info@fpinnovations.ca
www.fpinnovations.ca

PERFORMANCE EVALUATION OF COMMERCIALLY AVAILABLE WILDLAND FIRE CHEMICALS USING A CUSTOM-BUILT THERMAL CANISTER

Razim Refai
Eder Alain Villa Coronel
Dr. Andre McDonald

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This report is not restricted.

This study focuses on evaluating the relative performance of different commercially available wildland fire chemicals using a custom-built sensible enthalpy rise calorimeter, known as the 'Thermal Canister.' Six different fire chemicals were evaluated in this study: Blazetamer 380, AquaGel-K, Firewall II, WD 881C, Thermo-Gel 200 L, and FireIce 561. The evaluation of the relative performance of the fire chemicals was conducted by using the average heat release rate as the primary metric.

It was found that under the test conditions, Thermo-Gel 200L at 3% concentration and FireIce 561 at 1.4% concentration were the most effective at suppressing combustion. The fire chemicals that were least effective at suppressing combustion were Firewall II at 0.25% and 2% concentration and WD 881C at 0.1%, 0.3%, and 1% concentrations. The study also found that certain fire chemicals such as AquaGel-K and FireIce 561 at their highest approved mix ratios were too viscous to be applied and may prove to be challenging to use for firefighting operations.

Data from this study will be used in the Wildfire Chemical Roadmap, where results from multiple tests will help assess the effectiveness and cost of using gels.

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APPROVER CONTACT INFORMATION
Greg Baxter
Research Scientist
greg.baxter@fpinnovations.ca

REVIEWERS
Michael Benson, BC Wildfire Service

Revie Lieskovsky, Conair

Greg McBride, US Forest Service

Hunter Jones, US Forest Service

AUTHOR CONTACT INFORMATION
Razim Refai
Wildfire Scientist
Wildfire Operations
(780) 817-1840
razim.refai@fpinnovations.ca

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

NOMENCLATURE

A	surface area (m^2)	*Greek symbols*	
C_p	specific heat capacity ($Jkg^{-1}K^{-1}$)	α	thermal diffusivity (m^2s^{-1})
D	diameter (m)	ε	emissivity
L	length (m)	ν	kinematic viscosity (m^2s^{-1})
L	characteristic length (m)	ρ	density (kgm^{-3})
P	pressure (N/m^2)	σ	Stefan-Boltzmann constant (W/m^2K^4), 5.67 x 10^{-8} W/m^2-K^4
Re	Reynolds's number, $\mathrm{Re} = \frac{ul}{\nu}$	∞	ambient
q'	heat transfer rate (W)		
T	temperature (°C)	*Subscripts*	
t	time (s)	c	cross-section
u	velocity of fluid (ms^{-1})	e	exhaust
V	velocity (ms^{-1})	i	initial
W	thickness of wall (m)	s	surface
x	position (m)	t	total

BACKGROUND

Although water-enhancing gels have been around for decades, there is little documented evidence regarding its capabilities as a fire-control agent. This lack of information has limited the acceptance of gel products in Canada. In collaboration with the Canadian Interagency Forest Fire Center (CIFFC), Alberta Agriculture and Forestry (AAF), and the British Columbia Ministry of Forests, FPInnovations has designed a project called the 'Wildfire Chemical Roadmap' to answer the many questions surrounding the effectiveness of gel as a fire-control agent.

Currently, there are multiple tests that have been completed or are in progress to evaluate the performance of wildfire chemicals. These include the US Forest Service's LIFT Test, the Thermal Canister test, and the Crib Test. Each of these test methods offers a different take on how to evaluate these chemicals, providing valuable information.

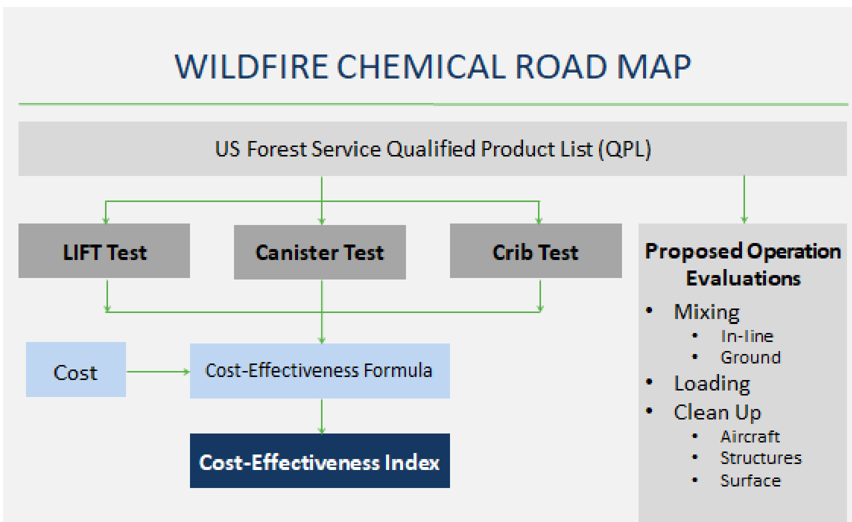

Figure 1. Wildfire chemical roadmap to evaluate wildfire chemicals.

The goal of the Wildfire Chemical Roadmap is to consolidate data from these tests and identify which chemicals are most effective as suppressants. In this report, the results from the Thermal Canister test will be discussed in detail.

INTRODUCTION: THERMAL CANISTER

A laboratory test methodology was developed by Anderson (2015) to evaluate the performance of wildland fire chemicals. The test methodology utilized a custom-built thermal calorimeter, referred to as the 'Thermal Canister' in this study, which consisted of a rectangular aluminum enclosure that was used to house vegetative fuel beds made of red-stemmed feather moss, and an electric-powered radiant heater that was used to supply a uniform heat load to ignite the fuel. Temperature data gathered from the thermocouples attached to the front and back surfaces of the enclosure was used as inputs to a one-dimensional heat conduction model to estimate the heat release rate at three-second intervals from the vegetative fuels during combustion. The total heat release rate in the Thermal Canister on which this model is based was given as

$$q'_{\mathrm{Total}}(t) = \rho C_{\mathrm{p}} A_{\mathrm{c}} V \Delta T_{\mathrm{e}} + \sum_{i=1}^{10} \frac{A_{\mathrm{s}}}{\varepsilon} \left\{ \left(\frac{k}{W} \Delta T_{\mathrm{w}} + \sigma\varepsilon [T_2(W,t)^4 + T_1(0,t)^4 - T_{\infty}{}^4] \right) \right\}_i . \quad \text{(Refai 2017)}$$

The fabrication of the Thermal Canister assembly and the experimental procedure of the test methodology, as well as justification for the fuel type used have been outlined by Refai[2]. Several experimental burns were conducted by Refai (2017) to assess the Thermal Canister test methodology for repeatability and validity. The experimental burns used water, foam, and gels (water enhancers) at different concentrations. The heat release rate data from the experimental burns suggested that the Thermal Canister test methodology produced good repeatability and was found to be valid for the purpose of assessing the performance of various fire chemicals. This study focuses on utilizing this newly developed test methodology to evaluate the relative performance of six commercially available fire chemical products at different mix ratios approved by the U.S. Forest Service in accordance with Forest Service Specification 5100-306A (as amended).

METHODOLOGY

Preparation of Fire Chemicals

The fire chemicals that were evaluated in this study included: Blazetamer 380, AquaGel-K, Firewall II, WD 881C, Thermo-Gel 200 L, and FireIce 561. The fire chemical products were provided by FPInnovations in their respective concentrated states to the University of Alberta and were mixed with tap water in the Advanced Heat Transfer and Surface Technologies Laboratory at the University of Alberta. Each fire chemical product was mixed at or within its respective lowest and highest concentrations approved on the Qualified Product List (QPL) that is maintained by the U. S. Forest Service. Dry chemical concentrates were mixed by weight and wet chemical concentrates were mixed by volume. The mixing ratios used for the various fire chemicals are presented in Table 1. It should be noted that the WD 881C was the only foam product tested in this study. All other fire chemicals tested were water enhancers (gels).

Table 1. Fire chemical product mixing ratios

Fire chemical product	Mixing ratio (low)	Mixing ratio (high)	Additional mixing ratio
Blazetamer 380*	0.65%	N/A	-
AquaGel-K**	0.4%	1.2%	-
Firewall II	0.25%	3%	1%, 2%
WD 881C	0.1%	1%	0.3%
Thermo-Gel 200L	0.5%	3%	1%, 1.5%
FireIce 561	1.4%	2.1%	-

*Blazetamer 380 has only one mixing ratio approved on the QPL
**AquaGel-K has been removed from the QPL as of September 2017 due to the product no longer being commercially available

The foam and gel products were thoroughly mixed by using a high-performance blender (Ninja, Euro-Pro Operating LLC, Ville St. Laurent, Québec, Canada). A Marsh funnel (Fann Instrument Company, Houston, Texas, USA) was used to determine the time required for a fixed volume of the foam and gel products to flow through the funnel. The time was indicative of the viscosity of the product. One thousand, five hundred (1500) mL of foam and gel products was used in each Marsh funnel test, and each test was repeated three times (n = 3).

The fire chemical products were applied using a spray bottle on to the red-stemmed feather moss fuel bed. Red-stemmed feather moss was selected as the fuel of choice due to its ability to absorb water and water-based compounds (foams and gels) well. A spray bottle was used to stimulate a drop from an air tanker where atomization of a bulk liquid would take place during the drop. Following treatment of the fuel bed with the fire chemicals, the fuel bed was placed in the Thermal Canister assembly. The delay between the application of fire chemicals on the fuel bed and the start of the experimental burn was less than four minutes. This delay was necessary for the placement of the treated fuel bed as well as the proper insertion of thermocouples in the Thermal Canister assembly.

Experimental Burns & Data Analysis

The Thermal Canister was setup with data loggers programmed to record the temperatures and differential voltages at three-second intervals. The data recording process was initiated when the radiant panel with a set-point temperature of 600°C was switched on. The experiments were repeated three times (n = 3) for each type of fuel treatment under the same parametric conditions: mixing ratio, mass of fuel, coverage level (CL 4), and heat flux. Data obtained from the experiments was extracted and Eq. 1 was used to calculate the heat release rate. The lower the value of heat release rate produced during the experimental burns, the better is the performance of the fire chemical under these specific test conditions.

The performance of the fire chemicals was evaluated in terms of percentage increase or decrease in average heat release rates in comparison to the average heat release rate of water-treated fuels at five different times: 300, 450, 600, 750, and 900 seconds. The use of water-treated fuels as a control measure would enable the relative comparison of different fire chemical products. Heat release rate data from the experimental burns involving water-treated fuel beds was obtained from Refai[2]. Since the repeatability of the Thermal Canister test methodology has already been assessed by Refai[2], repeatability standard deviation, and coefficient of variation were not calculated.

RESULTS AND DISCUSSION

Marsh Funnel Test

The Marsh Funnel test was used to provide an indicator of the viscosity of the different fire chemicals at different concentrations. This test is an easy, quick, and cost-effective method to ensure that chemicals are being mixed at the intended concentrations during operations. The results from the Marsh funnel test are presented in Table 2.

Three fire chemical products at specific mixing ratios were found to have significantly high flow times in the Marsh funnel test: AquaGel-K at 1.2% concentration, Firewall II at 3% concentration, and FireIce 561 at 2.1% concentration. The high viscosity of the aforementioned three fire chemicals was visibly observed during the Marsh funnel test where the mixed products resisted separation from the bulk fluid, resulting in high flow times.

AquaGel-K, at 1.2% concentration, was found to have a flow time that was greater than 15 minutes (900 seconds), suggesting that the mixed product had very high viscosity. The Marsh funnel test was discontinued after 15 minutes due to the high viscosity of the product. The high viscosity of AquaGel-K at 1.2% concentration led to difficulties in application of the mixed product on to the fuel bed using a spray bottle. Since this product was unable to be applied on to the fuel bed, no experimental burns were conducted using AquaGel-K at 1.2% concentration.

Firewall II at 3% concentration resulted in high flow time (603 ± 3 seconds) during the Marsh funnel test, suggesting high viscosity. The behavior of Firewall II at 3% during the application of the product on to the fuel bed has been discussed later in this report in Section 3.2.3.

FireIce 561 at 2.1% concentration also resulted in a highly viscous gel that did not flow through the Marsh funnel apparatus, resulting in an invalid flow time. The high viscosity of FireIce 561 at 2.1% concentration did not allow for application of the product using a spray bottle on to a fuel bed. Therefore, experimental burns involving FireIce 561 at 2.1% concentration were not conducted.

Thermo-Gel 200L at 3% concentration and FireIce 561 at 1.4% concentration were found to have flow times that were relatively higher than the other fire chemicals, but not as high as AquaGel-K at 1.2% concentration, Firewall II at 3% concentration, and FireIce 561 at 2.1% concentration. Comments about Thermo-Gel 200L at 3% and FireIce 561 at 1.4% concentration are presented in Section 3.3 of this report.

Table 2. Fire chemical product flow time through a Marsh funnel

Fire chemical product	Mixing ratio	Time (s)
Blazetamer 380	0.65%	23 ± 2
AquaGel-K	0.4%	24 ± 1
AquaGel-K	1.2%	N/A
Firewall II	0.25%	23 ± 1
Firewall II	1%	39 ± 3
Firewall II	2%	123 ± 16
Firewall II	3%	603 ± 3
WD 881C	0.1%	22 ± 1
WD 881C	0.3%	22 ± 1
WD 881C	1%	24 ± 1
Thermo-Gel 200L	0.5%	21 ± 1
Thermo-Gel 200L	1%	32 ± 3
Thermo-Gel 200L	1.5%	40 ± 11
Thermo-Gel 200L	3%	62 ± 1
FireIce 561	1.4%	140 ± 4
FireIce 561	2.1%	N/A

**N/A – time not available. Chemical was too viscous to complete Marsh funnel test*

Relative Performance of Fire Chemicals

This section of the report discusses the performance of the various fire chemicals that were evaluated based on the estimated heat release rates that were measured during the respective experimental burns. Average heat release rate data from the experimental burns of different fire chemical products at different concentrations is compared with data from experimental burns that used water-treated fuels, which served as a control measure in this study. The relative performance of a chemical indicates the percentage reduction in the average heat release rate of the treated fuel in comparison to that of water at the associated time. The greater the percentage reduction, the better a chemical is said to perform at suppression combustion under these specific test conditions.

Blazetamer 380 at 0.65% Concentration

Figure 2 shows a comparison between the average heat release rates of Blazetamer 380 at 0.65% concentration and water. The average heat released in the Blazetamer 380-treated fuels is lower than the water-treated fuels experiment. This suggests that Blazetamer 380 was more effective in this test at suppressing combustion of the vegetative fuels than water. Table 3 shows a quantitative comparison of the relative performance of Blazetamer 380 and water, where the relative performance column shows the reduction in average heat release rates produced by the fire chemical. It should be noted that Blazetamer 380 has only one approved mixing ratio in the QPL and therefore Figure 1 does not present a second data set showing the performance of the product at different mixing ratios.

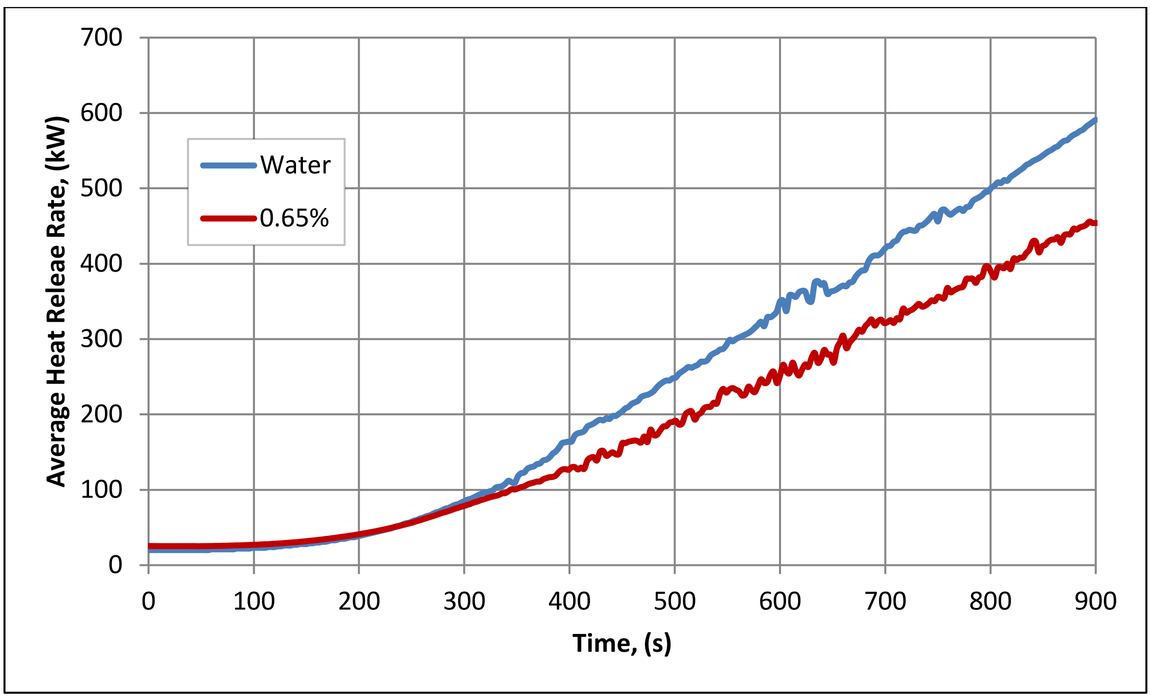

Figure 2. Comparison of average heat release rates between Blazetamer 380 at 0.65% concentration and water.

Table 3. Relative performance of Blazetamer 380 in comparison to water-treated fuel beds

Time (s)	Average heat release rate (kW)		Relative performance (%)
	Water	Blazetamer 380 at 0.65%	
300	85	79	7.05
450	204	162	20.58
600	350	251	28.28
750	456	356	21.92
900	591	454	23.18

AquaGel-K at 0.4% Concentration

AquaGel-K was approved by the U.S. Forest Service QPL document at two limiting concentrations: 0.4% and 1.2%. However, the product has been taken off the QPL document as of September 2017 since it is no longer commercially available. Since this study began in July 2017 and experiments involving AquaGel-K were conducted in August 2017, they have been included in this report.

Figure 3 presents a comparison between the average heat release rates produced from experimental burns involving AquaGel-K at 0.4% concentration and water-treated fuel beds. The graph indicates that under the specific test conditions, AquaGel-K at 0.4% concentration resulted in lower average heat release rates than water, suggesting that it was more effective at suppressing combustion. The quantitative comparison of the average heat release rates of AquaGel-K at 0.4% concentration and water has been presented in Table 4 where the relative performance column shows between 19 and 24% reduction in average heat release rates produced by the fire chemical in four out of the five times that were studied.

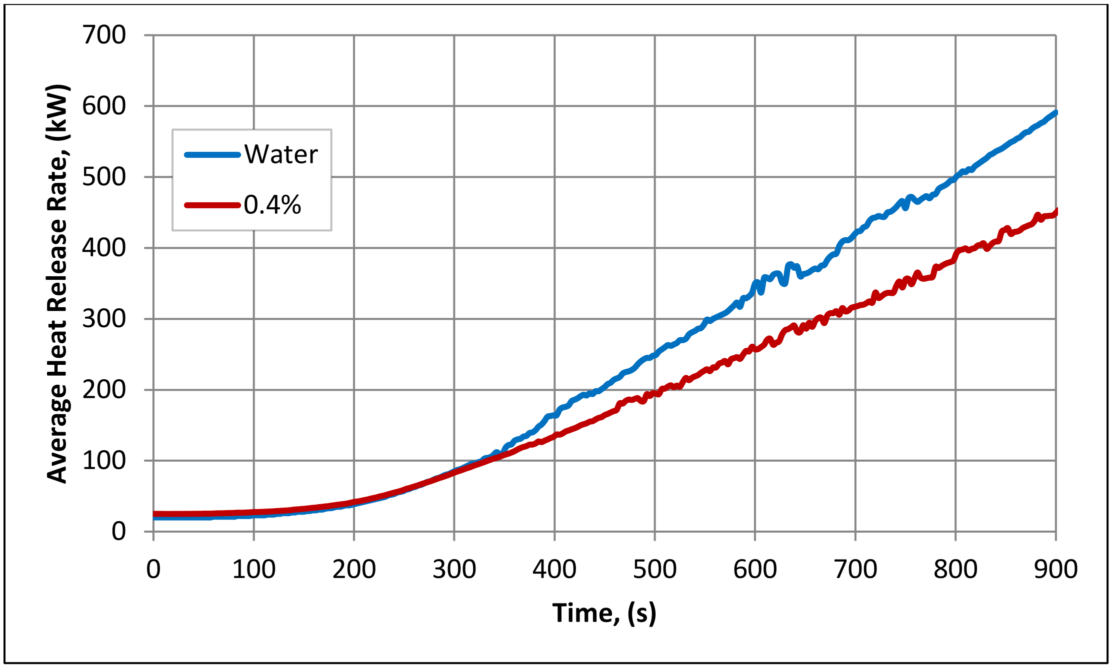

Figure 3. Comparison of average heat release rates between water and AquaGel-K at 0.4% concentration.

Table 4. Relative performance of AquaGel-K in comparison to water-treated fuel beds

Time (s)	Average heat release rate (kW)		Relative performance (%)
	Water	AquaGel-K at 0.4%	
300	85	83	2.35
450	204	164	19.60
600	350	257	26.57
750	456	356	21.92
900	591	449	24.02

Firewall II at 0.25%, 1%, 2%, and 3% Concentrations

Figure 4 shows the average heat release rates of experimental burns with fuel beds treated with Firewall II at concentrations of 0.25%, 1%, 2%, and 3% compared with fuel beds treated with water. The graph suggests that under the specific test conditions, there was no significant reduction in the average heat release rate of the fuel bed by using Firewall II at 0.25% concentration compared to water. This suggestion is affirmed quantitatively in Table 5 which shows that the relative performance of Firewall II at 0.25% concentration is 10.50% or less in four out of the five trials. Two of the trials at 0.25% generated a negative relative performance at 750 and 900 seconds which could imply that the properties of Firewall II mixed at 0.25% change after exposure to heat or that the concentration of the fire chemical being tested is too low. Similar observations were recorded at a mixed ratio of 2%. Heat release rate data suggests that Firewall II performed the best at a mix ratio of 3%.

As shown earlier in Table 2, Firewall II at 3% concentration resulted in a high flow time in the Marsh funnel test, indicating that the mixed product has a high viscosity. Therefore, more shear force was required in order to spray the mixed product onto the fuel bed. It was observed that the spray bottle used for the Thermal Canister experiments did not impart sufficient shear force onto the mixed product, resulting in the product ejecting out of the funnel as a singular stream. This resulted in a reduction of product coverage area on the fuel bed and consequently higher average heat release rates.

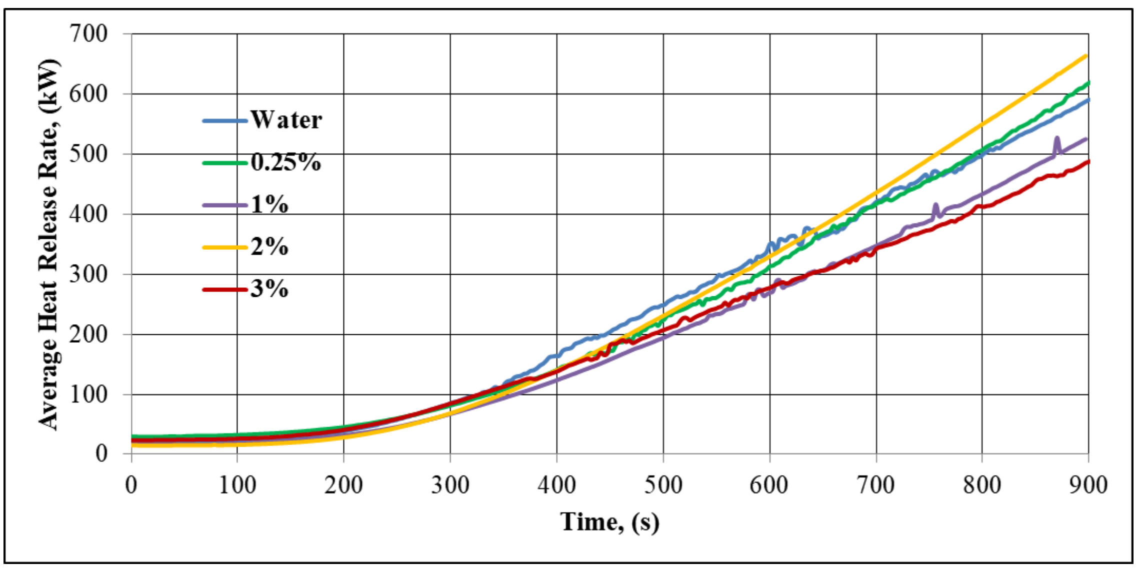

Figure 4. Comparison of average heat release rates between water and Firewall II at 0.25%, 1%, 2%, and 3% concentrations.

Table 5. Relative performance of Firewall II in comparison to water-treated fuel beds

Time (s)	Average heat release rate (kW)					Relative performance (%)			
	Water	Firewall II at 0.25%	Firewall II at 1%	Firewall II at 2%	Firewall II at 3%	Firewall II at 0.25%	Firewall II at 1%	Firewall II at 2%	Firewall II at 3%
300	85	81	67	68	85	4.70	20.80	19.53	0.00
450	204	172	158	183	182	15.68	22.48	10.35	10.78
600	350	313	269	330	277	10.57	23.03	5.78	20.85
750	456	457	389	493	374	-0.21	14.59	-8.03	17.98
900	591	619	528	668	488	-4.73	10.73	-12.95	17.42

WD 881C at 0.1%, 0.3%, and 1% Concentrations

Figure 5 presents the average heat release rates of experimental burns involving WD 881C foam at mixed ratios of 0.1%, 0.3%, and 1%. The graph suggests that there is no significant reduction in the average heat release rates produced by fuel beds treated with any of the three concentrations tested, in comparison to the average heat release rate produced by beds treated with water. This suggestion is supported quantitatively by data presented in Table 6 that shows the relative performance of the three different concentrations in comparison to that of water at five different times.

It is important to note that WD881C is a foam product, unlike the other fire chemical products tested in this study, which are all gel products. Refai (2017) had documented that due to the lack of a cooling mechanism in the Thermal Canister, a 24-hour time period was required between experimental burns to allow the system to cool down. This 24-hour time period allowed the gas fraction and the bubble size of the foam mixture to decrease, which could have potentially influenced the performance of the foam in mitigating combustion. This issue could have been avoided by preparing a new batch of foam for each experimental burn. However, the preparation of a new batch of foam product for each experimental burn involved the risk of small changes in concentrations in each new batch. These small changes in concentration can impact significantly on the performance of the foam product due to the recommended mix ratios for the foam product being as low as 0.1%.

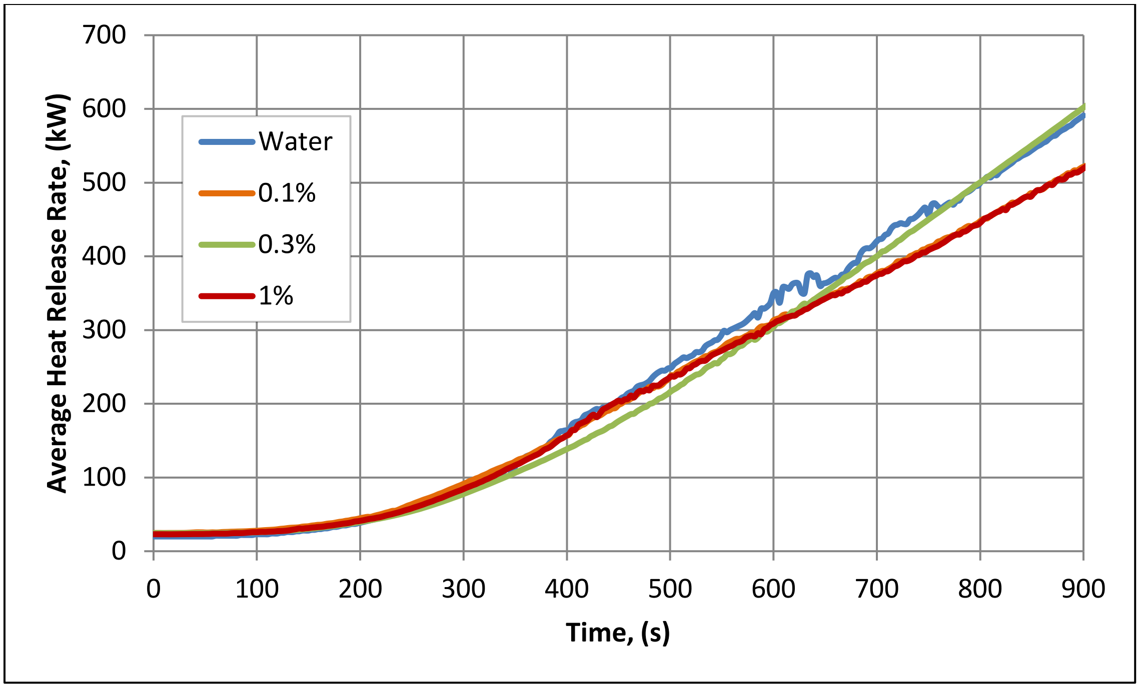

Figure 5. Comparison of average heat release rates between water and WD 881C at 0.1%, 0.3%, and 1% concentrations.

Table 6. Relative performance of WD 881C in comparison to water-treated fuel beds

Time (s)	Average heat release rate (kW)				Relative performance (%)		
	Water	WD 881C at 0.1%	WD 881C at 0.3%	WD 881C at 1%	WD 881C at 0.1%	WD 881C at 0.3%	WD 881C at 1%
300	85	91	78	84	-7.50	8.23	1.17
450	204	198	176	204	2.94	13.72	0.00
600	350	313	304	309	10.57	13.14	11.71
750	456	413	450	408	9.42	1.31	10.52
900	591	522	602	519	11.67	-1.86	12.18

Thermo-Gel 200L at 0.5%, 1%, 1.5%, and 3% Concentrations

Figure 6 presents a comparison between the average heat release rates during experimental burns involving Thermo-Gel 200L at mixed ratios of 0.5%, 1%, 1.5%, and 3% and water. The graph indicates that under the specific test conditions, Thermo-Gel 200L at all four concentrations produced lower average heat release rates compared to water. Thermo-Gel 200L at a mixed ratio of 3% out performed the lower concentrations and produced the lowest average heat release rate values. The relative performance column in Table 7 confirms the significant improvement in combustion suppression capabilities of Thermo-Gel 200L under these test conditions, with heat release rate percentage reductions between 35-40% for 0.5% concentration and 40-48% for the 3% concentration when compared to water.

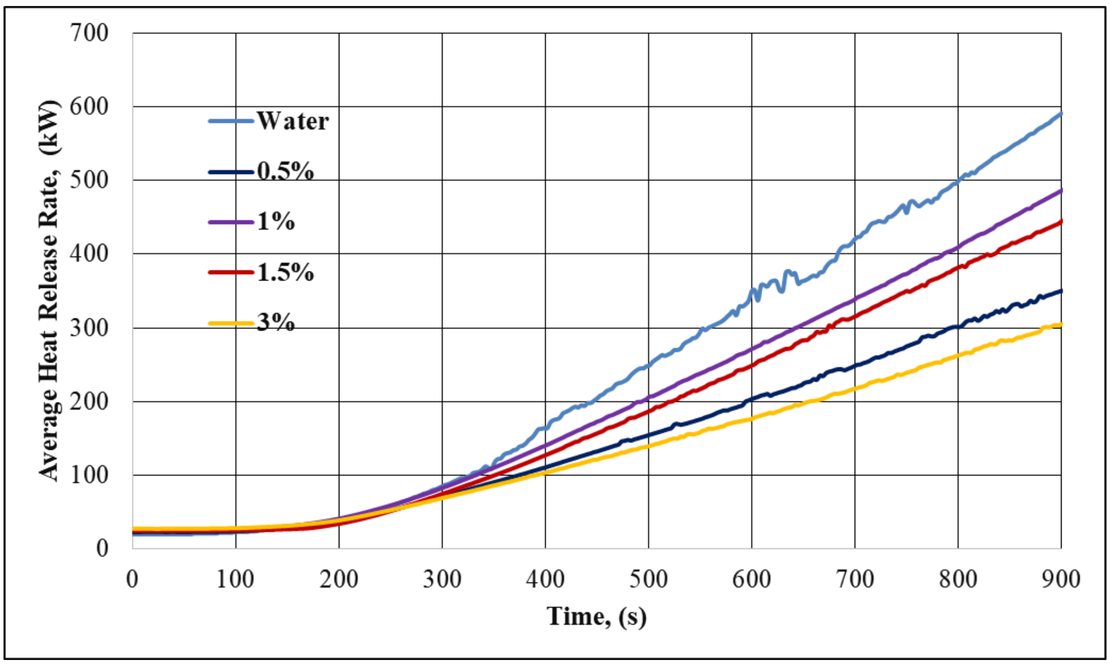

Figure 6. Comparison of average heat release rates between water and Thermo-Gel 200L at 0.5%, 1%, 1.5%, and 3% concentrations.

Table 7. Relative performance Thermo-Gel 200L in comparison to water-treated fuel beds

Time (s)	Average heat release rate (kW)					Relative performance (%)			
	Water	Thermo-Gel 200L at 0.5%	Thermo-Gel 200L at 1%	Thermo-Gel 200L at 1.5%	Thermo-Gel 200L at 3%	Thermo-Gel 200L at 0.5%	Thermo-Gel 200L at 1%	Thermo-Gel 200L at 1.5%	Thermo-Gel 200L at 3%
300	85	71	83	75	69	16.47	2.35	11.76	18.82
450	204	132	173	157	121	35.29	15.20	23.04	40.68
600	350	203	271	249	176	42.00	22.57	28.86	49.71
750	456	275	373	350	239	39.69	18.20	23.25	47.58
900	591	350	486	445	305	40.77	17.77	24.70	48.39

FireIce 561 at 1.4% Concentration

Figure 7 presents a comparison between the average heat release rate of experimental burns involving FireIce 561 at mixed ratio of 1.4% and water. The graph suggests that under the test conditions, a lower average heat release rate produced by FireIce 561 in comparison to that of water. The relative performance of FireIce 561 is quantitatively presented in Table 8 which shows that the fire chemical produced a 40-50% reduction in average heat release rate as compared to that produced by water in four out of the five trials.

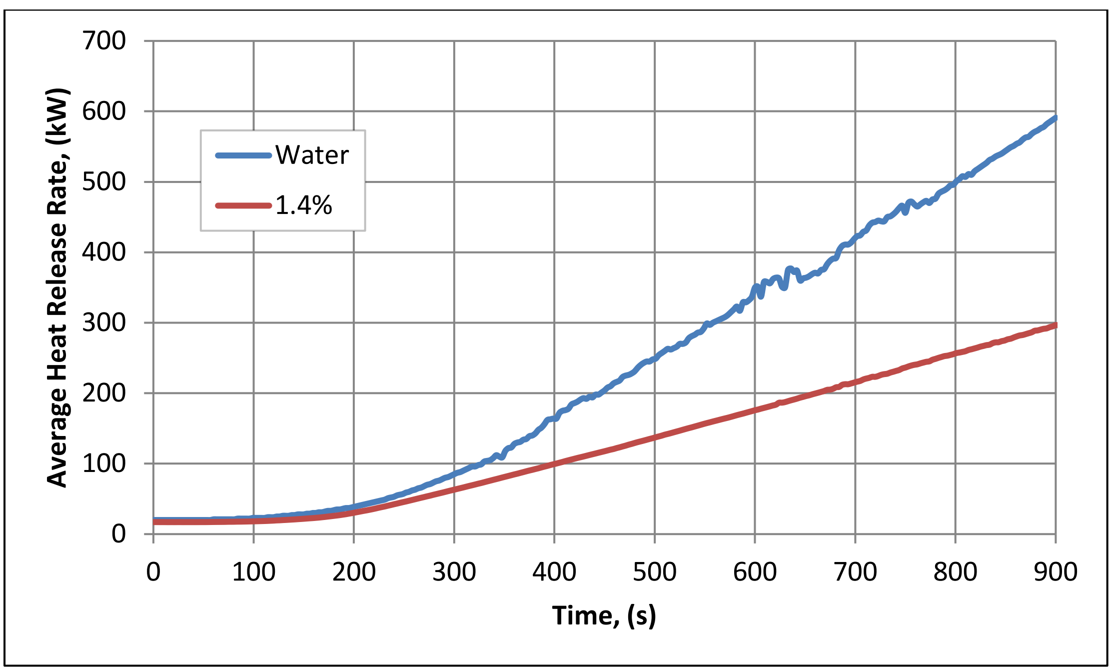

Figure 7. Comparison of average heat release rates between water and FireIce 561 at 1.4% concentration.

Table 8. Relative performance of Fire Ice 561 in comparison to water-treated fuel beds

Time (s)	Average heat release rate (kW)		Relative performance (%)
	Water	FireIce 561 at 1.4%	
300	85	63	25.88
450	204	118	42.15
600	350	176	49.71
750	456	236	48.24
900	591	297	49.74

Relative Comparison of Fire Suppression Chemicals

Table 9 shows the aggregate relative performance at five different times of all the fire chemicals evaluated in this study. AquaGel-K at 1.2% concentration and FireIce 561 at 2.1% concentrations have been intentionally included to show that experimental burns were not conducted due to the high viscosities and difficulty in the application of the mix products. Table 9 suggests that, under the specific test conditions, the fire chemicals that were found to be the most effective at suppressing combustion were Thermo-Gel 200L at 3% concentration and FireIce 561 at 1.4% concentration. These two fire chemicals are followed by Thermo-Gel 200L are 0.5% which was found to be marginally less effective at suppressing combustion than Thermo-Gel 200L at 3% and FireIce 561 at 1.4% concentration. The fire chemicals that were found to be the least effective at suppressing combustion were Firewall II at 0.25% and 2% concentration and WD 881C at 0.1%, 0.3%, and 1% concentrations.

The performance of the two most effective fire chemicals, Thermo-Gel 200L at 3% concentration and FireIce 561 at 1.4% concentration, also had relatively high flow times in the Marsh funnel test as shown in Table 2. This suggests that there may be an ideal viscosity range where the performances of fire chemicals are most effective at suppressing combustion. Viscosities below this range may lead to combustion capabilities that are less effective whereas viscosities that are above this range may lead issues related to the application of the fire chemical on to the fuel. The viscosity of a mixed fire chemical product can affect the coverage area as well as the seepage of a product into the fuel. In addition, viscosity also affects how well a fire chemical product can be applied to the fuel bed using a spray bottle. These factors can influence the performance of a fire chemical and therefore, further experiments may be required to confirm or rebut the hypothesis that an ideal viscosity range may exist for optimum performance of fire chemicals.

Table 9. Relative performance of fire chemicals in comparison to water-treated fuel beds

Fire chemical product	300 s (%)	450 s (%)	600 s (%)	750 s (%)	900 s (%)
Blazetamer 380 (0.65%)	7.05	20.58	28.28	21.92	23.18
AquaGel-K (0.4%)	2.25	19.60	26.57	21.92	24.02
AquaGel-K (1.2%)	-	-	-	-	-
Firewall II (0.25%)	4.70	15.68	10.57	-0.21	-4.73
Firewall II (1%)	20.80	22.48	23.03	14.59	10.73
Firewall II (2%)	19.53	10.35	5.78	-8.03	-12.95
Firewall II (3%)	0.00	10.78	20.85	17.98	17.42
WD 881C (0.1%)	-7.5	2.94	10.57	9.42	11.67
WD 881C (0.3%)	8.23	13.72	13.14	1.31	-1.86
WD 881C (1%)	1.17	0	11.71	10.52	12.18
Thermo-Gel 200L (0.5%)	16.47	35.29	42	39.69	40.77
Thermo-Gel 200L (1%)	2.35	15.20	22.57	18.20	17.77
Thermo-Gel 200L (1.5%)	11.75	23.04	28.86	23.25	24.70
Thermo-Gel 200L (3%)	18.82	40.68	49.71	47.58	48.39
FireIce 561 (1.4%)	25.88	42.15	49.71	48.24	49.74
FireIce 561 (2.1%)	-	-	-	-	-

It should be noted that viscosity is an easily measurable characteristic of a fire chemical – however, it provides only a partial understanding of the rheology of a fire chemical. The rheology of a fire chemical is far more complex and influences the chemical's behaviour in ways that have currently not been explored. To fully understand how different fire chemicals perform in different situations, an in-depth study assessing the rheology of fire chemicals may be necessary.

It is important to note that the results found in this study, specifically the less than favorable results of Firewall II and WD 881C, do not suggest that these are not effective products. For example, the performance of Firewall II could have resulted in lower heat release rates if the delivery system of the mixed product imparted sufficient force to enable dispersion of the product. This would result in better coverage of fuel, and potentially lower heat release rates. However, the Thermal Canister test methodology cannot be altered to suit the specific properties of different fire chemicals. It is therefore essential to have different test methods such as the Crib Test and the LIFT test to evaluate the performance of fire chemicals using different performance metrics. A collective analysis of the performance of fire chemicals from different tests as suggested in the Wildfire Chemical Roadmap would provide more useful information than relying exclusively on a single test method. In addition, assessing the influence of water quality on the performance of different fire chemicals may be beneficial since the hardness of water can affect the viscosity of fire chemicals.

HANDLING OF FIRE CHEMICALS

This section presents important observations that were made during the process of preparation and application of the fire chemicals that were evaluated in this study. The information presented here may be useful for practitioners and manufacturers to understand that performance of a fire chemical should not be the only factor considered while selecting a fire chemical for fire suppression operations. These notes are purely qualitative and based on the researcher's experience in handling these products.

- **Blazetamer 380:** The mixing of the chemical concentrate, application of the mixed product, and clean-up of utensils used to mix the product was relatively easy.
- **AquaGel-K:** The mixing of the concentrate, application of the mixed product, and clean-up of utensils used to mix the product was relatively easy at a concentration of 0.4%. The mixing of the product at a concentration of 1.2% was relatively difficult using the high-speed blender. It was observed that the blender did not impart enough shear force to the mixture to be able to uniformly mix the product and water. This was due to the high viscosity of the mixed product that was able to resist deformation in areas of the blender that was away from the rotating blades. The clean-up of the utensils used to mix the product at 1.2% was easy with water able to flush away the gel product.

- **Firewall II:** The mixing of the concentrate with water at both mixing ratios was relatively easy. However, clean-up of the utensils used to mix the product was relatively difficult. Transporting the product from the blender to the Marsh funnel, plastic containers, and/or the spray bottle was challenging at a mixed ratio of 3% as the mixed product had high adhesive properties and stuck to the walls of the container. This made the application of the product using the spray bottle relatively difficult. The adhesive properties of the more concentrated solution resulted in very little penetration into the fuel bed. These adhesive properties could also result in challenges during cleaning and maintenance of aircraft mixing systems and ground mixing systems.
- **WD 881C:** All three concentrations of the foam product mixed relatively easily and were easy to apply to the fuel bed. The amount of froth formed by the mixed product increased as the concentration of the product increased. Foam froth may benefit suppression operations since the air present in the froth can act as an insulating barrier which can help prevent fuel ignition. The clean-up of the utensils used to mix the foam product was found to be relatively easy.
- **Thermo-Gel 200L:** The product was easy to mix and apply at both mixed ratios. This resulted in good coverage of the fuel bed. It was observed that there was some fuel bed left over in the Thermal Canister at the end of all three experimental burns at 3% concentration. This suggests that the product was very effective at suppressing combustion. Clean-up of the utensils used to mix the product was relatively easy.
- **FireIce 561:** The product was viscous even at its lower concentration, compared to the other products. The product was however, able to mix well in the high-speed blender and was easy to pour in the Marsh funnel, plastic containers, and spray bottle. Application of the product was found to be relatively easy, with good coverage of the product onto the fuel bed when sprayed with a spray bottle. The product at its highest concentration was very viscous, which led to difficulties mixing the product with the high-speed blender. The high-speed blender was unable to impart sufficient shear force to produce a uniform mixture. The mixed product did not flow, which created difficulties during the transportation of the product from the blender to the plastic storage containers. This high viscosity can lead to challenges during cleaning, maintenance, and use and aircraft and ground mixing systems. The clean-up of the product at both concentrations was relatively easy.

CONCLUSION

The objective of this study was to utilize the Thermal Canister to evaluate the relative performance of commercially available wildland fire chemicals. The fire chemicals selected for this study were Blazetamer 380, AquaGel-K, Firewall II, WD 881C, Thermo-Gel 200L, and FireIce 561. The selected fire chemicals were evaluated at their highest and lowest mixing ratios that were approved and listed on the US Forest Service's Qualified Product List (QPL).

Each fire chemical at pre-determined mixing ratios was evaluated, in triplicate, using the Thermal Canister to obtain sufficient data for statistical consistency. The raw data from the experimental burns was used as input for a heat conduction model developed to estimate the heat release rate for each product in comparison to water, which served as the experiments control.

Thermo-Gel 200L at 3% and FireIce 561 1.4% concentrations were the most effective at suppressing combustion in the red-stemmed feather moss fuel bed under the test conditions. Thermo-Gel at 0.5% concentration was found to be only slightly less effective at suppressing combustion compared to the two aforementioned products at those specific concentrations. The fire chemicals that were least effective at suppressing combustion under the test conditions were Firewall II at 0.25% and 2% concentration and WD 881C at 0.1%, 0.3%, and 1% concentrations. AquaGel-K at 1.2% concentration and FireIce 561 at 2.1% concentration were found to be too viscous to be sprayed on to the fuel bed and were therefore removed from the study. Alternate delivery mechanisms for fire chemicals with very high viscosities should be explored in the future to determine the effects to aerial and ground-based applications.

Data from this Thermal Canister study is only one data set in the effort to understand the performance of wildfire chemicals. Results from this report will serve as input to the Wildfire Chemical Roadmap, where information from multiple test methods will be aggregated and analyzed to obtain comprehensive performance data on wildfire chemicals.

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FPInnovations

info@fpinnovations.ca
www.fpinnovations.ca

OUR OFFICES

Pointe-Claire
570 Saint-Jean Blvd.
Pointe-Claire, QC
Canada H9R 3J9
(514) 630-4100

Vancouver
2665 East Mall
Vancouver, BC
Canada V6T 1Z4
(604) 224-3221

Québec
1055 rue du P.E.P.S.
Québec, QC
Canada G1V 4C7
(418) 659-2647