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Flammability of antifreeze agents for automatic sprinkler systems

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Abstract
This article evaluates several antifreeze agents for automatic sprinkler systems by focusing on the expected contribution of the combustion energy of such agents to a fire. Such an energy contribution could potentially result in an excessive number of sprinklers being activated and thereby overtax the capacity of the water supply. To investigate this, an analysis and experimental program were initiated involving several different antifreeze agents. The results of this study show that only two of the antifreeze solutions did not increase the intensity of the fire source compared to water only, namely calcium chloride and potassium acetate. The other antifreeze agent solutions that were tested resulted in a significant increase in fire heat release rate. In some cases, the energy released during the period of application was 1.5–2 times higher than that found when only water was used. These results correlated well with the analysis calculations.

Keywords
Sprinkler systems, cold storage, antifreeze, heat release rate, intermediate scale fire tests

Introduction

There is a common misconception that −18°C (or 0°F) is the ideal temperature for cold storage of food. This easily remembered temperature level originates from the introduction of freezer technology in the USA to consumers. When freezer technology was introduced in Europe in the late 1940s, these recommendations were directly translated into the operating manuals. However, lowering the

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temperature from −18°C to −30°C doubles the storage life of food products. A typical temperature in a cold storage warehouse is −25°C and −18°C is the highest recommended temperature during transportation and for short-term storage and display in freezer cabinets in stores [1].

NFPA 13 [2] has permitted the use of antifreeze agents in sprinkler piping since at least the 1952 edition. According to the 2010 edition, an antifreeze sprinkler system is a wet-pipe sprinkler system employing automatic sprinklers attached to a piping system that contains an antifreeze solution and that is connected to a water supply. When automatic activation of the sprinklers occurs, the antifreeze solution that was within the cold storage area is discharged, followed by the normal water supply.

For sprinkler systems supplied by potable water connections, antifreeze solutions of glycerin or propylene glycol are recommended by the 2010 edition of NFPA 13. If potable water is not connected to the sprinkler system, solutions of diethylene glycol and ethylene glycol may also be used. Previous editions of NFPA 13 did additionally recommend solutions of calcium chloride and antifreeze solutions were recommended only for systems not exceeding 151 L [3]. The 2010 edition requires that friction loss calculations for systems greater than 151 L shall be made, using the Darcy–Weisbach equation, and adjustments to the K-factors of the nozzles shall be based on the fluid properties of the antifreeze solutions used. It is also required that the use of antifreeze solutions shall be in conformity with state and health regulations [2].

According to [2] antifreeze shall not be used in early suppression fast response (ESFR) sprinkler systems unless at least one of the two following conditions are met: (1) for antifreeze solutions not referenced in NFPA 13, the antifreeze solution shall be specifically listed for ESFR applications; (2) for antifreeze solutions referenced in NFPA 13, the ESFR sprinkler shall be specifically listed for use with the antifreeze solution.

Practical experience with antifreeze

The use of antifreeze agents in sprinkler systems is a complex issue due to one or more of the following reasons: increased viscosity of the agent which changes the hydraulics and may require larger pipe sizes, material compatibility issues related to corrosion, or gasket aging, increased risk for leakage due to lower surface tension compared to water, the potential flammability of the solution, environmental aspects, health issues, increased system complexity, and increased cost.

Gill [4] describes a sprinkler system concept for a cold storage warehouse that illustrates the increased complexity of a system. The system uses a 50/50% propylene glycol and water antifreeze solution. This concentration corresponds to a freezing temperature of approximately −30°C. The part of the piping system subject to freezing is filled with the pressurized antifreeze solution maintained from a pump system connected to a small antifreeze solution tank, which controls and maintains the desired antifreeze solution pressure. In addition to the antifreeze solution tank, the system requires a reclaim tank for drainage of the system and for pressure control of the system riser. Any increase in temperature in the freezer will increase the pressure in the system piping, and the tank is used to collect any solution vented from the system due to this temperature expansion. Once the pressure in the system normalizes, a digital pressure switch resets the solenoid drain valve to close and stop the flow to the reclaim tank. The reclaim tank is sized for the largest single system capacity. If the system piping pressure is too low, due to the temperature in the freezer being lowered, additional antifreeze solution is automatically pumped into the system from the antifreeze solution tank.

The system requires one isolation valve, an alarm valve, and two check valves, downstream of the alarm valve. All valves should be positioned in a heated area and the pipe volume from the first check valve onward is filled with the antifreeze solution. The reason for this arrangement is the high thermal conductivity of the antifreeze solution. Experience from previous systems which had an alarm valve between the antifreeze solution and water, has shown that a thermal transfer system was set up within the antifreeze system pipe-work, where colder, denser solution from inside the warehouse flowing toward the alarm valve was capable of removing enough energy from the warmer water beneath the alarm valve to cause it to freeze and form an ice plug (effectively taking the system out of operation). This occurred because of the difference in density between the cold solution inside the freezer and the warmer solution outside the freezer. Current systems employ two check valves and a pre-action control valve to maintain an air gap between the antifreeze solution and the water, removing the possibility of ice plug formation [4].

Antifreeze solutions have commonly been used in sprinkler systems installed in heritage buildings in the Nordic countries in recent years. The interior of such buildings and items inside are especially vulnerable to damage. Indeed, damage due to leakage or careless handling of antifreeze solutions has been documented [5].

Kung et al. [6] have investigated the possibility of using a propylene glycol solution for ESFR systems for cold storage protection. A series of three large-scale fire tests was conducted to evaluate the effectiveness of two different ESFR sprinklers. The Standard Class II commodity was used as the fuel in order to simulate the fire challenge found in cold storage warehouses. The tests demonstrated that a K-36 ESFR sprinkler was able to suppress a fire in a 9.1- and 10.7-m high rack storage in a 12.2-m high building. The total pre-charged volume of antifreeze solution in the piping was 4160 L. A K-20 ESFR sprinkler was not able to control the same fire scenario.

The flammability of an antifreeze agent may have contributed to an explosion that killed a woman and injured four others [7–9]. The incident occurred in the kitchen of an apartment protected by a residential sprinkler system in Truckee, CA, USA. Apparently, the fire started in a frying pan on the kitchen stove. While the pan was being moved by one of the residents toward the kitchen sink, a sprinkler at the ceiling above the pan activated and upon activation a violent explosion resulted. A woman was standing in the living room next to the kitchen and the resulting explosion caused her death and caused severe burns on the resident who handled the pan. As a result of the explosion, 8 of the 10 residential sprinklers within the apartment activated. The kitchen cabinets were scorched but not heavily burnt and several windows in the apartment were broken. The sprinkler system was filled with a mixture of water and glycerin.

Antifreeze agents

This study focuses on the potential contribution of combustion energy from an antifreeze agent to a fire. The contribution of energy to a fire could potentially result in an excessive number of sprinklers being activated, thereby overtaxing the capacity of the water supply. To investigate this, a theoretical analysis and experimental program were initiated, which involved several different antifreeze agents. In addition, questions regarding toxicity, environmental impact, changes in freezing point, corrosion, and viscosity were studied. A full report is given in [10].

The following antifreeze agents were studied (in alphabetical order):

- Calcium chloride,
- Ethanol,
- Glycerin,
- Methanol,
- Potassium acetate,
- Propylene glycol, and
- Urea.

A short description of each of the agents is given below. All product data are from Material Safety Data Sheets. The information thus obtained was then supplemented by information from a literature survey. Finally, the rationale for the selection of each specific agent is given.

Calcium chloride

- Name: Calcium chloride
- Chemical formula: $CaCl_2$
- Applications: Road salt and heat transfer fluid
- Appearance: A solid in the form of flakes, powder, or granules
- Color: White
- Odor: None
- Solubility: 745 g/L at 20°C
- Health hazards: Irritant to skin and eyes upon contact
- Environmental risks: Relatively harmless. No special precautions or safety measures are required.

- Comments: Calcium chloride was previously recommended in NFPA 13 as an antifreeze agent, although the practical use is probably quite limited. The main product benefit is that it is environmentally benign and inexpensive. For solutions where the concentration is close to the saturation concentration (in low-temperature systems), the risk of precipitation of salt, which can have a negative influence on the functioning of the system, needs to be taken into account.

Ethanol

- Name: Ethanol (also known as ethyl alcohol and industrial alcohol)
- Chemical formula: C_2H_5OH
- Applications: Solvents, intoxicants
- Appearance: Volatile liquid
- Color: Colorless
- Odor: Characteristic, strong odor
- Volatility: Volatile
- Solubility: Completely miscible with water and miscible with most organic solvents.
- Health risks: Moderate health concern. Inhalation of high concentrations may cause headaches, fatigue, and nausea, impairing the ability to react. Skin contact will degrease the skin and eye contact gives severe irritation. Ingestion in concentrated form will cause pain and give similar symptoms to those cited for inhalation. Toxic in high doses. Denaturants are generally unpleasant, but give no increased health risk.
- Environmental hazards: Low toxic effect on soil and aquatic organisms and is readily biodegradable. Introduction of large concentration in sewage treatment plants can lead to disruption of biological degradation.
- Comments: The main advantage of ethanol is its low toxicity and high solubility in water. The pure product is highly flammable. The pure product can damage gaskets, varnished and painted surfaces, protective grease coating, and rubber materials.

Glycerin

- Name: Glycerin (also glycerol)
- Chemical formula: $C_3H_5(OH)_3$
- Applications: Skin care products
- Appearance: Viscous liquid
- Color: Colorless
- Smell: Slightly sweet
- Volatility: Severely volatile

- Solubility: Miscible with water; Hygroscopic.
- Health hazards: Minor health hazard, toxic in large quantities.
- Environmental risks: Completely biodegradable. No adverse effects on the environment have been identified.
- Comments: Glycerin is commonly used as an antifreeze agent in sprinkler systems and is recommended by NFPA 13. It should be noted that glycerin is compatible with chlorinated polyvinyl chloride (CPVC) piping. If CPVC piping is filled with improper antifreeze, failure of the piping is likely. A study [11] has shown that it takes twice as much water–glycerin mixture to extinguish a fire in a wood crib compared to water only. Another study [12] by Underwriters Laboratories Inc. has tested water–glycerin for use with residential sprinkler systems, but experience from these trials is too limited to draw any conclusions. There are presently commercially available, approved, antifreeze agent solutions based on glycerin with corrosion inhibitors and biostatic additives [13].

Methanol

- Name: Methanol (also known as methyl alcohol and wood alcohol)
- Chemical formula: CH_3OH
- Applications: Charcoal lighter fluid and cleaning solvents
- Appearance: Liquid
- Color: Colorless
- Odor: Characteristic odor
- Volatility: Volatile
- Solubility: Completely miscible with water
- Health hazards: Ingestion can result in fatal poisoning or permanent blindness. Inhalation can cause headaches, fatigue, nausea, and dizziness. Indeed, high levels of inhalation may, after several hours, result in vomiting, abdominal pain, shortness of breath, visual disturbances, and unconsciousness. Skin contact will degrease the skin, which may cause cracking and redness. Extended contact with damaged skin may cause the same symptoms as inhalation. Eye contact results in pain and redness.
- Environmental risks: Harm to living organisms in water and soil. Harm to biological degradation in sewage treatment plants. Readily biodegradable. Release to the environment should be avoided. Must be disposed of as hazardous waste.
- Comments: The main disadvantage of methanol is its toxicity. The pure product is also highly flammable and explosive. Among the benefits are its solubility in water and its low cost. Methanol can damage gaskets, varnished and painted surfaces, protective grease coatings as well as natural, and some synthetic materials.

Potassium acetate

- Name: Potassium acetate
- Chemical formula: CH3COOK
- Applications: De-icing agents, heat transfer fluid
- Appearance: White powder
- Color: White
- Odor: None
- Solubility: Very soluble in water
- Health risks: Low, used as preservatives in foods
- Environmental hazards: None listed
- Comments: Not much information was found about potassium acetate. One reason is probably that it is a fairly harmless product. There are commercially available, approved, antifreeze agent solutions based on potassium acetate with the necessary corrosion inhibitors and biostatic additives that have been tested in a similar fashion as that described in this article, proving that it does not contribute energy to a fire [14].

Propylene glycol

- Name: Propylene glycol (1,2-propanediol, monopropyleneglycol)
- Chemical formula: $CH_3CH(OH)CH_2OH$
- Applications: Heat transfer fluid, de-icing fluids
- Appearance: Slightly viscous liquid
- Color: Colorless
- Odor: Almost odorless
- Volatility: Severely volatile
- Solubility: Completely miscible with water and alcohol. Hygroscopic.
- Health hazards: Is relatively harmless. No inhalation hazard exists because of its low vapor pressure. Prolonged skin contact may ultimately result in irritation. Eye contact may cause transient irritation. Ingestion of large amounts may cause nausea, dizziness, and fatigue.
- Environmental risks: Low toxicity to aquatic organisms and terrestrial mammals. Readily biodegradable. Releases to the environment should be prevented. Must be disposed of as hazardous waste.
- Comments: Propylene glycol is one of the products that is currently used as an antifreeze agent in sprinkler systems and is recommended by NFPA 13. The main benefit of the product is its high water solubility and its relatively good environmental and toxicity properties. NFPA 13 also recommends the use of ethylene glycol and diethylene glycol, but they are considered to have poorer environmental characteristics and only propylene glycol was studied in this project. It should be noted that propylene glycol is not compatible with CPVC piping.

The literature study revealed that there have been attempts to extinguish fires with portable extinguishers and various concentrations of ethylene glycol. These experiments indicated that the higher the concentration of propylene glycol, the longer it takes to extinguish a fire in a wood crib [15]. Calculations suggest that for the same reduction in the freezing point of water, ethylene glycol would contribute less energy to a fire than propylene glycol (see below). There are commercially available, approved, antifreeze agent solutions based on propylene glycol with the necessary corrosion inhibitors and biostatic additives [13]. Glycols are stable in water, but they do decompose slowly and acidic reaction products are formed, which are highly corrosive. The decomposition of glycols is also accelerated by metal ions such as iron and copper.

Urea

- Name: Urea
- Chemical formula: $(NH_2)_2CO$
- Uses: Fertilizer, de-icing fluids
- Appearance: Solid, often in granular form
- Color: White
- Odor: None
- Solubility: Very soluble in water, approximately 100 g/L at 20°C
- Health hazards: Dust can irritate the airways and eyes. In case of contact, rinse with water.
- Environmental risks: Biodegraded relatively quickly by naturally occurring microorganisms. Can contribute to eutrophication of lakes and water traction.
- Comments: The main disadvantage of urea is that the minimum freezing point when mixed with water is approximately −17°C, below which it precipitates. Another drawback is that urea in aqueous solution degenerates slowly to produce ammonia and carbon dioxide. Ammonia is also formed during heating. The main benefits of urea are the relatively low toxicity, environmental impact, and cost.

The risk of corrosion

The risk of corrosion in a system that can be regarded as closed, for example a sprinkler system, is determined primarily by how the system is designed with regard to the risk of intrusion of oxygen. Without the presence of oxygen, corrosion will be slow. Note that the low-temperature environment such as inside a freezer will reduce the rate of corrosion.

Although most of the antifreeze agents studied here are well known, it is difficult to find relevant data in the literature that could serve as a basis for assessing suitable metal construction and antifreeze solution combinations [16]. Testing is therefore recommended in each case. The different antifreeze agents in this study can roughly be divided into three categories with regard to risk for corrosion:

- Category I consists of a mixture of water and ethanol or methanol, which are all less corrosive than pure water. Therefore, there are no special requirements concerning the construction materials relative to pure water.
- Category II consists of a mixture of water and propylene glycol, glycerin and urea, all of which are more corrosive compared to the previously mentioned antifreeze solutions. For use in systems where the intrusion of oxygen is low, corrosion inhibitors should be added. The contents and pH of these systems should be checked regularly. Common factors that indicate corrosion problems in systems containing glycol or glycerin are: a reddish brown discoloration in the antifreeze, a pH below 5.5, and a sour odor. Foaming and a musty odor are also sometimes present [17]. Stainless steel is specifically recommended as the construction material for all parts in contact with urea [16].
- Category III consists of aqueous solutions of salts of calcium chloride or potassium acetate which are the most corrosive of the antifreeze agents in the study. Salt solutions are highly corrosive and their use should generally be restricted to closed systems where the intrusion of oxygen has been ostensibly eliminated. As an extra precaution, corrosion inhibitors should be added, e.g., for calcium chloride solutions, chromium inhibitors are recommended (pH of 7.0–8.5), in combination with stainless steel [9,18]. Calcium chloride solutions are generally much more corrosive compared to solutions with potassium acetate. Unfortunately, it has not been possible to find corrosion data for solutions with potassium acetate in the literature.

Physical properties and theoretical energy contribution

To obtain a basis for the selection of a suitable antifreeze, a compilation of known physical data was made (Table 1). Note, in particular, the relationship between the concentration of the antifreeze solution and the reduction in the freezing point. The viscosity as a function of concentration has also been listed, for cases where these data were available. The viscosity data in Table 1 apply to 20°C or at the freezing point. At low temperatures, the viscosity increases significantly.

Limited information about potassium acetate was found during the literature study, and it was decided to conduct the intermediate scale fire tests with a 50/50% solution. Later, it was determined that this mass concentration corresponded to a freezing point of approximately −55°C. Table 1, however, contains data relevant for a freezing point of −15°C and −30°C, respectively.

It is reasonable to assume that the organic fraction in a water–antifreeze solution will be incinerated if applied to a fire. Therefore, the maximum energy

Table 1. Physical data for the antifreeze solutions included in the study [19,20].

Agent	Concentration with water (mass%)	Approximate freezing point (°C)	Kinematic viscosity at 20°C (cSt)	Kinematic viscosity at the freezing point (cSt)
Calcium chloride	17.9	−15	1.50	4.0
	26.1	−30	2.11	9.8
Ethanol	24.5	−15	2.49	15.8
	40.9	−30	3.09	53.0
Ethylene glycol[a]	30.5	−15	2.11	8.2
	45.3	−30	3.10	31.0
Glycerin	39.5	−15	3.24	15.0
	56.0	−30	7.4	163
Methanol	20.0	−15	1.66	6.7
	33.6	−30	1.92	15.7
Potassium acetate	24.0	−15	1.67	5.4
	34.0	−30	2.21	18.3
Propylene glycol	33.0	−15	3.32	20.0
	48.0	−30	5.74	198
Urea	37.8	−15	1.36	N/A
	44.0	−17.6	1.51	N/A

[a]Agent not used in the intermediate scale fire tests described here.

available and the amount of water per liter of solution were calculated for the solutions included in this study, as given in Table 2.

The products of combustion from the content of organically bound hydrogen and carbon are gaseous water and carbon dioxide. No account was taken of contributions from the solution heat. For potassium acetate, the reaction product was adopted as solid potassium oxide, K_2O. The basis for calculating the heat of combustion has been the combustion and enthalpy change of formation given in [19]. Potassium acetate gives the lowest contribution of energy to the fire of the organic components studied for a comparable decrease in the freezing point.

The energy contribution per liter of water is of interest as a sprinkler system would be designed for a volume flow rate of solution rather than the mass flow rate. In these terms, the solutions of propylene glycol, glycerin, and ethanol, corresponding to a freezing point of −30°C show the greatest energy contribution. Potassium acetate provides the lowest energy contribution with the exception of calcium chloride which is not expected to give any energy contribution.

Table 2. Estimated maximum energy contribution.

Agent ($-\Delta h_c$)	Concentration with water (mass%)	Approximate freezing point (°C)	Density at 20°C (kg/L)	Amount of water (kg/L)	Energy contribution (MJ/L)
Calcium chloride	17.9	−15	1.157	0.95	–
	26.1	−30	1.240	0.92	–
Ethanol	24.5	−15	0.962	0.73	6.32
(26.80 MJ/kg)	40.9	−30	0.933	0.55	10.23
Ethylene glycol[a]	30.5	−15	1.038	0.72	5.39
(17.04 MJ/kg)	45.3	−30	1.058	0.58	8.17
Glycerin	39.5	−15	1.098	0.66	6.97
(16.06 MJ/kg)	56.0	−30	1.146	0.50	10.30
Methanol	20.0	−15	0.966	0.77	3.85
(19.93 MJ/kg)	33.6	−30	0.946	0.63	6.33
Potassium	24.0	−15[b]	1.123	0.85	1.64
acetate	34.0	−30[b]	1.180	0.77	2.44
(6.08 MJ/kg)	50.0	−55	1.276	0.64	3.87
Propylene glycol	33.0	−15	1.039	0.69	7.50
(21.65 MJ/kg)	48.0	−30	1.062	0.55	11.04
Urea	37.8	−15	1.104	0.69	3.78
(9.05 MJ/kg)	44.0	−17.6	1.124	0.63	4.48

[a]Agent not used in the intermediate scale fire tests described here.
[b]Concentration not used in the intermediate scale fire tests described here.

Intermediate scale fire tests

The fire tests were conducted at an intermediate scale. A burning wood crib was used as the fire source and the antifreeze solution was evenly distributed above it with spray nozzles. The heat release rate was measured continuously using oxygen depletion calorimetry. The results were compared to tests using water only. Conclusions were based on the energy released over the first 8-min period (of 10 min) when water or antifreeze solution was applied.

The experiments were carried out under the furniture calorimeter used in ISO 9705 [21] which enables the measurement of heat release rate. The fire source was a wood crib consisting of 12 alternate layers of eight $730 \times 40 \times 40\,mm^3$ wood sticks (Figure 1). The overall weight of the wood crib was approximately 60 kg. The wood crib was placed on a rotating table, which is normally used for testing fire extinguishers in accordance with SS 1192 [22]. The table rotates at 5 rpm and is equipped with a propane gas burner consisting of a loop with a number of holes drilled under a gravel bed.

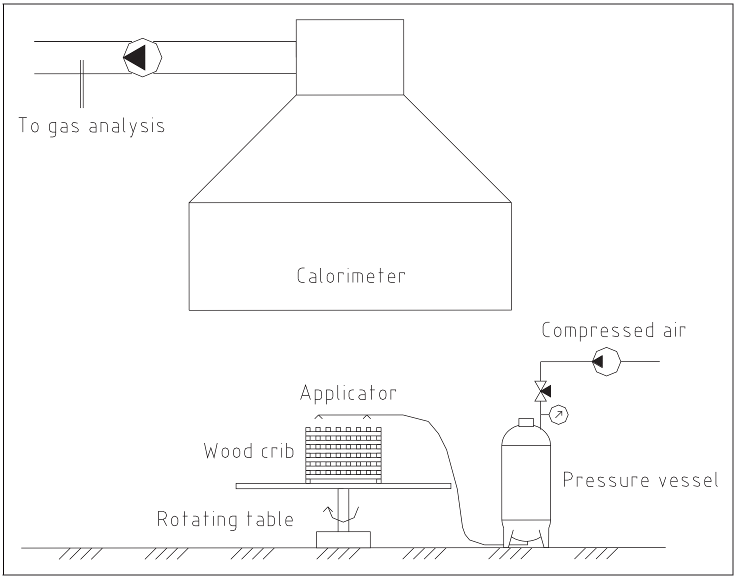

Figure 1. The intermediate scale fire test set-up.

The gas burner under the wood crib was allowed to burn for 3 min (gas flow 5 g/s) after which the gas supply was stopped, the hose for the supply of propane gas was disconnected, and the table began to rotate. After another minute, the discharge was begun and nominally continued for 10 min.

The applicator was constructed from 25-mm steel tubing and was fitted with four nozzles spaced approximately $450 \times 450\,mm^2$. The nozzles were positioned approximately 150 mm above the top of the wood crib. The nozzles had a spray angle of 120° and a 0.70-mm orifice opening.

The agent solution mass flow was calibrated using a square, $730 \times 730\,mm^2$, tray where the agent solution was collected and the content weighed. The mass flow was measured prior to and after each test to ensure that none of the spray nozzles had clogged during the test. The agent solution was filled in a pressure vessel (nominal volume 150 L) connected to a supply of compressed air *via* a pressure reducing valve. By adjusting the air pressure, the desired mass flow could be obtained. All agents were maintained at room temperature during the tests.

Three reference tests with water were conducted. These three tests indicated repeatability in test results better than ±10%. In all the reference tests, the water pressure was adjusted to 3.0 bar resulting in a flow of 2.95 kg/min. This represented an estimated water application density of 5.5 mm/min ((L/min)/m^2) above the wood crib. The same mass flow of antifreeze agent solution was used. In some cases, the pressure had to be slightly increased to compensate for the increased viscosity of the antifreeze solution compared to that of pure water. In other cases, the pressure was slightly reduced to compensate for the higher density of the antifreeze solution.

One test was conducted with a mass concentration corresponding to a freezing point of −15°C and another test with a mass concentration corresponding to −30°C. An exception was made for the tests with urea which were conducted at concentrations corresponding to −10°C and −15°C, and with potassium acetate where only one test was conducted at a concentration which corresponds to a freezing point of approximately −55°C.

Results and observations

During the first 3 min of the fire tests when the gas burner was used to initiate the fire, the heat release rate stabilized at approximately 1100 kW. When the gas flow was shut off, the heat release rate decreased to approximately 800 kW. The application of water reduced the heat release rate to approximately 500–600 kW. This was considered a moderate and useful level since the fire was clearly reduced, without losing too much intensity.

The heat release rate stabilized rather well during the first 8 min of discharge, however, when the wood cribs had almost been consumed over the last 2 min, the heat release rate began to decline rapidly. This reduction was primarily caused by the collapse of the interior parts of the wood cribs. The exterior, however, remained relatively intact. In order to compare results from the tests, the energy measured during the first 8 min of discharge was calculated. Figure 2 shows the measured heat release rate for three of the tests and the different phases during testing.

The droplet size distribution from the nozzles used is probably smaller than that from a standard sprinkler. It is unknown whether this affects the outcome of the tests, but it is expected that it is insignificant in this case for the following reasons: (1) the nozzles were positioned so close to the top of the wood crib that all of the agent solution reached the top surface and flowed through the stack, thereby eliminating issues related to droplet deflection and vaporization as the sprays travelled through the flame above the top surface of the stack, and (2) there were no visual observations of flames in the nozzle sprays, except for the tests with ethanol.

In some of the tests, smaller pool fires occurred under and at the side of wood crib. This occurred in both the tests with propylene glycol and glycerin. In the tests, with calcium chloride and potassium acetate, a white powder was formed under the wood crib. The powder was not analyzed but it is expected that it was comprised of precipitated calcium and potassium salts, respectively.

Figure 3 shows the relative contribution of energy as compared to water for the agent solutions corresponding to a freezing point of −15°C.

Figure 4 shows the relative contribution of energy as compared to water for the antifreeze solutions corresponding to a freezing point of −30°C.

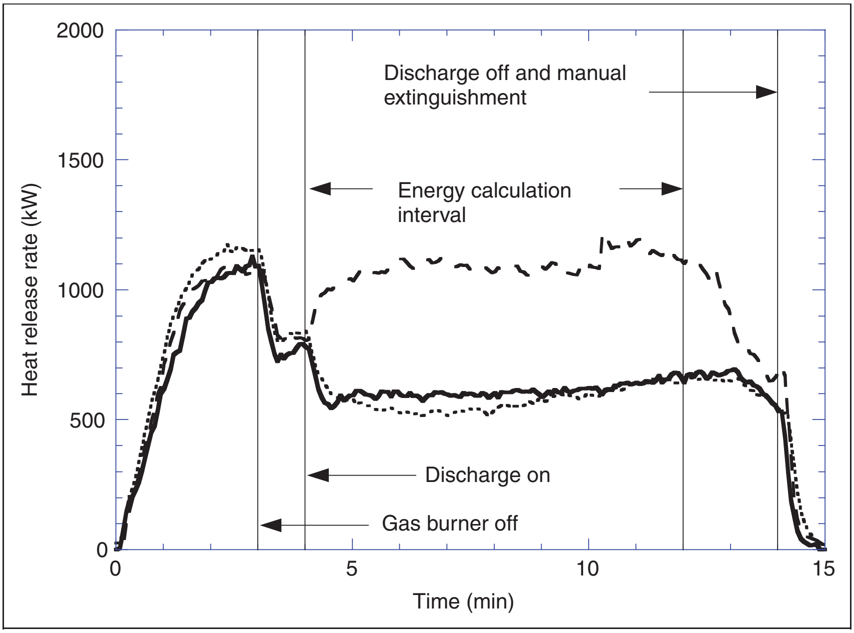

Figure 2. Examples of test results showing the measured heat release rate for water only (solid line), propylene glycol (−30°C, dashed line), and calcium chloride (−30°C, dotted line).

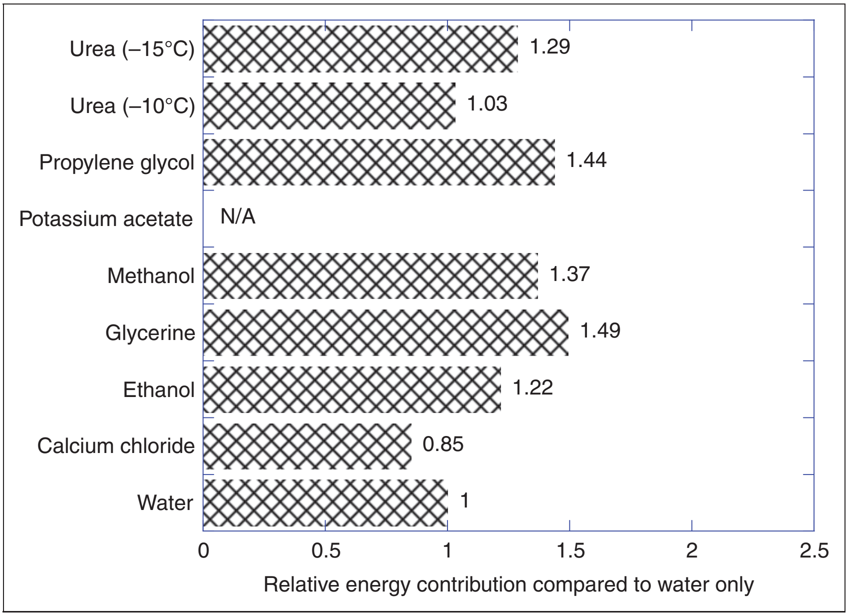

Figure 3. The relative energy contribution as compared to water for antifreeze solutions corresponding to a freezing point of −15°C.

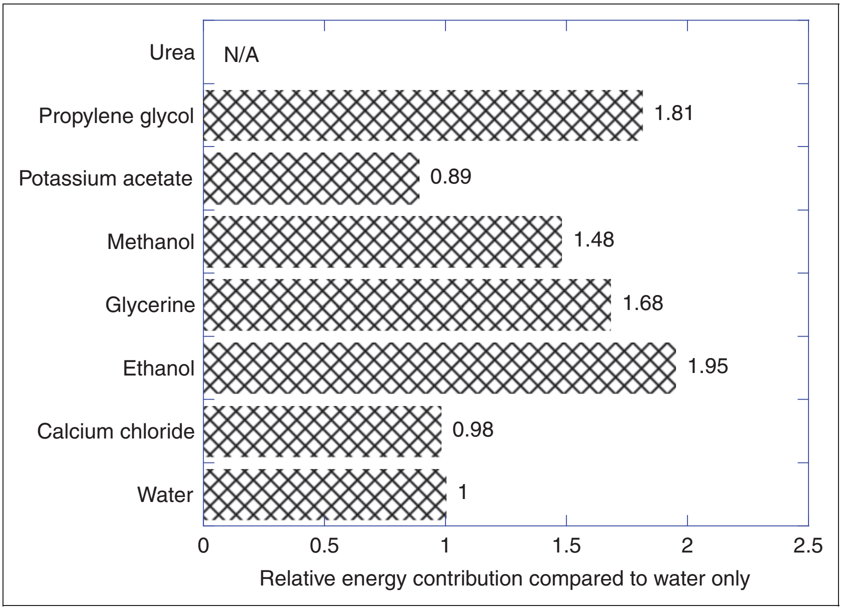

Figure 4. The relative energy contribution as compared to water for antifreeze solutions corresponding to a freezing point of −30°C (−55°C for potassium acetate).

Measured compared to calculated energy contribution

The theoretical increase in energy was calculated using Equation (1).

$$E = x \cdot \Delta h_c \cdot \dot{m} \cdot \Delta t \tag{1}$$

where E is the energy contribution in MJ; x the mass fraction of agent in the solution; Δh_c the heat of combustion of the agent in MJ/kg; $\dot{m}$ the mass flow rate of agent in kg/min; and t the discharge time in min.

The measured increase in energy was compared to the theoretical increase at −15°C and −30°C; refer to Tables 3 and 4, respectively.

Due to insufficient burning efficiency, it is expected that the calculated energy generally should exceed the measured values. This holds for all except for two tests; methanol (−15°C) and ethanol (−30°C). The test results for calcium chloride and potassium acetate indicate a slight improvement of the extinguishment efficiency as compared to water only.

Discussion

The contribution of energy to a fire by an antifreeze agent solution may be a factor that needs to be considered for some sprinkler system applications, for example large sprinkler systems used for the protection of cold storage warehouses.

Table 3. The measured and calculated increase in energy during the first 8 min of discharge for antifreeze solutions corresponding to a freezing point of −15°C.

Agent solution	Approximate freezing point (°C)	Measured increase in energy (MJ)	Calculated increase in energy (MJ)
Calcium chloride	−15	−42	0
Ethanol	−15	62	155
Glycerin	−15	141	150
Methanol	−15	105	94
Potassium acetate	N/A	N/A	N/A
Propylene glycol	−15	125	169
Urea	−10	8	81
Urea	−15	82	94

Table 4. The measured and calculated increases in energy during the first 8 min of discharge for antifreeze solutions corresponding to a freezing point of −30°C.

Agent solution	Approximate freezing point (°C)	Measured increase in energy (MJ)	Calculated increase in energy (MJ)
Calcium chloride	−30	−7	0
Ethanol	−30	272	259
Glycerin	−30	194	212
Methanol	−30	138	158
Potassium acetate	−55	−31	72
Propylene glycol	−30	234	245
Urea	N/A	N/A	N/A

If the fire is sufficiently intense to vaporize the mixture and release its heat of combustion, the burning rate of the fire may increase, which could potentially result in an excessive number of sprinklers being activated.

For other applications, this factor may not be important, for example in sprinkler systems with limited pipe volumes and associated limited amounts of antifreeze agent in the overall antifreeze solution. However, practical experience has shown that the flammability of antifreeze agent solutions may contribute to dangerous fire and explosion hazards under certain conditions. Such effects should be considered in any applications where life safety is a concern.

The following conclusions can be drawn from the tests:

1. Solutions giving a freezing point of −15°C: The test with calcium chloride show that no contribution of energy to the fire, compared with water only, occurred.

Urea provides a marginal energy contribution at a mass concentration corresponding to a freezing point of $-10^{\circ}C$. At a mass concentration corresponding to a freezing point of $-15^{\circ}C$, the relative energy contribution was 1.3. Ethanol, glycerin, methanol, and propylene glycol, contributed between 1.2 and 1.5 times more energy compared to water only.

2. Solutions giving a freezing point of $-30^{\circ}C$: The tests with calcium chloride and potassium acetate show that no contribution of energy to the fire, compared with water only, occurred. Ethanol, glycerin, methanol, and propylene glycol contributed between 1.5 and 2.0 times more energy compared to water only.

Conclusion

The results of this study show that only two of the tested antifreeze solutions did not increase the intensity of the fire source compared to water only, namely calcium chloride and potassium acetate. The other antifreeze agent solutions that were tested resulted in a significant increase in the heat release rate upon suppression of the fire relative to suppression with water only. The results correlate well with theoretical calculations.

Other benefits of calcium chloride and potassium acetate include the relatively moderate increase in viscosity (at low temperatures) compared to most of the other antifreeze agents studied. The main drawbacks of these two agents include an uncertainty regarding their increased corrosion potential compared to the other agents. This may be the reason why calcium chloride is not recommended in later editions of NFPA 13.

Further studies should focus on establishing corrosion data for solutions with, e.g., potassium acetate and determine appropriate corrosion inhibitors. Such work should naturally also focus on the materials, e.g., metals and metal alloys, gaskets, and seals, used in sprinkler systems and tests should be conducted under conditions that are as close to actual conditions as possible.

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