LABORATORY OPTIMIZATION AND MEDIUM SCALE SCREENING OF IODIDE SALTS AND WATER MIXTURES

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INTRODUCTION

U.S. Army combat vehicle engine compartments and crew spaces are now protected with Halon 1301. Halons operate as fire suppressants by a complex chemical reaction mechanism involving the disruption of free-radical chain reactions. Halon 1301 is desirable as a fire extinguishing agent because it is effective, leaves no residue (i.e., evaporates completely), and does not damage equipment or facilities to which it is applied. Recently, however, Halon 1301 has come to be recognized as an environmental threat due to its ability to cause stratospheric ozone depletion and global warming. The Montreal Protocol on Substances that Deplete the Ozone Layer and the U.S. Clean Air Act of 1990 required the production phaseout of Halons by the year 2000; the Copenhagen Amendments (November 1992) accelerated the production phase-out to January 1, 1994. Therefore, substitutes for Halon 1301 used in U.S. Army ground vehicle fire extinguishing systems are needed. Evidence developed at the New Mexico Engineering Research Institute (NMERI) and at the Army Research Laboratory (ARL) indicate that salt solutions can enhance the fire suppression performance of water (Reference 1). Due to their low volatility, such materials would have no impact on either stratospheric ozone or global warming. The project reported in this paper involved the testing of water based salt solutions to determine mixtures with optimal fire suppression and freeze point performance.

The criteria for the combat vehicle tire suppression application include a zero ozone depletion potential (ODP), low atmospheric lifetime, and a near zero global wanning potential (GWP). The agent or any constituent thereof shall not contain Class I or Class II Ozone Depleting Chemicals (ODC) as specified by the Clean Air Act of 1990. The agent must be safe to handle and use (low toxicity). It must also have an operating temperature range of -60 to 160" F (-51 to 71° C) and a pH range of 4 to 10.

OBJECTIVE

The objective of the project was to recommend one or more water based fire suppressant agents as a replacement for Halon 1301 in U.S. Army combat vehicles. This project consisted of laboratory studies, and two field-scale test phases. The laboratory studies were performed to determine salt solutions which would meet the cold temperature operational requirement. During the Phase I laboratory-scale testing a small discharge extinguishment apparatus was used to assess fire extinguishment performance and agent delivery characteristics. Based on the results of this testing, candidates were selected for the Phase II field-scale testing. Field tests were performed on the NMERI M1-Engine Compartment Simulator (ECS) and the Aberdeen Test Center (ATC) Phase I and II M-60 combat vehicle engine compartment test fixtures. Table 1 presents a list of the compounds considered and their availability. It lists the costs of laboratory-scale and field-scale costs for each agent, along with possible sources from whom to purchase the compound.

TABLE 1. TESTED COMPOUNDS AND THEIR AVAILABILITY.

Compound	Laboratory-Scale costs, $1100 g	Field-Scale Costs, $/kg (100 kg lots)	Possible Sources
NH_4Br	4.66	2.43	Van Water & Rogers (VWR) Scientific
NH_4I	5.14	5 1.40	Spectrum Chemical Mfg. Corp. and West Florida Ordnance, Inc. (WFO)
LiBr	8.07	34.00	Acros-Fisher Scientific, Inc. and WFO
LiCl	---	---	---
LiI	39.80	90.00	Acros-Fisher Scientific, Inc. and WFO
$CaCl_2$	4.50	0.66	VWR
$CaBr_2$	8.00	7.74	Spectrum
CaI_2	20.00	37.16	Aldrich, Baker, and VWR
KBr	5.60	7.79	Spectrum
KCI	9.00	---	---
KI	---	19.10	VWR
NaI	---	---	---
Pyrocap™ Urea Foam	18 per gal. conc.	---	Pyrocap International, Inc.
Cold Fire™	10 per gal. conc.	---	Firefreeze Worldwide, Inc.
$FeNO_3$	---	---	---
K Lactate	1.83	$650 per 55 gallon drum	Acros-Fisher Scientific
K Acetate	10.00	7.64	J.T. Baker

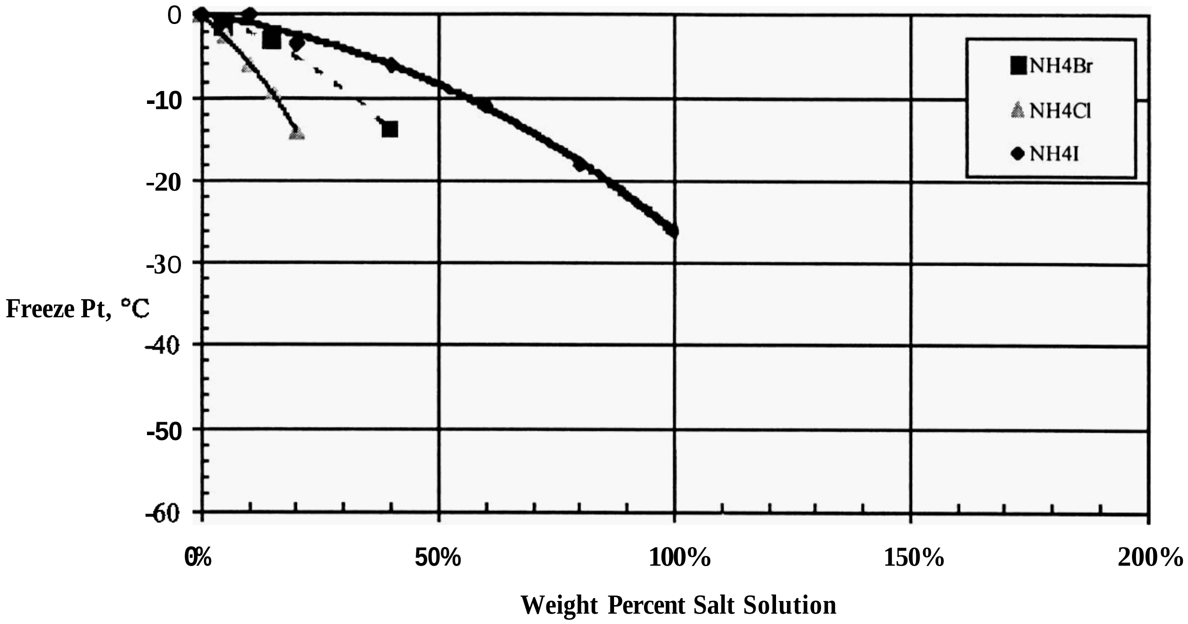
FREEZE POINT AND PH DETERMINATION

The halide salts tested were from the ammonium, lithium, calcium, potassium, and sodium families. Other salts included: potassium acetate, potassium lactate, and ferric nitrate. Two surfactant water foaming and wetting compounds, Cold Fire'''' and Pyrocap™ were also investigated. ***Two conventions can be used to express the solution strength of typical solids dissolved in a solution. The halide salts that were investigated were mixed with***

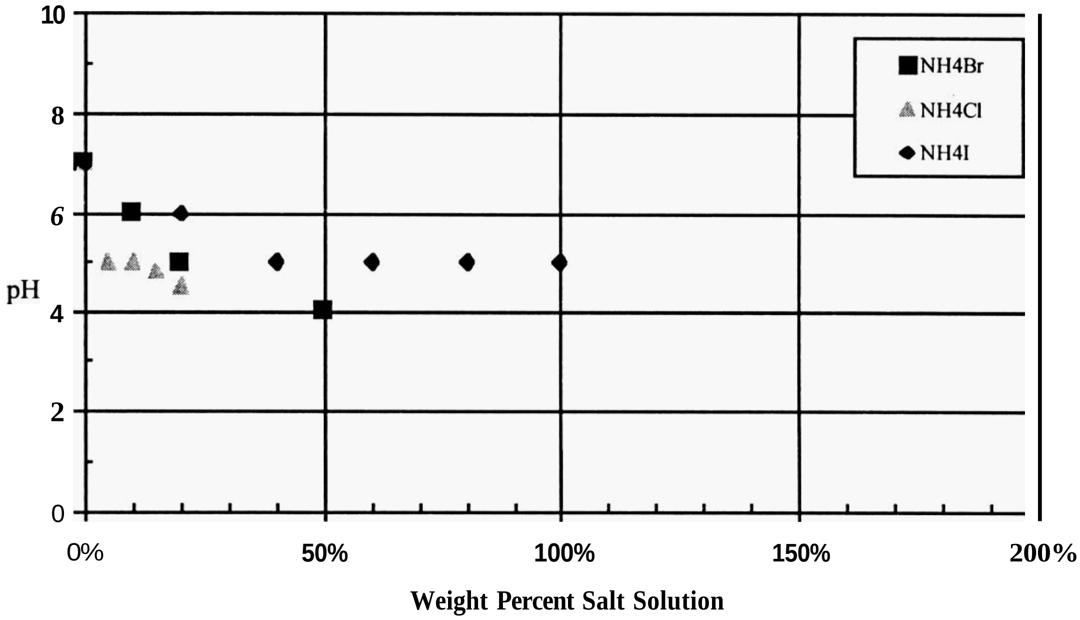
water based on weight. For example, mixing 100 g solid salt with 100 g of distilled water gives a 100 % salt solution, and mixing 50 g solid salt with 100 g water gives a 50 % by weight solution. This convention was chosen because of the ease with which to mix these solutions and the simplicity to calculate how much salt was in a solution. This convention is the ratio of the amount of salt to the amount of water. The typical convention would be to report the weight of salt divided by the total weight of salt plus water (e.g., 50 g solid salt in 100 g water would be 50/150 = 33 wt. %). This convention would be the ratio of the weight of salt to the total solution weight.

The first step in the project was to determine the freezing points and pH for each salt at ***various*** solution strengths. A dewer flask filled with dry ice and methanol was used as a cryogenic bath. The temperature of the cryogenic bath was approximately -60 °C (-76 °F). Various solution strengths for each salt were made up in 12 mL samples. The sample was placed in a capped, glass vial. A thermocouple was inserted through the cap and immersed into the sample. The vial was then held in the cryogenic bath while being gently agitated. The sample was monitored for freezing or the salts precipitating out of solution. When the sample started to freeze and/or salt began to precipitate, the temperature of the sample was recorded. The sample was then placed in a warm water bath. and the freezing point was tested again to ensure accuracy. The sample ***was*** then warmed to room temperature and the pH was measured with a pH meter. If the solution did not meet the freeze point criteria, a stronger solution strength was prepared and the freeze point and pH were again determined. Freeze point and pH curves were generated for each of the salt solutions. Curves were also developed for Cold Fire™ and LiI and K Ace mixtures.

Figures 1 through 5 show these curves of freeze point and pH versus weight percent salt solutions. The freeze point curves are stopped at the point where the salts started to precipitate out of the solution upon freezing. As can be easily seen, the iodide salts did not depress the freezing point of the solution as much as the other salts. None of the ammonium halide salts met the freeze point criteria. NH_4I was only able to get down to -26 "C. The NH_4Cl and NH_4Br solutions only went down to about -15 °C. However, all of the ammonium halide salt solutions met the pH criteria. All of the calcium halide salt solutions met the freeze point and the pH criteria. Solutions of 30 wt.% LiCl and 120 wt.% LiI met both the pH and the freeze point criteria. LiBr solutions did not meet the freeze point criteria. Other salt solutions that met both the pH and freeze point criteria were a 90 wt.% solution of K Ace and a 60 wt.% solution of K Lac. Mixtures of 10 ***vol. %*** Cold Fire™ with 90 wt. % K Ace and 120 wt. % LiI also met the freeze point and pH criteria. Table 2 summarizes the acceptable freeze point and pH results for all of the salt solutions.

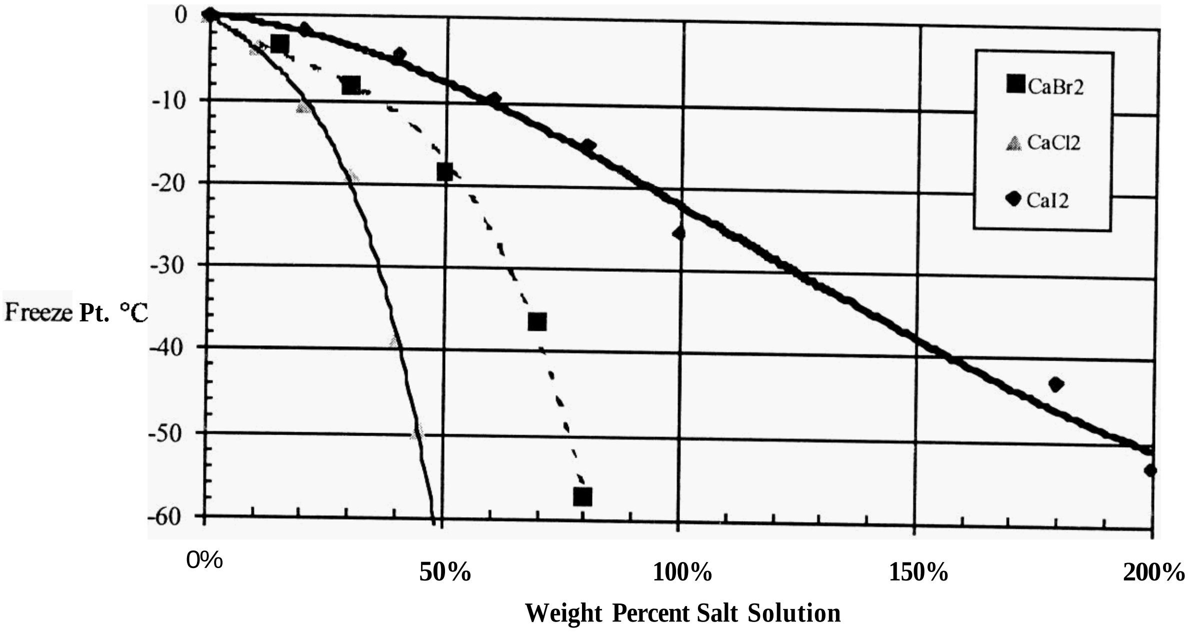


a) Freeze Point versus Solution Strength.

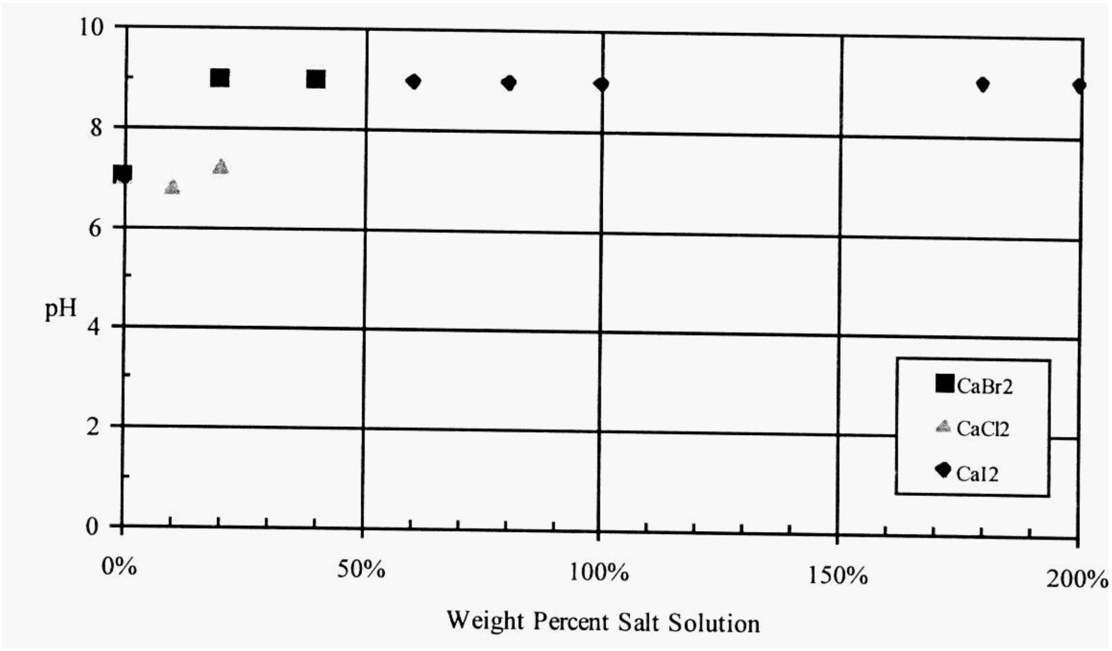


b) pH versus Solution Strength.

Figure 1. Ammonium Halide Salt and Water Solution Strength and Freeze Point Data.

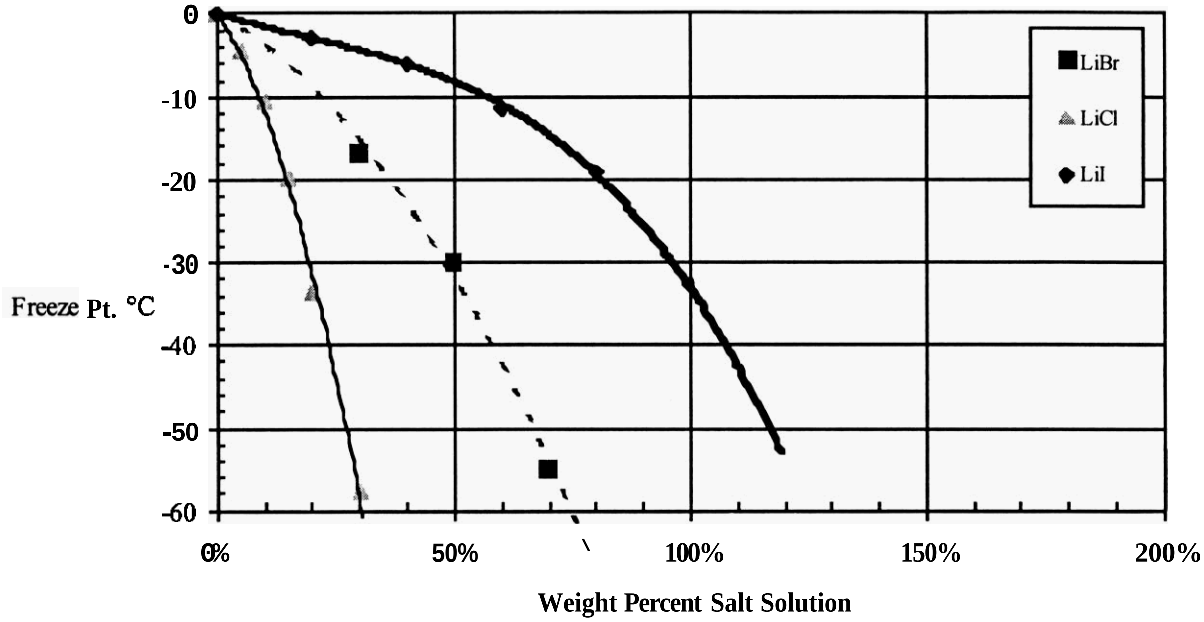


a) Freeze Point versus Solution Strength.

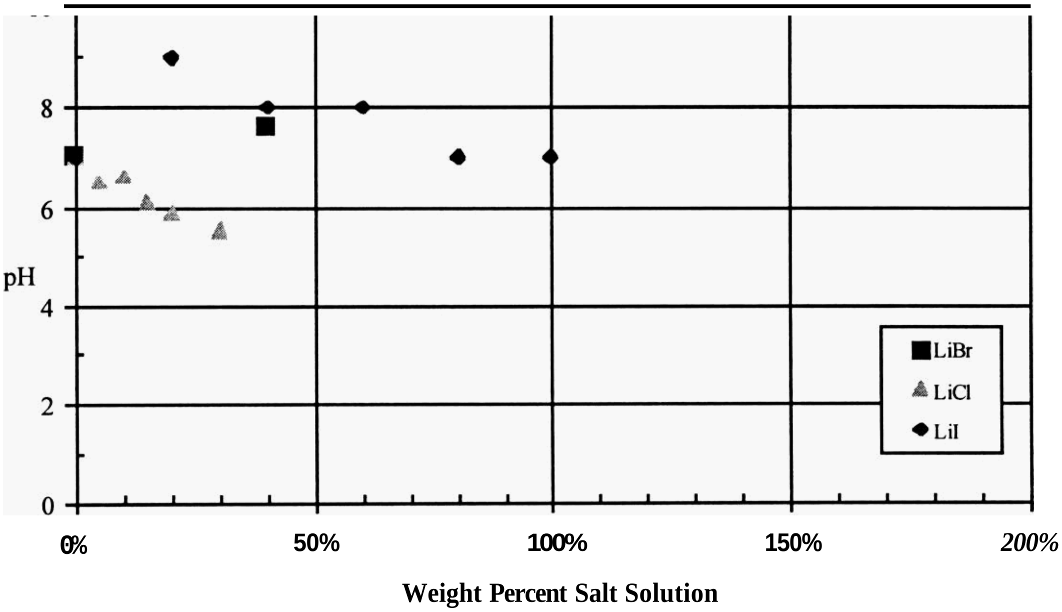


b) pH versus Solution Strength.

Figure 2. Calcium Halide Salt and Water Solution Freeze Point and pH Data

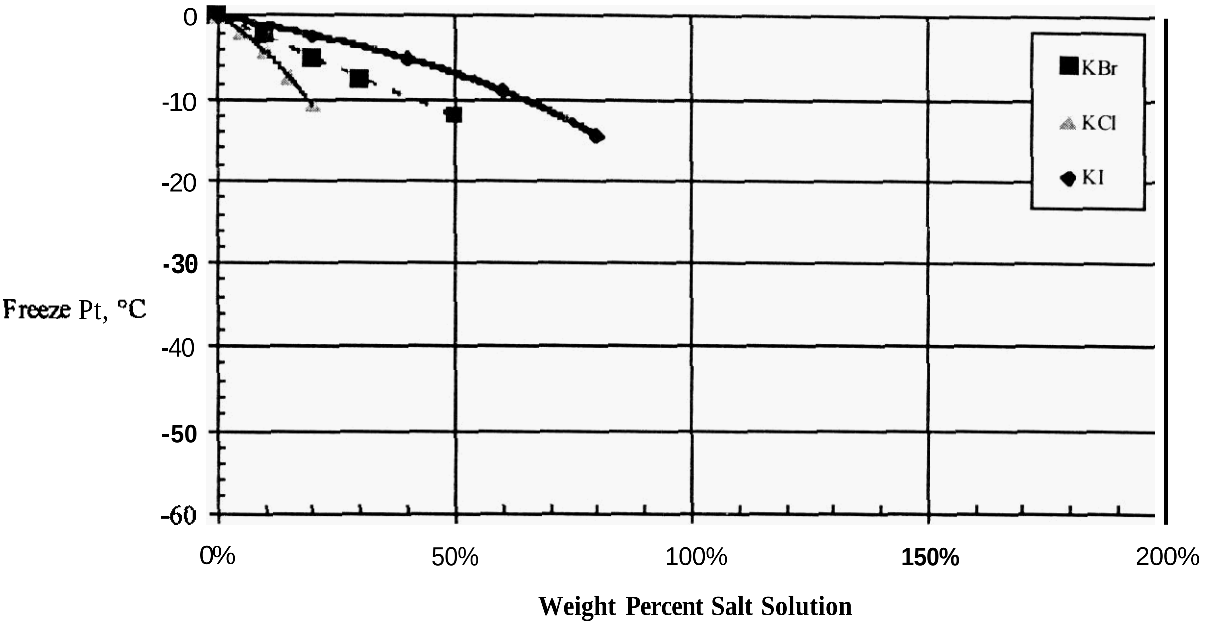


a) Freeze Point versus Solution Strength.

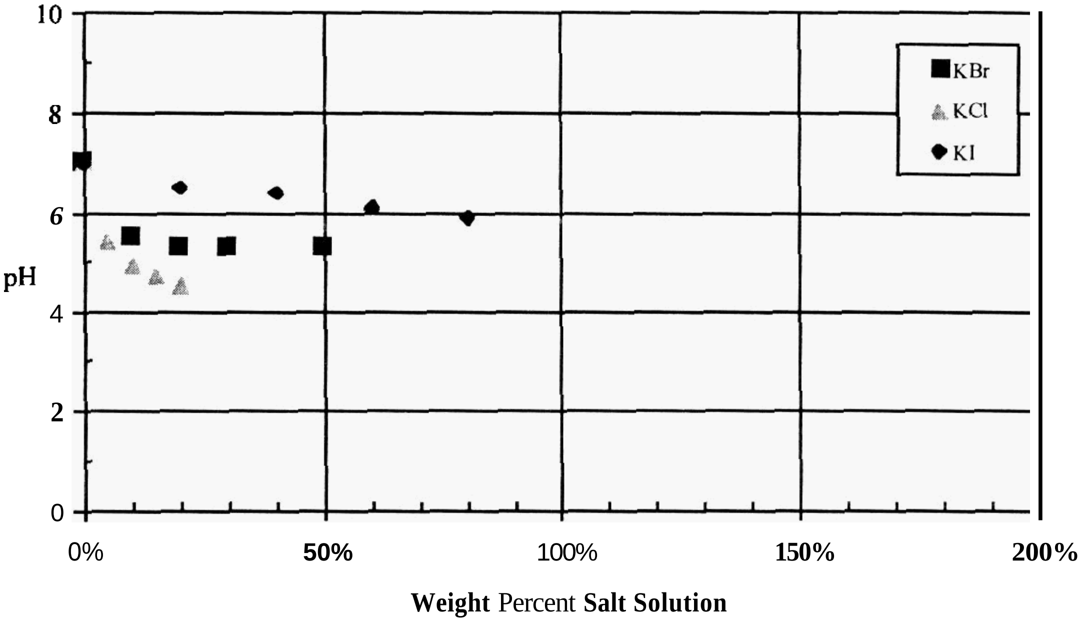


b) pH versus Solution Strength.

Figure 3. Lithium Halide Salt and Water Solution Freeze Point and pH Data.

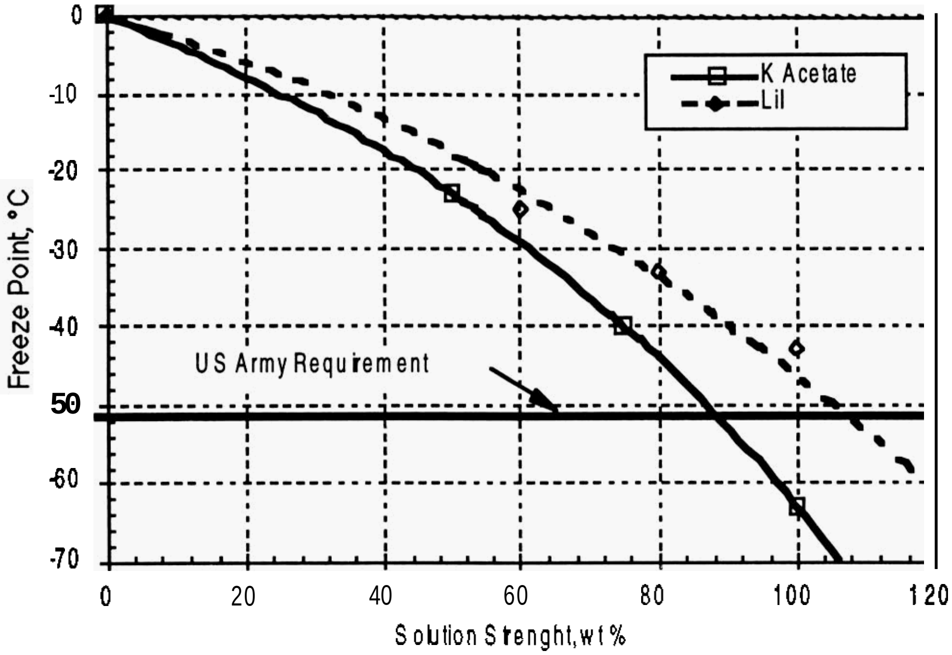


a) Temperature versus Solution Strength.

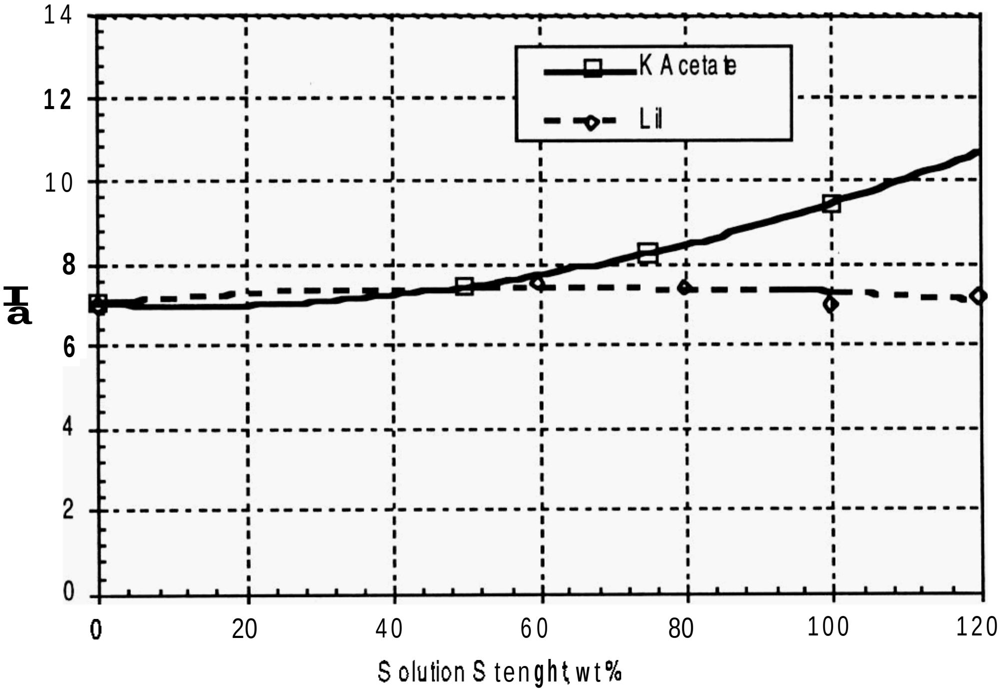


b) pH versus Solution Strength.

Figure 4. Potassium Halide Salt and Water Solution Freeze Point and pH Data.



a) Temperature versus Solution Strength,



b) pH versus Solution Strength

Figure 5. 10 vol. % Cold Fire™ and Salt Solution Strengths (Ratio Salt to Amount of Water) Freeze Point and pH Data.

TABLE 2. SUMMARY OF ACCEPTABLE FREEZE POINT AND pH RESULTS.

[a]Salt Solution	[b]Solution Strength, wt.%	Freeze Point, °C	pH
$CaBr_2$	90	-58	7.6
$CaCl_2$	45	-50	7.2
CaI_2	200	-53	9.1
LiBr	80	-55	7.2
LiCl	25	-58	5.5
LiI	120	-15	7.1
K Lac	60	-15	6.8
K Ace	90	-57	9.0
10 vol. % Cold Fire™ w/90 wt. % K Ace	90	-55	8.3
10vol. % Cold Fire™ w/120 wt. % LiI	120	-70	7.0

'None of the ammonium salts had acceptable freeze points.

LABORATORY FIRE SUPPRESSION TESTS

The NMERI Laboratory-Scale Discharge-Extinguishment (LSDE) Apparatus, which determines the extinguishment capability of agents based upon a critical application rate was used during the laboratory fire suppression studies. The LSDE Apparatus has exchangeable nozzles, variable fire-pan sizes. and variable discharge geometry (Figure 12). The apparatus allows determination of agent flow rates by continuous weighing of the storage cylinder during discharge. In the LSDE testing, the salt solutions were applied to n-heptane pan fires using an overhead spray nozzle. The fire pan was a 4-in by 4-in square pan (16 in^2), I-in high, tilled with 125 mL of *n*-heptane for each fire. The nozzle was placed *8* in back from the center of the fire pan and 4 in above the center of the fire pan. This resulted in a total distance of 9 in from the center of the fire pan. The n-heptane was given a 90 sec pre-burn before the agent was discharged. As soon as the fire was extinguished, the spray was stopped, and the time and the quantity discharged were recorded. After each test, the n-heptane was discarded and the pan was placed in a bath of water to cool.

Baseline tests were developed with water as the extinguishment agent. Selected salt solutions that met the freeze point and pH criteria were tested in laboratory fire suppression tests. FM-200 was also tested. The purpose of these tests was to rank the salt solutions in order of extinguishment capability. Plots were made of quantity versus time, and flow rate versus time. A linear fit was applied to the data points. The equation for the linear tit was then used to generate curved lines for the flow rate versus time plots. Figure 6 presents the plot of quantity versus time for the water solution with the linear fit of the data. Figure *7* presents the plot of flow rate versus time for the water solution along with the curve generated from the linear tit of the quantity versus time data presented in Figure *7*.

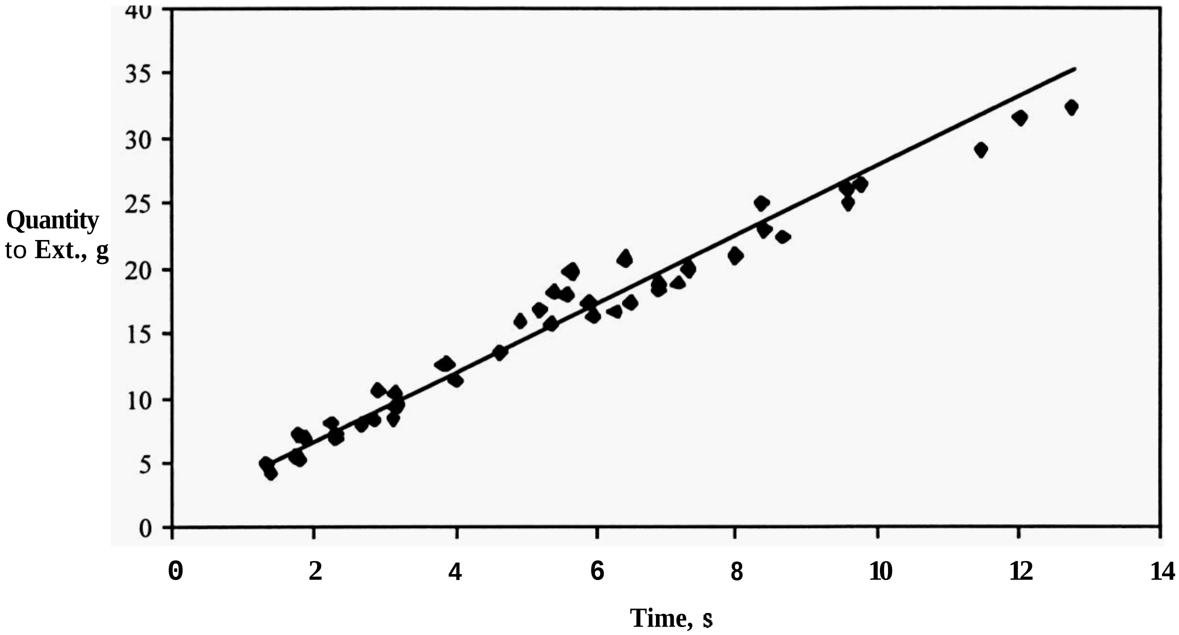


Figure 6. Quantity to Extinguish versus Extinguishment Time for Water

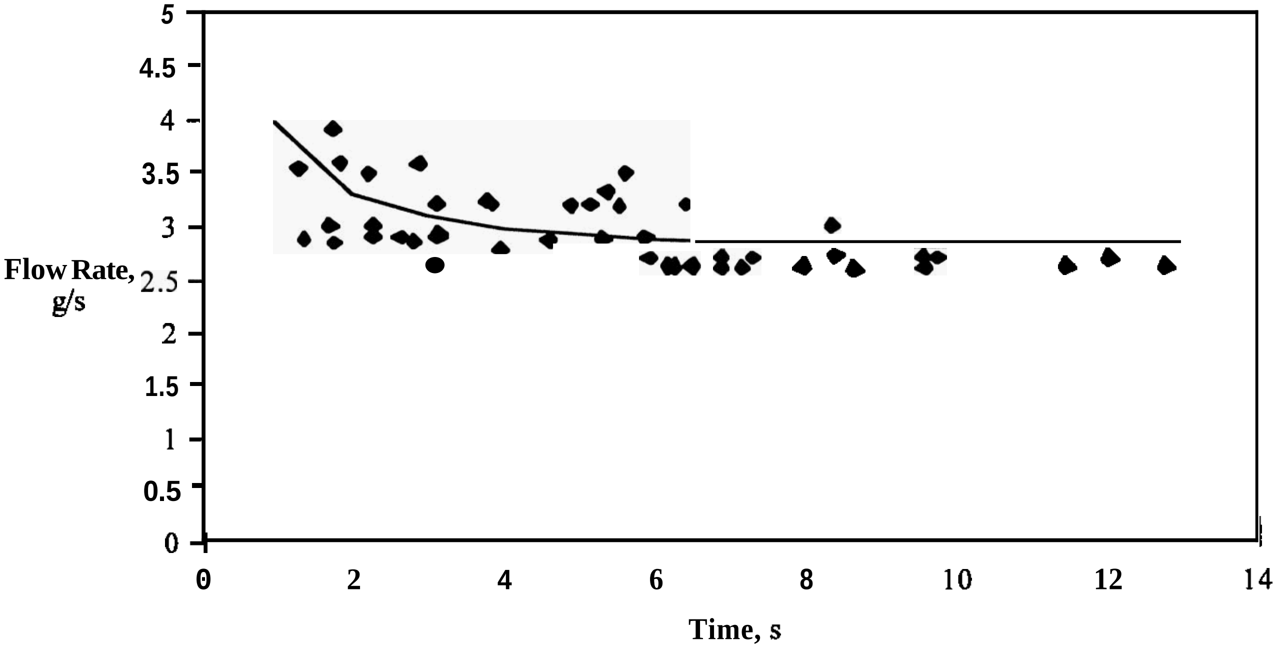


Figure 7. Flow Rate versus Extinguishment Time for Water.

Figures 8 through 15 present the plots of quantity versus time and flow rate versus time for LiI solutions, potassium compounds, Pyrocap™ and Cold Fire™ solutions, and FM-200, respectively. Based on these test results, a 120 wt.% LiI solution, a 60 wt.% K Lac solution, and a 90 wt.% K Ace solution were chosen **as** the primary candidates for field-scale testing. Cold Fire™ mixtures with LiI and K Ace were also recommended for field-scale testing.

FIELD-SCALE STUDIES

NMERI MI-Engine Compartment Simulator – The NMERI M1-ECS has been constructed to provide a full-scale fire extinguishment testing environment relevant to the tire scenarios occurring in tactical vehicles. The simulator design was based on the relevant portions of the M1 Abrams Combat Tank. The agent distribution system was actual M1 Abrams hardware with no modifications. The agent cylinders and valves were also those used on actual combat vehicles. The general fire test scenario was based on the "worst case" scenario for a peace time, engine compartment fire in the M1 Abrams Tank. This included a ruptured fuel line spraying on the gas turbine combustor dome. The NMERI Ml-ECS has been used during several test series (References 2, 3, and **4).**

In the typical test, the bottom front portion of the test fixture was fitted with a 4-ft^2 circular steel fire pan. During a second larger fire scenario another 4-ft^2 square fuel pan was placed in the back portion of the test fixture. The fire pans were filled to a level of 1 to 2 inches with Jet A fuel. During the test, the pan(s) was ignited and the temperature of the simulated combustor dome was recorded. When the combustor dome reached 400 °C (752 °F), a high pressure fuel spray was turned on. The fire/spray burned for an additional 15 sec before the agent was discharged. Video cameras were used to record the tests. The tapes were used later to determine the extinguishment and discharge times for the test. In these tests, the quantity of agent used and the nibogen overpressure were varied to determine the minimum quantity necessary to extinguish the fire.

The tested salt solutions included: an E0 wt.% LiBr solution, a 100 wt.% CaI_2 solution, a 120 wt.% LiI solution. a 60 wt.% K Lac solution, and a 90 wt.% K Ace solution. Solutions of 6% Pyrocap™ and 6% Cold Fire™ were also tested. In these tests, the quantity of agent used and the nitrogen overpressure was varied to determine the minimum quantity necessary to extinguish the fire scenario. The NMERI MI-ECS test results indicated that the 120 wt.% LiI solution and the 90 wt.% K Ace solution were the best fire suppressants. Additions of 10 vol. % Cold Fire™ appeared to enhance the fire suppression performance and deliverability of the salt mixtures.

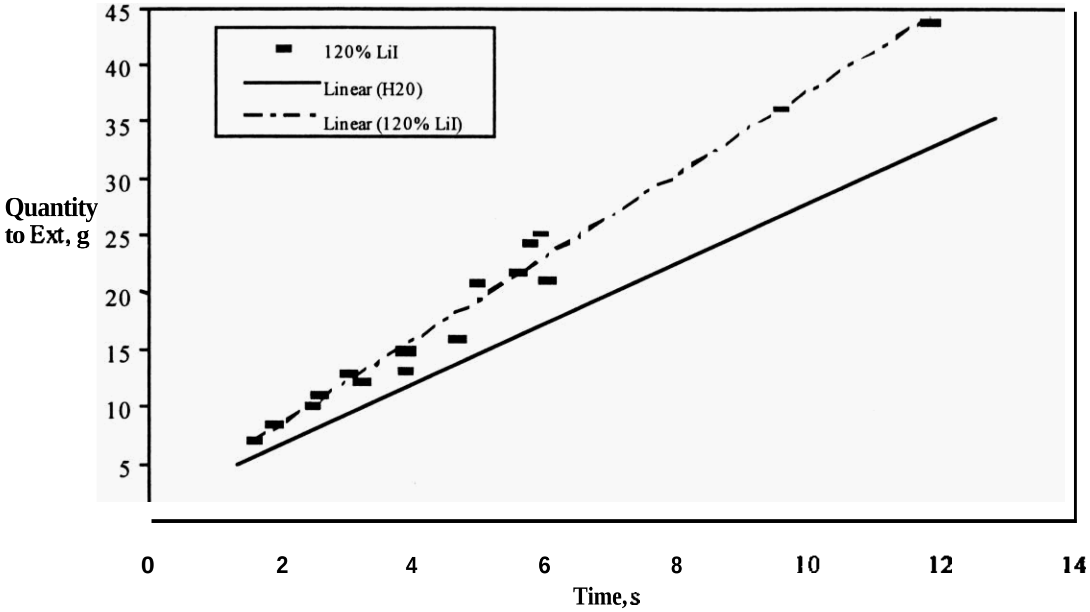


Figure 8. Quantity to Extinguish versus Extinguishment Time for LiI.

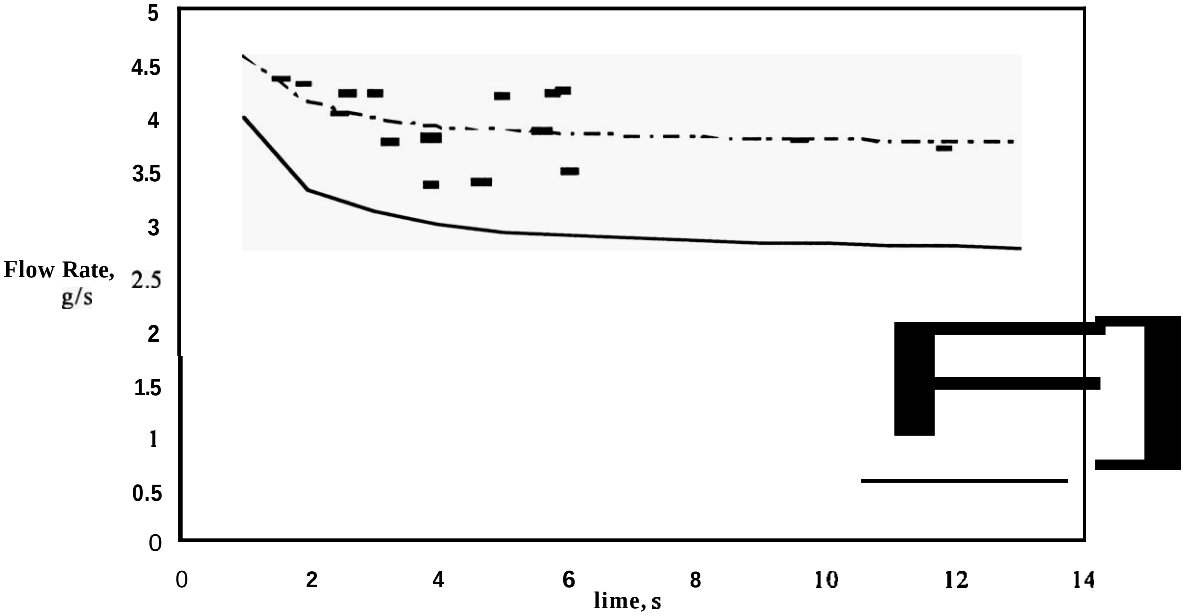


Figure 9. Flow Rate versus Extinguishment Time for LiI.

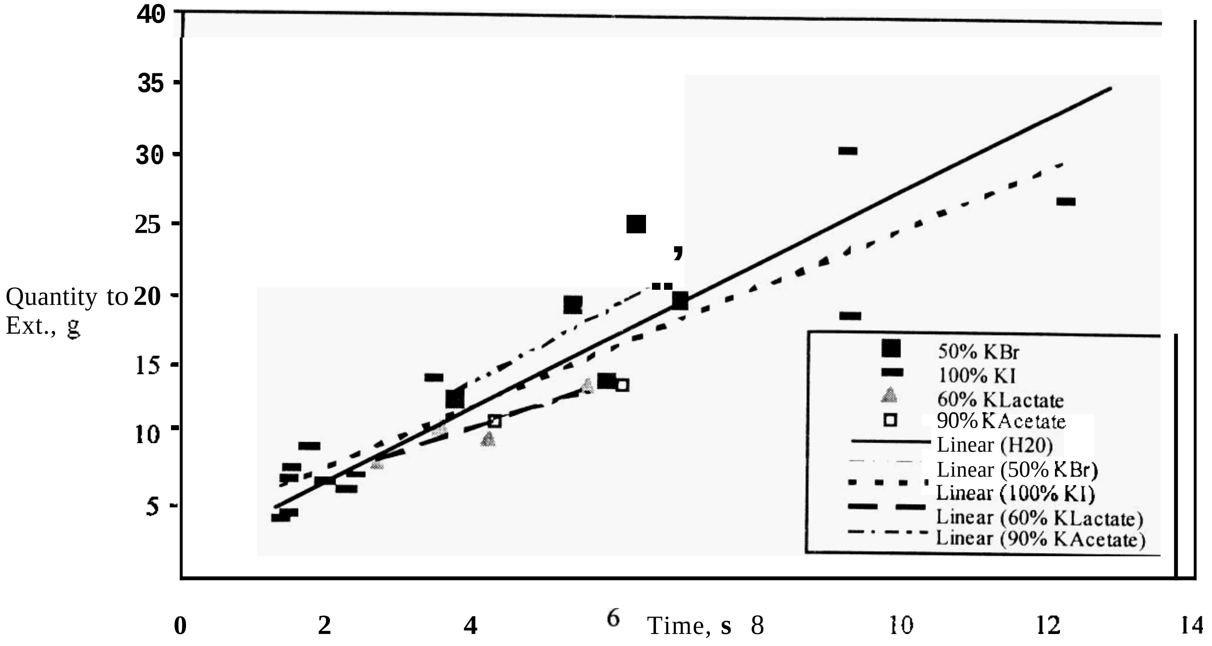


Figure 10. Quantity to Extinguish Versus Extinguishment Time for Potassium Compounds,

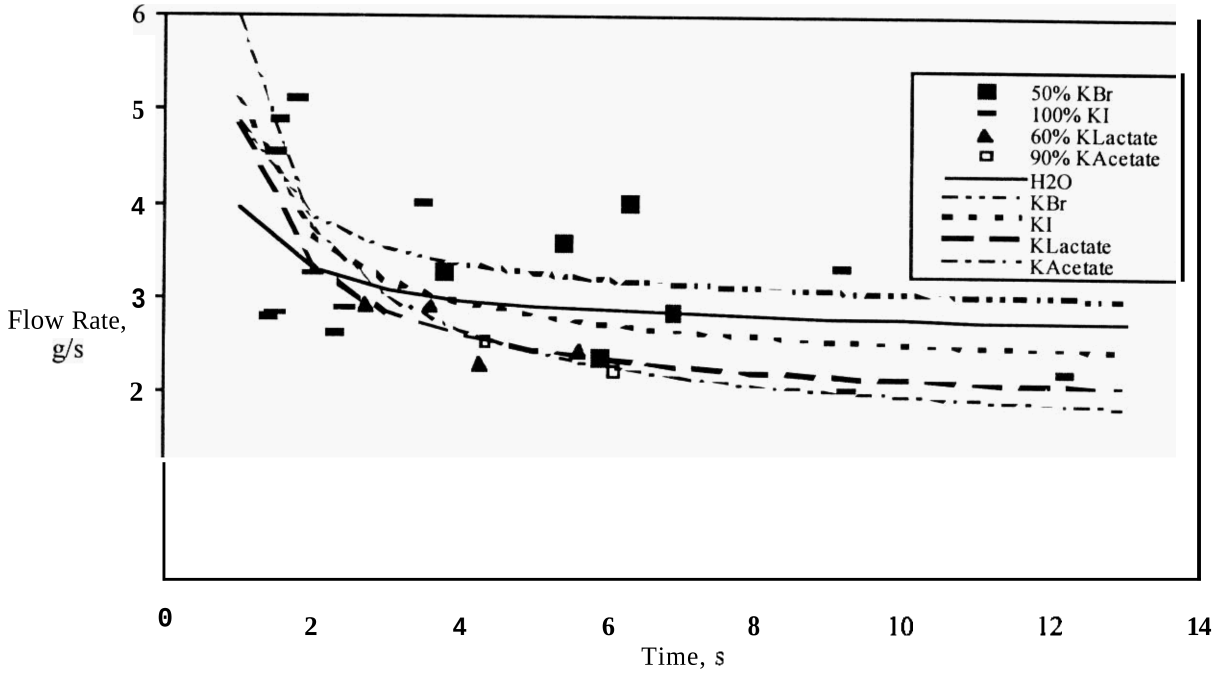


Figure 11. Flow Rate versus Extinguishment Time for Potassium Compounds.

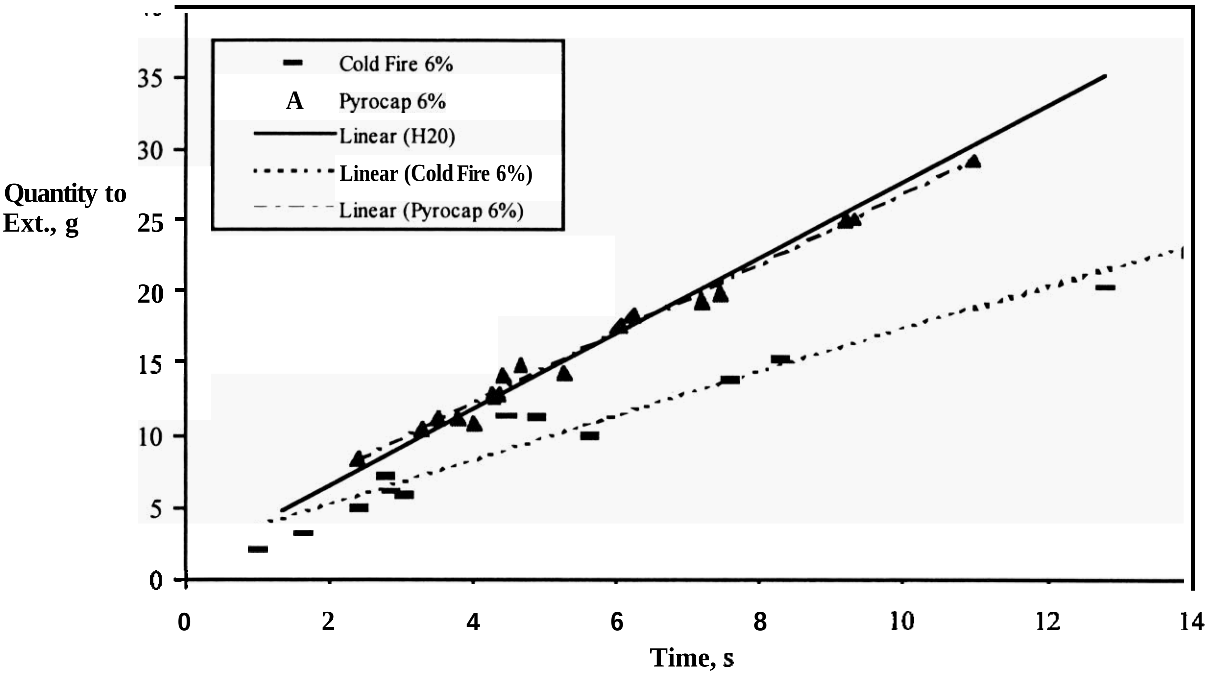


Figure 12. Quantity to Extinguish versus Extinguishment Time for Pyrocap and Cold Fire Solutions.

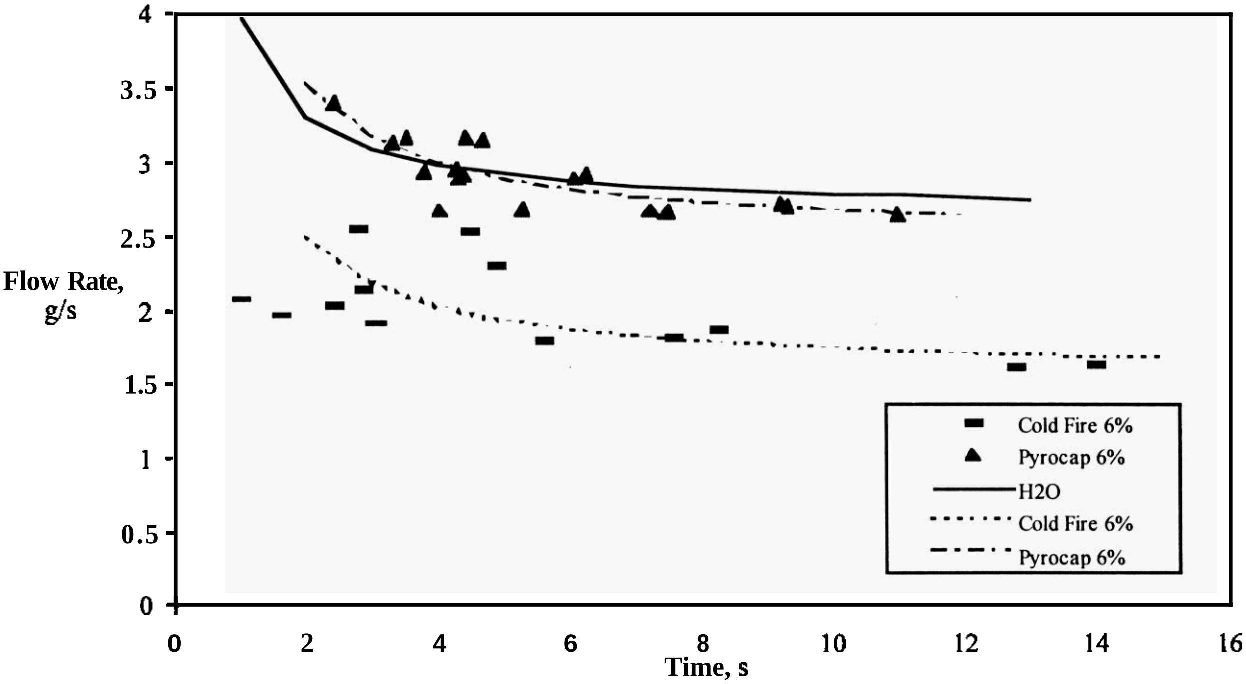


Figure 13. Flow Rate versus Extinguishment Time for Pyrocap and Cold Fire Solutions.

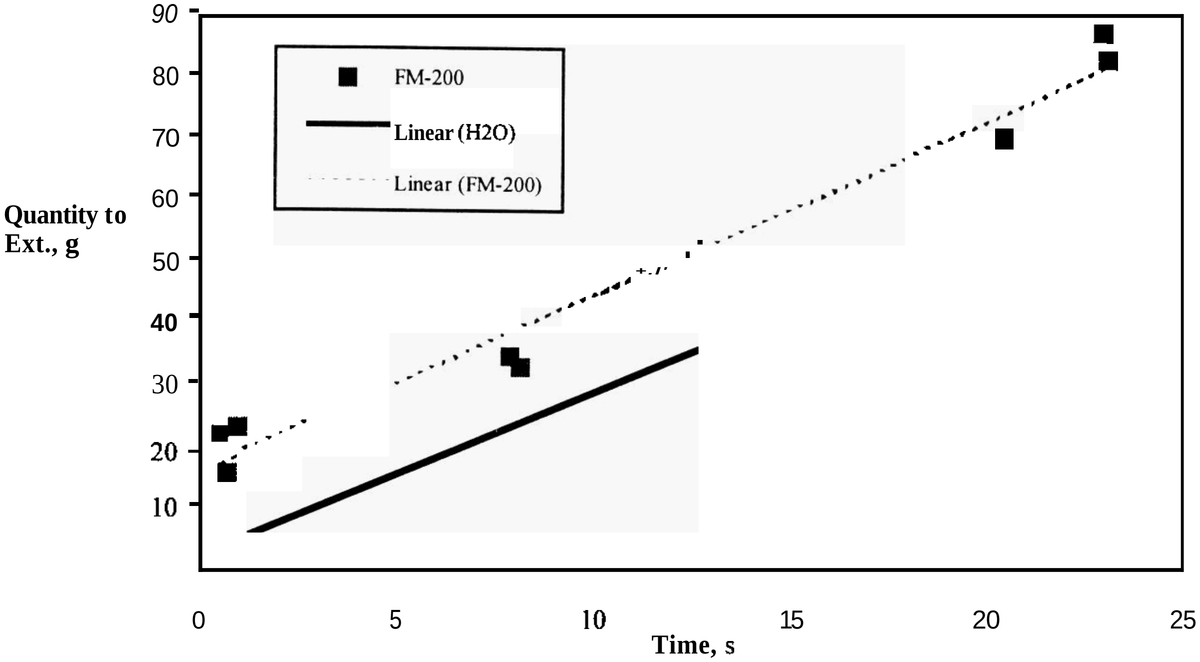


Figure 14. Quantity to Extinguish versus Extinguishment Time for FM-200.

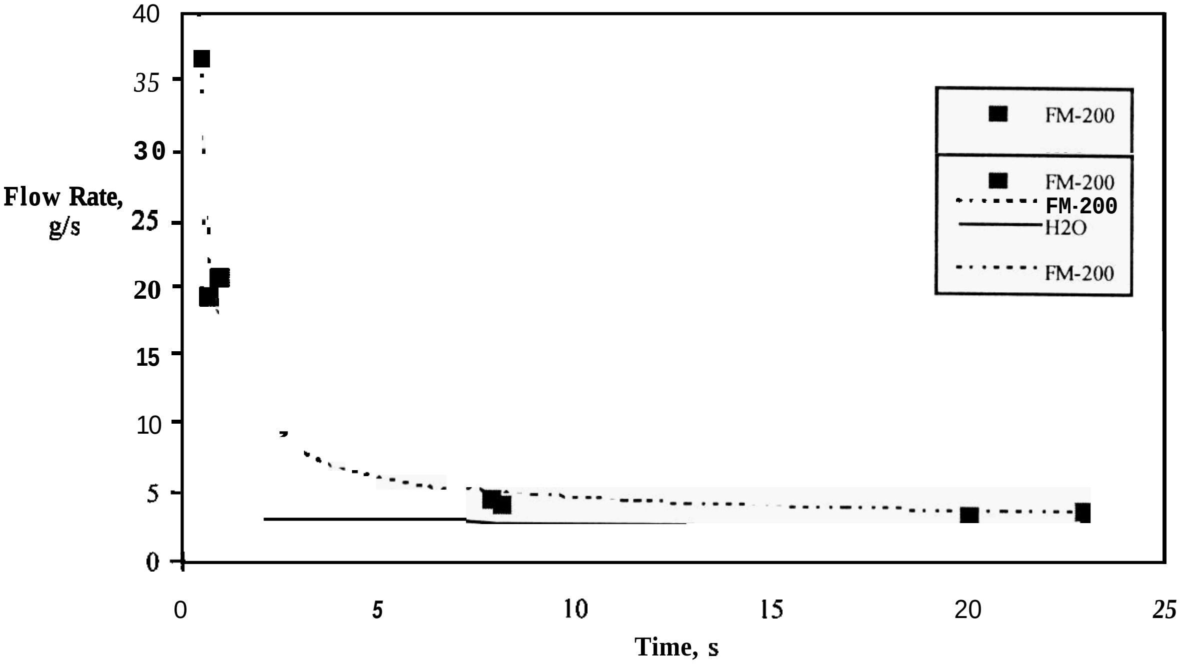


Figure 15. Quantity to Extinguish versus Flow Rate for FM-200.

Aberdeen Test Center Real-Scale Tests --- The U.S. Army TACOM has sponsored the development a three-phase program to test and evaluate fire extinguishing agents for combat vehicle engine compartments at the ATC in Maryland (Reference 1). The test fixtures at ATC were built from M60A3 tank hulls. The Phase I fixture had a non-operation powerpack (Figure 16), while the Phase II fixture had an operating powerpack. The salt mixtures were tested against two standard fire types: (1) Type 2 -- combination bilge and spray fire w/o airflow and (2) Type 3 -- bilge only w/airflow (running powerpack). ***JP-8*** was used for all fires tested at ATC. Standard M60 fire extinguishing hardware was used. However, for some tests, slight modifications to the distribution piping was performed. The modifications consisted of drilling larger holes, reorientation of the holes, and additions of short branches.

During 12 - 13 February 1996, three tests were conducted on the Phase I test fixture, Type 2 scenario, with the LiI 120 wt. % and 90 wt. % K Ace solutions. The standard M60 distribution system with 118-in diameter holes at modified orientations was used. Both salt mixtures suppressed the Phase I Type 2 fire scenario with 3.7 L (10.8 lbs K Ace and 13.8 lbs LiI) of agent; however, reflash occurred. NMERI MI-ECS tests with the addition of Cold Fire™ to the salts indicated that reignition of the ATC test fire would be prevented. Therefore, tests were conducted on the ATC Phase II test fixture with the Cold Fire™ salt mixtures during 30 April and 1 May 1996. This time the Type 3 fire scenario was used (e.g., the most difficult to suppress). The Phase I fixture was no longer available for tests. The Cold Fire™ mixtures were unsuccessful at preventing reflash of the test scenario. The ATC test results showed that the agent distribution system will be critical to the agent performance. Additional distribution system design and optimization will be required to allow for the use of water-based salt mixtures. Additional testing; however, should be conducted at ATC using a distribution system specifically designed and optimized for this type of agent. The ATC tests were sponsored in part by WFO-Detroit.

TOXICOLOGICAL ASSESSMENT

A toxicological assessment was performed on LiI, K Ace, and Cold Fire▼▼ to determine what effects they could have on humans and the environment. This information was compiled from the chemicals MSDS's, the Kirk-Othmer Encyclopedia of Chemical Technology, the Sigma-Aldrich Library of Regulatory and Safety Data. Vol. 3, the Vanguard GS4 Fluid Properties & Engineering Guide, and Sax's Dangerous Properties of Industrial Chemicals (References 2, 3, 4, and ***5)***

The chemical, physical, and toxicological properties of LiI have not yet been thoroughly investigated. However, limited evidence shows that LiI can be potentially harmful if swallowed, inhaled, or absorbed through the skin. It may cause eye and skin irritation. It may cause congenital malformation in the fetus. Large doses of lithium ion have caused dizziness and prostration, and can cause kidney damage if sodium intake is limited. Central nervous system effects that include slurred speech, blurred vision, sensory loss, ataxia and convulsions may

Figure 16. ATC Phase I Test Fixture, Type 2 Fire Scenario, Prior to Agent Discharge.

occur. Prolonged exposures to iodides may produce skin rash, running nose, headache, and irritation to the mucous membranes. Any ecological or regulatory information about LiI is not yet available. No additional specific information was found on LiI..

K Ace may be slightly irritating to the eyes and could cause prolonged (days) impairment of vision. If swallowed, this substance is considered practically non-toxic to internal organs. Toxicity tests show that K Ace is considered practically non-toxic. It is less toxic to mammals than table salt (NaCl). In the event that K Ace gets into the drinking water, the threat to human health is minimal. Acetate biodegrades in the soil, in ground water, and in surface water (i.e., lakes and streams). Bacteria found in water and soil convert the acetate to carbon dioxide, water, and bicarbonate. The biodegradation process takes anywhere from a few days to a few weeks depending on conditions. Some localized oxygen depletion may occur. In the event of a ground spill, the soil pH will increase in the area of the spill. By the third day, essentially all of the acetate will have decomposed. The K Ace oral LD_{50} in rats is greater than 5.0 g/kg.

Cold Fire™ is a mixture of organic surfactants and water. It is designated as Surfactant Blend A by the U.S. EPA under the Significant New Alternative Policy (SNAP) Program. In use this concentrated mixture is diluted to strengths of 1 to 10 percent in water. The surfactants appear to enhance the heat absorbing capacity of water. Cold Fire™ is a blend of complex alcohols, lipids, and proteins. Each substance is biodegradable and the material has been assigned a hazardous materials identification system (HMIS) rating, developed by the National Paint and Coatings Association (NPCA) of 0-0-0 for health hazard, reactivity, and flammability. It is approved as a substitute for Halon 1211 by the U.S. EPA.

The toxicity of Cold Fire™ was evaluated by United States Testing Company, Inc., Biological Services, Hoboken, NJ, during March and April, 1993 (Reference 6). The following summary results were found (1) The acute toxicity of Cold Fire™ to the rainbow trout, oncorhynchus mykiss, was found to be 96 hr $LC_{50} = 105.1$ ppm, the No Observed Effect Concentration (NOEC) was 62.5 ppm. (2) The acute toxicity of Cold Fire™ to the water flea, Daphnia pulex, was found to be 48 hr $LC_{50} = 159.3$ ppm, the NOEC was 62.5 ppm. (3) The acute toxicity of Cold Fire™ to the fresh water alga, Selenastrum capricornutum, was found to be 96 hr $EC_{50} = 153.9$ ppm, the NOEC was < 93.75 ppm). (4) During testing with albino rabbits, Cold Fire™ was not considered to be a dermal irritant. The agent was shown to cause eye irritation in all six animals tested with complete recovery observed in all six animals by day 7. Cold Fire™ was not acutely toxic to laboratory animals following oral administration at 5.0 g/kg.

CORROSIVITY TESTS

Introduction — This section of the project was performed to determine the corrosive effects a 90 wt.% solution of K Ace might have on five different metals that are normally found in U.S. Army tanks. The five metals that were tested were stainless steel, aluminum, red brass, carbon steel, and copper. Weight loss was the method used for determining the corrosivity of K Ace. Both a 90 wt.% solution of K Ace and an inhibited 90 wt.% solution of K Ace called GS4 were tested. GS4 is a product used as a heat transfer fluid by Vanguard Plastics, Inc. The corrosivity was determined after 72 hours, 2 weeks, and 4 weeks of exposure.

Five Cold Fire™ and salt mixtures were also tested at a later date: (1) 90 wt.% solution of K Ace (baseline), (2) 90 wt.% solution of K Ace mixed with 10 vol. % Cold Fire™, (3) 10 vol. % Cold Fire™ mixed with water, (4) 120 wt.% LiI solution, and (5) 120 wt.% LiI solution mixed with 10 vol. % Cold Fire™. The corrosivity of the five Cold Fire™ mixtures was determined after 72 hrs of exposure.

Test Description -- Before the metal coupons were exposed to the salt solutions, they were sanded and immersed in their appropriate acid bath solutions. These acid bath solutions are in accordance to the ASTM standards on corrosivity testing. The coupons were then weighed on a digital scale with a precision of 10^{-4} g. The coupons were then placed in a **400** °C oven for **10** minutes. They were then removed and sprayed with their respective salt solutions until they were soaking wet. There was a set of reference coupons that were treated to the same conditions, however, they were not sprayed with any salt solutions. The coupons were then placed back into the oven for 5 more minutes. The coupons were finally moved into a desiccant where they stayed until their appropriate exposure time was up. After the coupons had been exposed to the salt solution for 12 hours, 2 weeks, or **4** weeks, they were taken out of the desiccant and weighed. Pictures of the coupons were then taken under a microscope. The metals were then rinsed with distilled water and methanol and placed in a 75 °C oven for **30** minutes. After the coupons were cooled, they were reweighed and put in their respective acid solutions for the appropriate length of time. They were again rinsed with distilled water and methanol and placed in the oven for **30** minutes. This cycle was repeated until the coupons showed negligible weight loss. Finally, pictures of the coupons were again taken under the microscope. A weight loss of milligrams per year was determined according to the ASTM standard. The weight loss values were then corrected against the reference coupons.

Corrosion Test Summary --- The corrosivity tests were designed to expose the coupons to the worst case scenario due to discharge of the agent in a fire situation. They were not designed for exposure of the agent to materials of construction during storage and delivery (e.g., cylinders, valves, piping, and fittings). The results of corrosivity tests are presented in Tables 3 and 4. When the metals were corrected against the blanks, the corrosion rates were not very significant (Table 5). The K Ace tended to have slightly higher corrosion rates than the **GS4.** The data on Tables **4** and 5 indicate that the LiI mixtures were significantly more corrosive to red brass, carbon steel, and copper, falling into the poor category (Table 5). Stainless steel and aluminum appear to have good resistance to the LiI mixtures. The Cold Fire™ and the Cold Fire™ with K Ace did not show a significant effect on the materials tested. The K Ace without the Cold Fire™ was shown to be slightly more corrosive. The carbon steel blank sample for the 4 wk exposure period was accidentally put into the wrong acid bath. Therefore, the corrosion rate for that sample could not be determined

The highest corrosion rate occurred for the ***12*** hr exposure time. This implies that most of the corrosion is occurring in the first 72 hours of exposure, rather than over an extended period of time. Long-term corrosivity testing for storage containers, etc., will be required should these mixtures be used in the future.

TABLE 3. CORROSION RATE (mpy).

Material	K Acetate			GS4			Blank		
	72hr	2 wk	4wk	72 hr	2 wk	4wk	72 hr	2 wk	4wk
Stainless Steel									
Raw Data	0.116	0.008	0.008	0.000	0.008	0.000	0.070	0.008	0.012
Corrected Against Blank	0.046	0.000	-0.004	-0.070	0.000	-0.012	---	---	---
Aluminum									
Raw Data	8.529	0.634	0.268	3.139	0.390	0.500	2.524	0.707	0.378
Corrected Against Blank	6.005	-0.073	-0.110	0.615	-0.317	0.122	---	---	---
Red Brass									
Raw Data	1.681	0.450	0.252	2.011	0.504	0.241	1.501	0.311	0.135
Corrected Against Blank	0.180	0.139	0.113	0.510	0.193	0.102	---	---	---
Carbon Steel									
Raw Data	6.049	2.125	0.979	2.908	1.241	-2.686	3,509	1.241	N/A
Corrected Against Blank	2.540	0.884	NIA	-0.601	0.000	NIA	---	---	---
Copper									
Raw Data	9.667	3.243	1.595	3.320	1.070	1.018	6.200	3.096	1.406
Corrected Against Blank	3.467	0.147	0.189	-2.880	-2.026	-0.388	---	---	---

TABLE 4. CORROSION RATES (mpy) FOR COLD FIRE™ MIXTURES AT 72-HR EXPOSURE.

Material	90 wt. % K Ace		120 wt. % LiI		Cold Fire™	**Blank**
	with 10 vol. % Cold Fire™	without Cold Fire™	ith 10 vol. % Cold Fire™	without Cold Fire™	10 vol. %	
Stainless Steel						
Raw Data	0.12	0.12	0.35	2.01	0.08	0.08
Cor. Against Blank	0.04	0.05	0.27	1.93	0.00	—
Aluminum						
Raw Data	8.53	8.53	16.7	16.8	11.8	11.1
Cor. Against Blank	-2.57	-2.57	5.57	5.69	0.68	—
Red Brass						
Raw Data	2.40	1.68	87.6	133	1.70	18.4
Cor. Against Blank	-16.0	-16.7	69.2	115	-16.7	—
Carbon Steel						
Raw Data	4.07	6.05	51.9	109	4.12	9.25
Cor. Against Blank	-5.18	-3.20	42.7	100	-5.12	—
Copper						
Raw Data	13.8	9.67	136	179	15.8	26.0
Cor. Against Blank	-12.2	-16.3	110	153	-10.2	—

Note: Negativ values indicate the corros n was less than that exp ienced by th lank (reference) coupons.

TABLE 5. RELATIVE CORROSION RESISTANCES FOR VARIOUS CORROSION RATES.

'Relative Corrosion Resistance	Corrosion Rate, mpy
Outstanding	<1
Excellent	1 - 5
Good	5 - 20
Fair	20 - 50
Poor	50 - 200
Unacceptable	200+

'Based on typical ferrous- and nickel-based alloys. For more expensive alloys, rates greater than 5 to 20 mpy are usually excessive. Rates above 200 mpy are sometimes acceptable for cheap materials with thick cross sections (e.g., cast-iron pump body).

CONCLUSIONS AND RECOMMENDATIONS

Halide salt and water solutions and two salt solutions (LiI and K Ace) mixed with Cold Fire™ were investigated. During this project freeze point and pH testing, field-scale fire suppression testing, toxicological assessment, and corrosivity tests were performed. Salt solutions and mixtures of Cold Fire™ and the two salts were able to meet freeze points below -51 “C (-60 °F). They were also effective at extinguishing the NMERI field-scale combat vehicle fire scenario. Realistic fire suppression tests were also conducted on the Phase I and II test fixtures at the U.S. Army Aberdeen Test Center (ATC), MD. The ATC test results showed that the agent distribution system will be critical to the agent performance. Additional distribution system optimization will be required. It was determined that the salt solutions and Cold Fire™ mixture are safe for humans and the environment. The K Ace appears to be the least toxic of the salts. Finally, low corrosivity on typical materials of construction (aluminum, carbon steel, copper, red brass, and stainless steel) was observed.

The K Ace salt solution was the most effective fire suppressant tested. The addition of Cold Fire™ to the salt solutions enhanced their deliverability, dispersion, and thus, effectiveness. It is recommended that additional fire suppression applications be considered and tested using the Cold Fire™ and the K Ace mixtures. The other applications should include cold temperature Class A and B streaming, other types of engine compartments, and explosion suppression applications. Additional testing should be conducted at ATC on the Phase II and or Phase III test fixtures using the Cold Fire™ and K Ace mixture. The tests should, however, be performed using a distribution system specifically designed and optimized for this type of agent.

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