AND CYLINDER ASSEMBLIES, HALON 13O1," MIL-DTL-62547.

h) Section 3.3.9 in "CYLINDERS, STEEL, COMPRESSED GAS, NON-SHATTERABLE, SEAMLESS, 1800 PSI AND 2100 PSI," MIL-DTL-7905.

Appendix C. Formulas and Definitions

Gaseous Agent Concentration

The predicted agent concentration (vol%) within the test chamber, where S_{agent} (cubic meters/kilogram) is the specific volume of the gaseous agent at the test temperature, W_{agent} is the weight of the gaseous agent (kilograms), and $V_{chamber}$ is the open-air volume of the test chamber (cubic meters).

$$Agent\ Concentration\ (\%) = \frac{100}{1 + \frac{V_{chamber}}{W_{agent} \times S_{agent}}}$$

Dry Chemical Agent Concentration

The predicted concentration for a dry chemical (grams/cubic meter) within the test chamber, where W_{powder} is the dry chemical weight (grams), and $V_{chamber}$ is the volume (cubic meters) of the test chamber.

$$Dry\ Powder\ Concentration = \frac{W_{powder}}{V_{chamber}}$$

Stored Energy

The stored energy (bar-liter/kilogram) within the charged cylinders, whereP_{fill} is the fill pressure (bar) of the cylinder, $V_{cylinder}$ is the cylinder's volume (liters), V_{agent} is the volume occupied by the agent, V_{powder} is the volume occupied by the dry chemical, W_{agent} is the weight of the gaseous agent (kilograms), W_{powder} is the weight (kilograms) of the dry chemical, and $W_{nitrogen}$ is the weight (kilograms) of the nitrogen. All stored energy values within this report were calculated at a temperature of 21 degrees Celsius.

$$Stored\ Energy = P_{fill} \times \frac{V_{cylinder} - V_{agent} - V_{powder}}{W_{agent} + W_{powder} + W_{nitrogen}}$$

Extinction Coefficient

Extinction Coefficient (m^{-1}), where T is the optical transmittance (%) and x is the path length (m) of the light through the discharged agent.

$$\text{Extinction Coefficient} = \frac{-\ln(\text{T})}{\text{x}}$$

Dew Point

Dew Point (°C) was calculated using the Magnus formula:

$$\gamma = ln\left(\frac{RH}{100}\right) + \frac{bT}{c + T}$$

$$Dew\ Point = \frac{c\gamma}{b - \gamma}$$

Where γ is the (%), RH is the relative humidity (%), and b and c are empirical coefficients, herein:

b = 18.678

c = 257.14°C

Appendix D. Test Plan and Setup Data

Test Plan:

Test Number	Agent	Path Length (m)	Chamber Area (ft^3)	Number of Extinguishers	Target Agent Weight (lbs)	Target Dry Powder Weight (lbs)	Agent Concentration (%)	Dry Powder Concentration (g/m^3)	Cylinder Size (in^3)	Charge Pressure (psi)	Stored Energy (bar-L/kg)
1	Halon	1.14	111	1	3.25	0.00	6.97	0.00	144	750	49.9
2	FM200-BC	1.14	111	1	6.00	0.60	10.6	86.6	213	900	29.4
3	KSA Only	1.14	111	1	0.00	1.25	0.00	180	144	750	191
4	Halon	1.14	111	1	3.25	0.00	6.97	0.00	144	750	49.9
5	Halon	2.27	222	2	6.50	0.00	6.97	0.00	144	750	49.9
6	FM200-BC	2.27	222	2	12.0	1.20	10.6	86.6	213	900	29.4
7	N/A										
8	KSA Only	2.27	222	2	0.00	2.50	0.00	180	144	750	191

* = Test was not completed

Test Setup Data:

Test Number	Bottle ID	Agent	Ambient Temperature (°F)	Humidity (%)	Empty Extinguisher Weight (lbs)	Added Dry Powder Total Weight (lbs)	Filled Extinguisher Weight (lbs)	Charged Extinguisher Weight (lbs)	Charge Pressure (psi)
1	A	Halon	67.3	60	14.495	14.495	17.745	18.045	750
2	C	FM200-BC	68.8	57	15.710	16.300	22.305	22.735	900
3	B	KSA Only	66.8	59	14.540	15.770	15.770	16.135	750
4	A	Halon	69.7	56	14.500	14.500	17.750	18.030	750
5	A	Halon	65.4	56	14.490	14.490	17.740	17.960	750
	B				14.545	14.545	17.790	18.035	750
6	C	FM200-BC	63.5	56	15.710	16.310	22.315	22.750	900
	D				15.830	16.430	22.435	22.905	900
7	A	N/A							
	B								
8	A	KSA Only	52.4	50	14.505	15.755	15.755	16.100	750
	B				14.530	15.775	15.775	16.150	750

Appendix E. List of Acronyms, Abbreviations, and Initialisms

AFES	Automatic Fire Extinguishing Systems
CO	Carbon Monoxide
CO_2	Carbon Dioxide
COF_2	Carbonyl Fluoride
GVSC	Ground Vehicle Systems Center
GWP	Global Warming Potential
HBr	Hydrogen Bromide
HCN	Hydrogen Cyanide
HF	Hydrogen Fluoride
HFC	Hydrofluorocarbon
HFO	Hydrofluoroolefin
LOAEL	Lowest Observed Adverse Effect Level
MDC	Minimum Design Concentration
NFPA	National Fire Protection Association
NONSHAT	Non-Shatterable Cylinders
NOx	Oxides of Nitrogen
SAFR	Safer Alternatives for Readiness
TARDEC	Tank-Automotive Research, Development and Engineering Center

Appendix F. References

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