info@fpinnovations.ca
www.fpinnovations.ca

Performance Assessment of Wildfire Suppressant Products Using the Crib Test Methodology

PROJECT NUMBER: 301014177

Razim Refai, E.I.T.
Stephen Paskaluk, P.Eng.

January 2021

FPInnovations' Wildfire Operations Advisory group has asked its researchers to explore a method by which the performance of water-enhancing products can be repeatedly assessed in the laboratory. A new test method, known as the *crib test,* was designed to evaluate the effectiveness of water-enhancing products on burning woody fuel to simulate direct-attack aerial operations.

This report outlines the methodology for the crib test and describes the findings from performance evaluation tests conducted at the Protective Clothing and Equipment Research Facility (PCERF) at the University of Alberta.

Project number: 301014177

Technical Report TR 2021 N2

ACKNOWLEDGEMENTS

This project was financially supported by Alberta Agriculture and Forestry. The authors would like to thank Mark Ackerman and Rex Hsieh for their guidance in this project.

APPROVER CONTACT INFORMATION
Michael Benson
Manager, Wildfire Operations
michael.benson@fpinnovations.ca

REVIEWERS
Greg McBride
Physical Scientist, U.S. Forest Service

Greg Adams
Air Attack Officer, B.C. Wildfire Service

Jeff Barry
Director of Business Development, Conair Group Inc.

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

Table of contents

List of figures

List of tables

1 Introduction

Among the various wildfire suppression efforts that agencies undertake every summer to battle wildland fires, aerial operations are arguably the most effective. Their effectiveness comes at a massive economic toll given the logistics, equipment, and suppressant product costs. Any operational efficiencies found related to their use will therefore result in large savings for agencies.

In the interest of improving the efficiency of aerial operations, an avenue that has drawn attention is the use of wildfire suppression chemicals. For years, aerial suppression operations have preferred water, foam, and long-term retardant as their products of choice. These products have their respective intended uses: water and foam are suppressants used for direct attack operations, while long-term retardant is preferred for indirect attack operations. An alternative suppressant to water and foam are water-enhancing products, often referred to as gels. These water-enhancing products, which are more expensive than water and foam, are marketed as being more effective at suppressing fires. However, the performance of water-enhancing products is challenging to quantify during aerial operations. The lack of reproducibility as well as the numerous variables at play during aerial wildfire operations make it difficult to maintain enough scientific rigour to definitively assess the performance of water-enhancing products. Thus, a laboratory route to assess the performance of these chemicals was deemed a logical step.

FPInnovations' Wildfire Operations Advisory Group has asked its researchers to explore a method by which the performance of various water-enhancing products could be repeatedly assessed in the laboratory and compared to water and foam. There are currently two laboratory tests that assess foam and water-enhancing products: the US Forest Service's LIFT test (USDA 2007) and FPInnovations' thermal canister test (Refai et al. 2020). Both tests provide valuable insight into the various physical characteristics of these products, as well as performance data. However, as with any test method, there are pros and cons. For the two aforementioned tests, the cons primarily revolve around the absence of application of the product on actively burning fuel. Therefore, a new test method, known as the *crib test* was designed whereby the suppressant (water, foam, water-enhancer) is applied to burning woody fuel to simulate direct-attack aerial operations.

This report outlines the methodology for the crib test, as well as the findings from performance evaluation tests of various commercially available wildfire suppressants conducted at the Protective Clothing and Equipment Research Facility (PCERF) at the University of Alberta.

2 Crib Test Methodology

The purpose of the crib test is to drop a pre-determined amount of suppressant onto a burning wooden crib. The resulting reduction in fire intensity will be used to evaluate the performance of the products relative to each other. This section presents the details of the crib test methodology.

2.1 Components of the test assembly

The following are the main components of the crib test experiment:

1. **Crib and crib holder:** The crib consists of wooden slats cut from SPF lumber (0.75” x 1.5” x 16”) placed in a multi-layered (*n* = 6) grid structure with equal spacing (Figure 1). To ensure consistent spacing between the slats, a custom steel crib holder was fabricated (Figure 1 and 2). This setup allowed researchers to vary the fire intensity by changing the number of layers in the crib. Preliminary tests were conducted to determine the appropriate number of layers in a crib (six). A total of 30 slats were used for the crib base and an additional 6 slats (1.5” x 0.75” x 14.5”) were used to make a crib top, which consisted of parallel slats placed with 0.25” spacing. The reduced spacing on the crib top was to prevent the burning crib from being completely extinguished during the application of the suppressant and to allow researchers to analyze the fire as it built back up. The wooden slats provided consistent flame heights and intensities, offering a good level of reproducibility throughout this study. The slats were air dried at room temperature for a minimum of six months; wood moisture content readings from a protimeter ranged from 5 to 7%.

Figure 1. A preliminary burn of a test crib with six slat layers. The crib top is absent in this image.

Figure 2. Crib holder without the wooden slats (center) and a torch applying propane.

2. **Ignition source:** Propane was routed from a pressurized cylinder through a torch at a fixed flow rate. A sparking mechanism on the torch ignited the propane. To ignite the crib, the torch was run continuously for 30 seconds to impart sufficient energy (Figure 2). The torch was turned off for the remainder of the test.

3. **Drop tank:** To ensure consistent drops onto the crib, a small open-topped holding tank was fabricated and placed on top of scaffolding on a track system above the crib holder (Figure 3). The tank bottom was designed to open completely (Figure 4) and was manually controlled by pulling a metal cord attached to a latch. After a product t was mixed at the appropriate mix ratio, a pre-determined volume of the mixed product was loaded in the tank before ignition of the crib. This drop tank setup allowed for consistent drops with no changes to the spatial location of the drop, relative to the crib, between tests.

Figure 3. Tank on tracks and exhaust fan in the ceiling.

Figure 4. Tank with the bottom open to allow suppressants to drop on a burning crib.

4. **Catchment tray:** A catchment tray was placed below the crib to collect and contain residual suppressant that did not remain on the crib (Figure 5).

Figure 5. Catchment tray located beneath the crib holder.

5. **Exhaust fan:** The burn room at PCERF has built-in a fixed flow rate exhaust fan (6635 CFM). This exhaust fan was located directly above the crib holder. The fan was run continuously during the tests. Air flow routing under the floor and into the corners of the room did not result in any sustained flame tilt during the tests.

2.2 Preparation of suppressants

Five water-enhancing products were evaluated in this study:

- BlazeTamer 380
- Firewall II
- WD881C (Foam)
- Thermo-Gel 200L
- FireIce 561

The products in their concentrate states were obtained and stored at PCERF. The products were mixed on the day of the coverage level tests and crib tests. The concentration of the mixed products (i.e., the mix ratio) was in accordance with the US Forest Service's Qualified Product List (QPL) that approves concentration based on corrosion, toxicity, and other environmental considerations (USDA 2020). The mix ratios tested in this study are presented in Table 1.

Table 1. Suppressant products tested and their associated mix ratios.

Suppressant Product	Low Mix Ratio	High Mix Ratio	Additional Mix Ratios
BlazeTamer 380	0.65%	N/A	-
Firewall II	0.25%	3%	1%, 2%
WD 881C (foam)	0.1%	1%	0.3%
Thermo-Gel 200L	0.5%	3%	1%, 1.5%
FireIce 561	1.4%	2.1%	-

Each product was prepared in a 20L bucket using a paint mixer and a power drill. The water used for mixing the products was City of Edmonton tap water (E.L. Smith Zone) with total dissolved solids ranging from 150 to 170 ppm. The products were mixed for a minimum of 60 seconds to ensure a homogenous mixture.

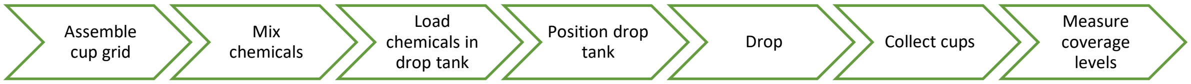
3 Coverage Level Tests

Before testing the performance of the products, coverage level tests were conducted to ensure that a burning crib would receive the same quantity of product when dropped (i.e., the volume of product delivered remained constant). Coverage level measurements also helped determine if the lateral distribution of product (drop pattern) onto the crib was consistent.

Coverage level 1 is defined as 1 US gallon/100 ft^2. Coverage level was measured using the cup-and-grid method (USDA 2000). A total of nine cups were used in a 3 x 3 grid, as shown in Figure 6.

Figure 6. Cup-and-grid method to measure coverage levels.

The following flowchart outlines the sequence of events for coverage level tests:



Coverage level 5 (5 US gallons/100 ft^2) was the target coverage for all products. Five coverage level tests (*n* = 5) were conducted for each product to ensure that consistent values were being obtained. Figure 7 shows a sequence of photos taken during a drop to measure coverage level.

Figure 7. Photo sequence (clockwise starting top left) of a drop to measure coverage level.

Since each product has its own physical (e.g. cohesion, adhesion, surface tension) and rheological (viscosity) characteristics that influence the drop pattern, different quantities of each product were required to achieve the same coverage level. The differences in working volume can be attributed primarily to product landing outside the crib area.

4 Performance Evaluation Tests

Once the working volumes for coverage level 5 were obtained from the coverage level tests, the performance evaluation tests were conducted. Performance evaluation tests involved dropping a product of a known working volume onto a burning crib to assess its effectiveness at fire suppression. Each product at a defined mix ratio was evaluated five times (*n* = 5) to improve the accuracy of estimates. The following sequence of steps was followed to execute a performance evaluation test:

Table 2 presents the duration and purpose of the four key phases in the performance evaluation test. These phases form the main components of when the performance data is recorded. Detailed information about the data capture and analysis process is outlined in the *Data Analysis* section of this report.

Table 2. Key phases in the performance evaluation tests.

Phase	Duration (s)	Purpose
Crib ignition using torch	30	Ignite fuel
Flame stabilization	60	Develop constant fire intensity
Water-enhancer drop	N/A	Suppression
Unaided flame re-growth	120	Observe effect of suppression

These phases have been pictorially presented in chronological sequence below:

Figure 8. Crib ignition using torch.

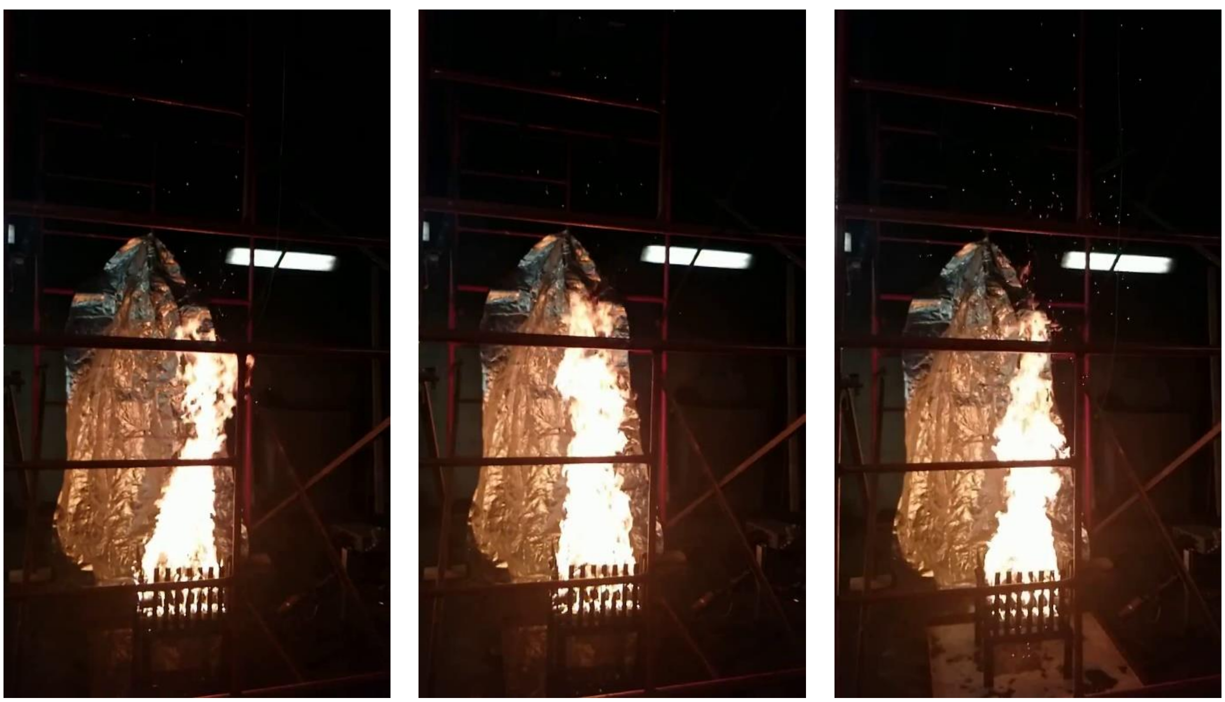


Figure 9. Flame stabilization.

Figure 10. Flame immediately prior to suppression.

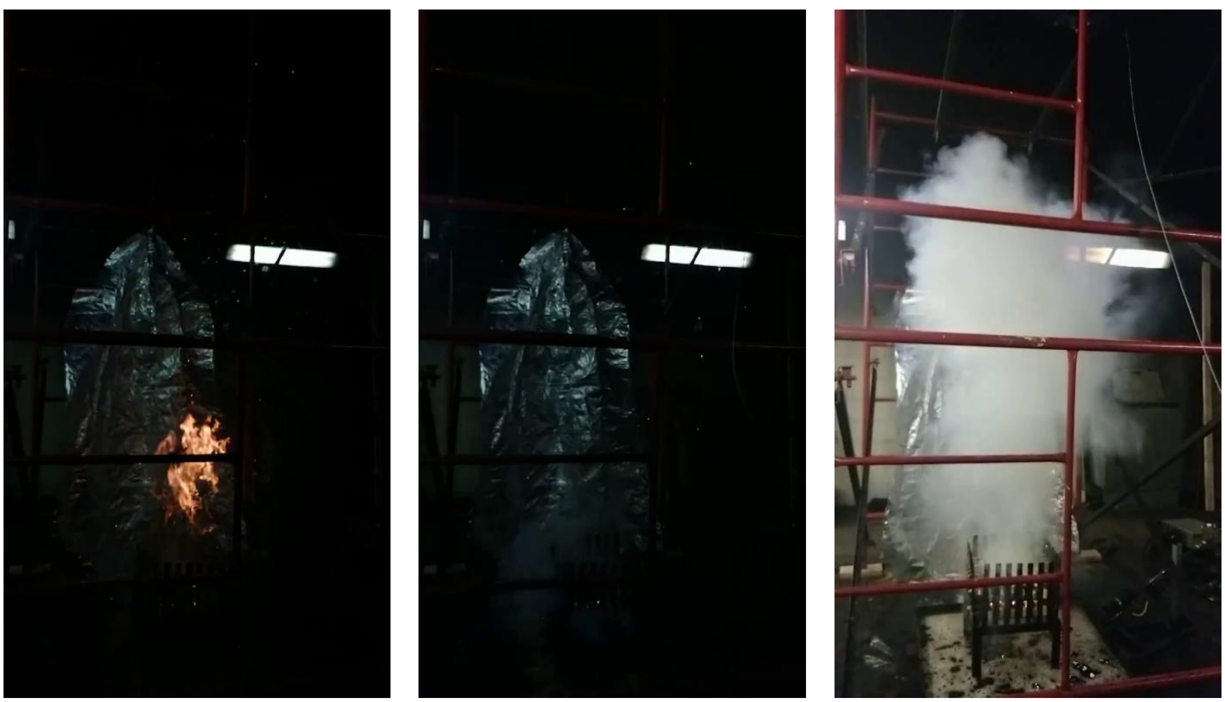


Figure 11. Resulting flame immediately after suppression.

Figure 12. Unaided flame re-growth.

5 Data Analysis

5.1 Data capture

To closely observe flame suppression and flame re-growth, all controlled burns and their respective suppression efforts were captured on video. Videos were taken on a Nikon D3200, with a AF-S DX 18-70 mm 3.5-4.5 G IF-ED lens set to 24 mm focal length and infinity focus. The focal length on the sensor provided a sensor-to-real-world scale of 1.36 mm height/width per pixel, or 1.85 x 10^{-6} m^2 of area for each pixel in the resulting images. The camera was set to manual mode with shutter speed at 1/100 s, aperture at f/8, and gain at ISO 200. Videos were shot at 1080p 30 FPS. The camera was placed 106 inches from the centre of the crib.

5.2 Data processing

To quantitatively assess the effectiveness of the products, image processing was used to calculate the flame area during suppression and re-growth. The images were extracted from the video footage of the controlled burns and processed using a combination of Microsoft PowerShell, FFmpeg, and ImageMagick. The time period selected for data processing was 150 seconds. The components of this 150-second time period are listed in Table 3.

Table 3. Breakdown of the time period following ignition selected for data processing.

Time	Component
0–30 seconds	Stable flame from burning crib prior to drop. This time period provided a baseline flame area for each burn, facilitating the estimation of normalized flame area decrease during suppression and relative flame area increase during flame re-build.
30-second mark	Occurrence of the drop (i.e., suppression).
30–150 seconds	Post suppression time period followed by flame re-growth time.

Images from this 150-second time period were extracted from the corresponding video at 30 images per second, matching the video frame rate. Each group of 30 images was then processed in the sequence presented in Table 4 and pictorially illustrated in Figures 13–16:

Table 4. Image processing sequence.

#	Task	Purpose
1	Greyscale conversion based on red channel	Remove colour information from images and retain brightness; minimize effects of any primarily blue or green light sources.
2	Mean average greyscale images	Provide image of stable portion of flame, removing changes in size and shape due to short pulses and flickers.
3	Convert greyscale mean image to black and white at 25% threshold	Obtain black and white image with distinct flame area outline.
4	Pixel count	Count number of white and black pixels in the image; white indicating area where flame is present and black indicating absence of flame.

Figure 13. Image processing phases - raw image.

Figure 14. Image processing phases - greyscale conversion based on red channel.

Figure 15. Image processing phases - mean average greyscale images.

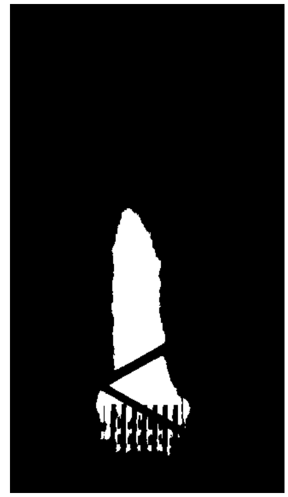


Figure 16. Image processing phases - convert greyscale mean image to black and white at 25% threshold.

The end-product from video processing yielded the flame cross-sectional area for each second of the test based on the pixel count in each processed image. To account for small differences in camera positioning and setting lens focal length, the flame area in each test was normalized against the average flame size for the 10-second period immediately before suppression. The normalized flame area was used as the primary metric to determine the effectiveness of the products. Mapping how the flame area changed with time allowed for a relative performance comparison of the different products.

The flame area information can be evaluated in two ways: (1) stand-alone flame area as a function of time, or (2) integrated flame area during re-growth. The stand-alone flame area method allows for a better understanding of the flame suppression process and highlights distinctions between the performance of different products at specific moments in time. The integrated flame area method provides one value that summarizes the relative performance of different products. Both these methods were found to be useful in different instances—the former offered granularity in data, while the latter offered an aggregated comparison.

6 Results & Discussion

6.1 Coverage level tests

Table 5 presents the results of the coverage level tests for the various suppressants. The crib test assembly proved capable of providing a setup wherein a reproducible coverage level could be achieved for most products.

6.1.1 Accuracy of drops

Achieving a greater level of accuracy between the drops of the same product was found to be challenging due to:

i. **Volume of fluid used:** Coverage level 5 was a relatively small volume of product to drop. Any minor changes to the volume added to the drop tank affected the resulting coverage level drastically. However, for practical applications of this test method, the authors found the level of accuracy achieved to be acceptable.

ii. **Fluid in free fall:** When products were dropped from the tank, it was challenging to obtain similar lateral spread between products, given the role viscosity plays in fluid drop dynamics.

Table 5. Results from the coverage level tests for different water-enhancing products at various mix ratios.

Product	Mix Ratio	Volume Dropped (L)	Average Coverage Level Achieved	Relative Standard Deviation
Water	-	2.0	4.7	7.4%
BlazeTamer 380	0.65%	1.9	5.1	22.9%
Firewall II	0.25%	2.1	5.0	13.5%
Firewall II	1%	1.5	5.1	18.2%
Firewall II	2%	Too viscous; unable to hit target crib with sufficient accuracy or even distribution.		
Firewall II	3%	Too viscous; unable to hit target crib with sufficient accuracy or even distribution.		
WD881C	0.1%	1.6	5.0	8.1%
WD881C	0.3%	1.6	5.1	15.1%
WD881C	1%	1.6	5.3	13.3%
Thermo-Gel 200L	0.5%	2.1	4.8	13.9%
Thermo-Gel 200L	1%	Too viscous; unable to hit target crib with sufficient accuracy or even distribution.		
Thermo-Gel 200L	1.5%	Too viscous; unable to hit target crib with sufficient accuracy or even distribution.		
Thermo-Gel 200L	3%	Too viscous; unable to hit target crib with sufficient accuracy or even distribution.		
FireIce 561	1.4%	Too viscous; unable to hit target crib with sufficient accuracy or even distribution.		
FireIce 561	2.1%	Too viscous; unable to hit target crib with sufficient accuracy or even distribution.		

6.1.2 Use of different drop volumes in tests

Table 5 shows that different drop volumes were needed to achieve the target coverage level of 5 U.S. gallons/100 sq. feet. As mentioned in the *Coverage Level Tests* section, this was due to the different physical and rheological characteristics of the products. In general, water-enhancing products function by increasing the viscosity of water, which often leads to increased adhesion to surfaces. In the case of these drop tests, a portion of the product stuck longer to the tank door when it was opened, causing the product to swing beyond the crib area. Therefore, larger volumes of some products were used to ensure that the crib area received the same target coverage level. For the foam product (WD881C), which works by reducing surface tension, there was minimal adhesion to the tank door. This resulted in a more vertical and targeted drop, and hence, a smaller volume was required.

6.1.3 Challenges in dropping certain products

Table 5 also shows that certain water-enhancing products could not be dropped using the tank apparatus developed for these tests. These products were found to be too viscous to be dropped from the tank to the extent that they resisted flow and did not form a cohesive drop on the target area. Figure 17 shows this resistance to flow; the product remained static and did not spread across the horizontal surface of the drop tank door. In some cases, the product either stuck to the tank door for extended periods of time and/or dropped a very small fraction of the volume onto the target area. This behaviour, where the product was too viscous to effectively drop, is presented in Figures 18 and 19.

Figures 20 to 24 highlight how highly viscous products drop differently compared to water and WD881C (foam). Physical limitations of the burn lab, as well as the lack of adequate spatial distribution and coverage across the target area, resulted in the inability to test these highly viscous products.

In an operational environment, it can be hypothesized that dropping a highly viscous product that resists flow could result in a drop that is highly concentrated in a very small area. In addition, adhesion to the tank of an aircraft could result in a drop with unpredictable and/or limited accuracy and could potentially limit the useful payload of the aircraft.

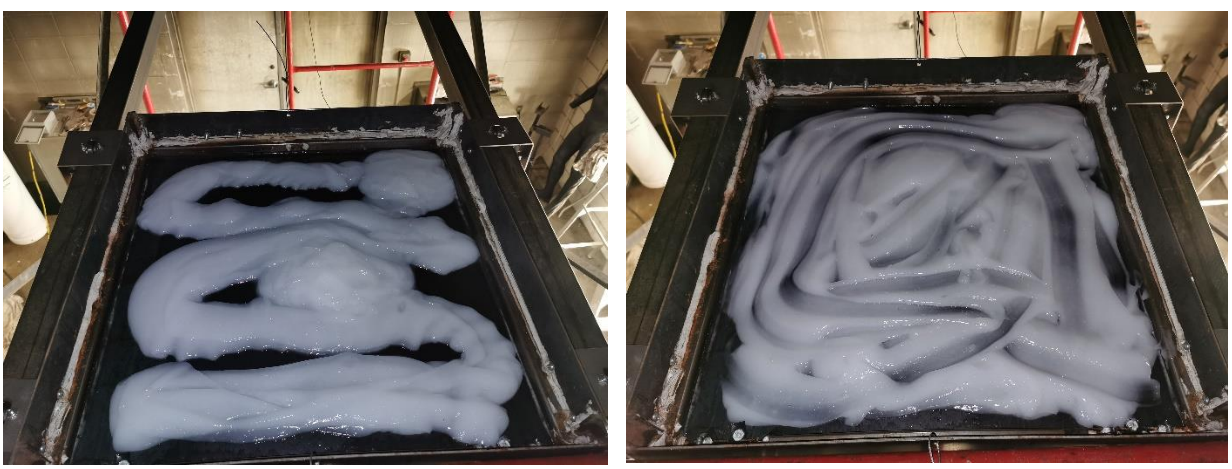


Figure 17. Thermo-Gel 200L at 2% resisting spread in the drop tank.

Figure 18. Thermo-Gel at 2% stuck to the drop tank door.

Figure 19. Firewall II at 2% stuck to the drop tank door.

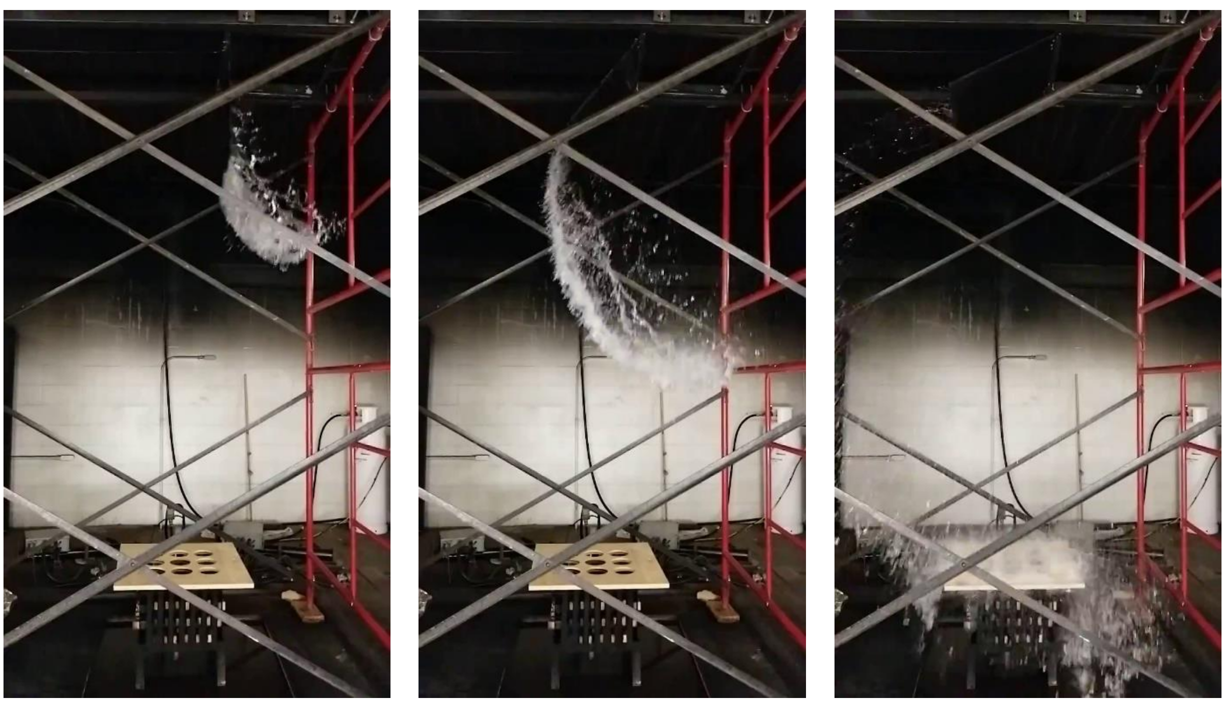


Figure 20. Drop dynamics of water (left to right).

Figure 21. Drop dynamics of WD881C at 0.3% (left to right).

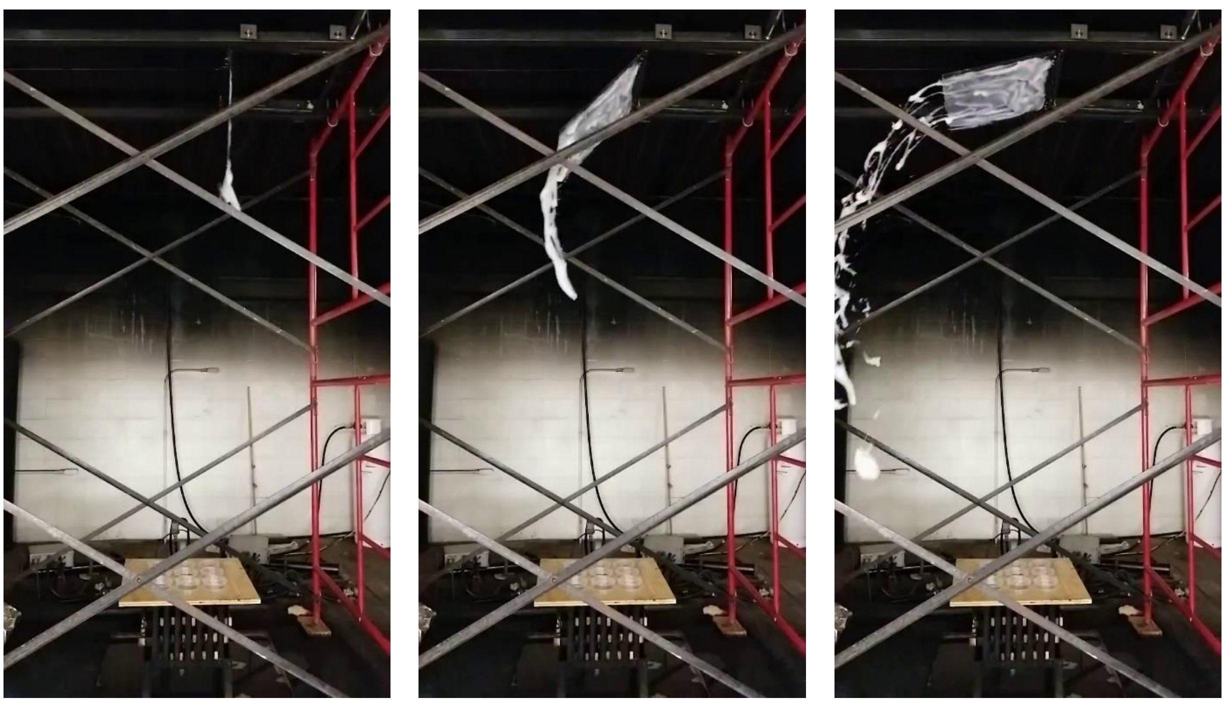


Figure 22. Drop dynamics of Thermo-Gel 200L at 2% (left to right).

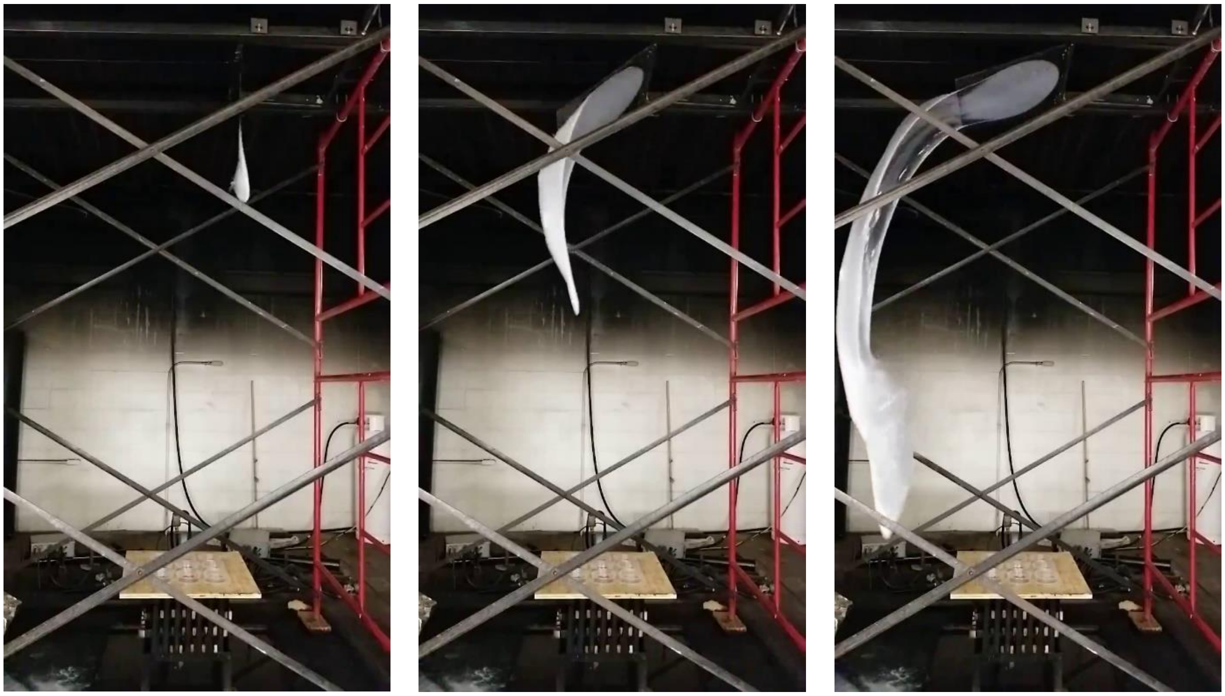


Figure 23. Drop dynamics of Firewall at 3% (left to right).

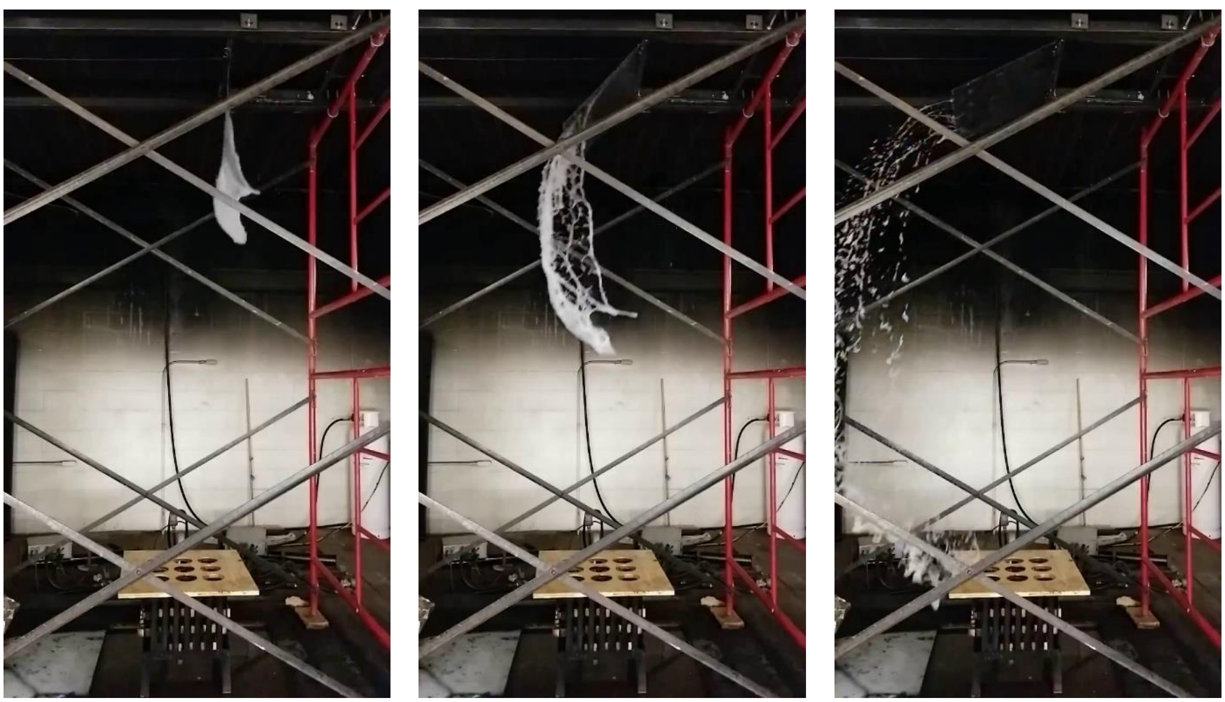


Figure 24. Drop dynamics of FireIce 561 at 1.4% (left to right).

6.2 Relative performance of suppressants to water

The following section reviews and discusses the performance results of the products tested using the crib test methodology. Each product's performance and the variances between repetitions have been provided in the appendix of this report. The seven suppressants that were too thick to successfully drop onto the crib have been excluded from the following discussion.

Figure 25 provides a guide for interpreting the results from the three key phases of the test. The X-axis represents the progress of the burn in terms of time (seconds), while the Y-axis represents the normalized flame area. In general, the smaller the normalized flame area, the better a suppressant performed; and the slower the rate of increase in normalized flame area, the better a suppressant performed.

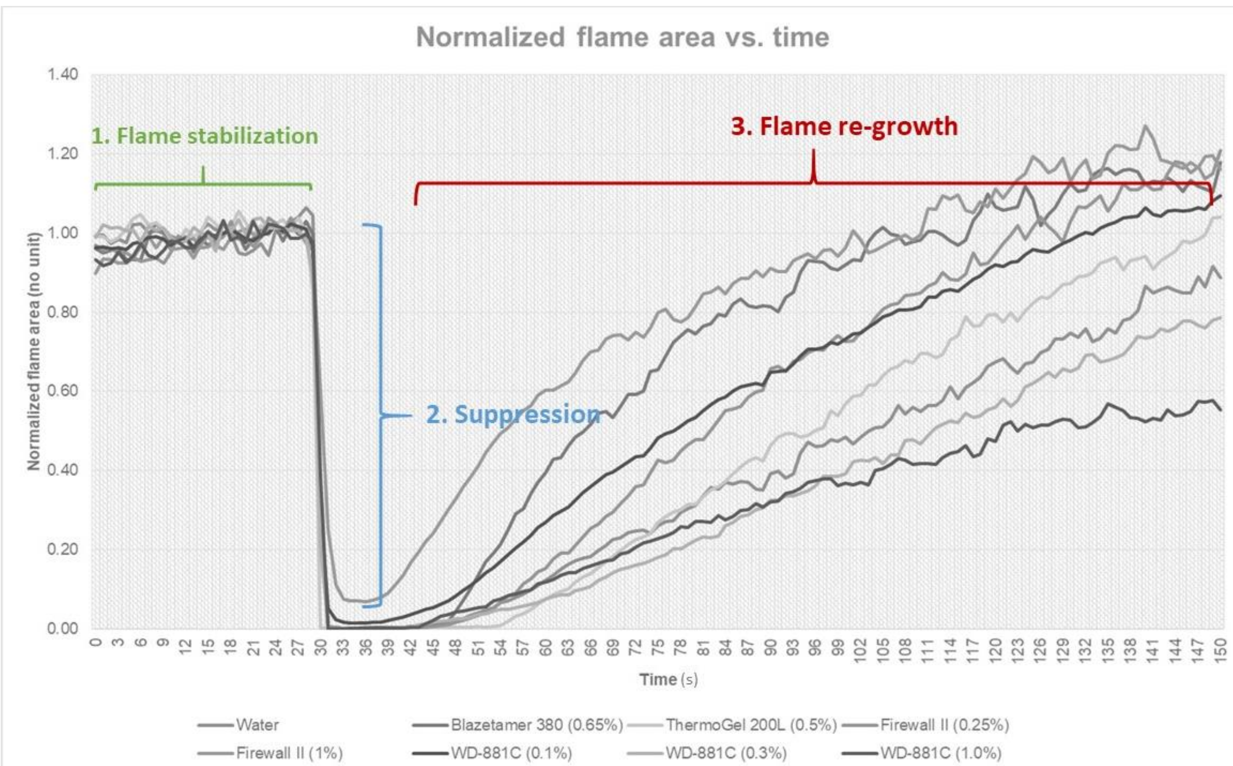


Figure 25. Guide to interpreting the phases of the crib test and understanding the results.

Figure 26 presents the results from the performance tests. Each line in Figure 26 represents the average performance of a product across five repetitions.

To facilitate the discussion of relative performance, water was used as a reference. It was found that only WD881C at mix ratios of 0.3% and 1.0%, had a lower normalized flame area than water on average, suggesting better performance. These two products were also found to exhibit the smallest flame area during the 30–60 second time period (i.e., the period immediately after suppression). The performance of WD881C at 0.3% and 1.0% compared to water can be attributed to its ability to penetrate the fuel better—WD881C's surfactant properties allowed it to better wet the fuel. The vertical nature of the crib structure offered some resistance to penetration; such resistance would also be characteristic of a forest canopy. Penetration of a suppressant to the lower slats in the crib structure would be easier if the surface tension of a suppressant were lowered. Based on these results, it is reasonable to assume that the surfactant qualities of WD881C at 0.3% and 1.0% facilitated its better performance. WD881C at 0.1% was found to perform worse than 0.3% and 1.0%. It is noteworthy that WD881C at 0.1% and 1% were the only products to fully extinguish the crib (each once), further suggesting that WD881C has better performance characteristics in the crib test.

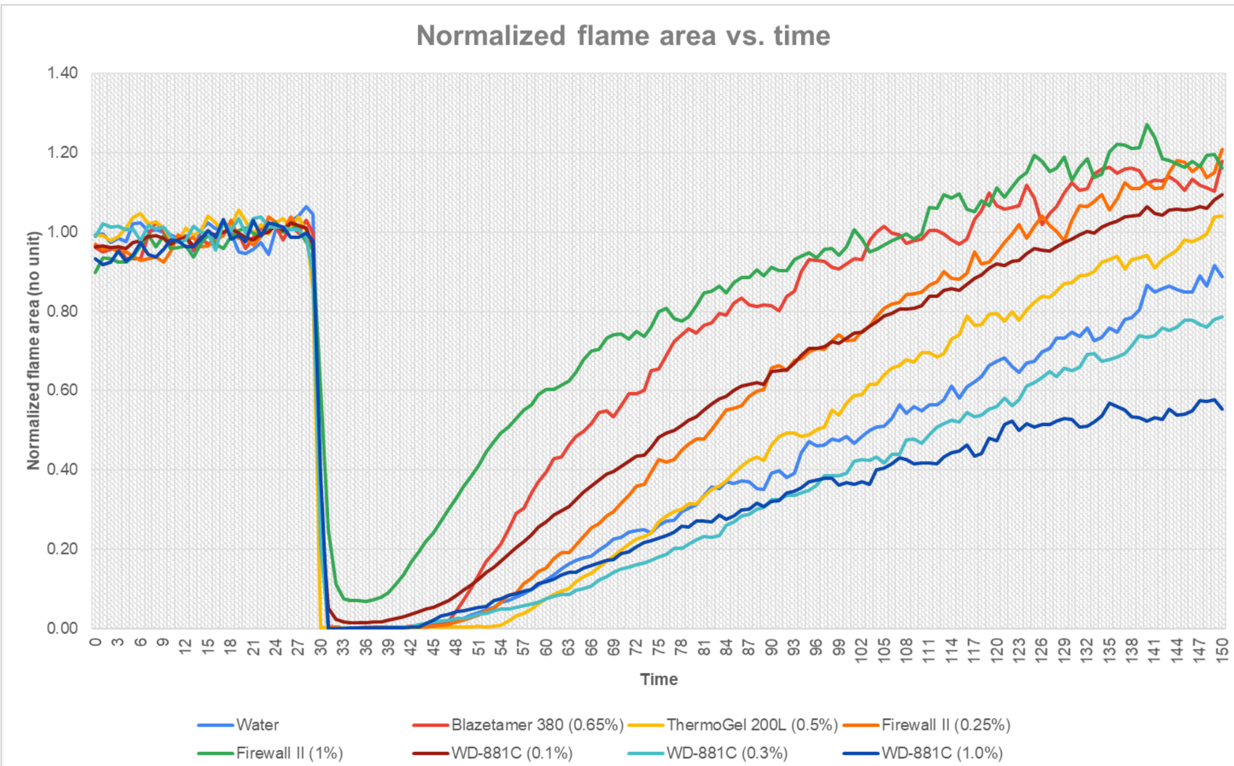


Figure 26. Performance of suppressant products assessed in the crib test.

The water-enhancing product that was closest to water in terms of performance was Thermo-Gel 200L at 0.5%. Thermo-Gel 200L at 0.5% was found to have a slow rate of initial flame re-growth; however, once past the initial flame re-growth phase, the normalized flame area eventually grew greater than that of water at comparative moments in time. Firewall II at 0.25% was also found to have a slow initial flame re-growth phase, with its eventual performance comparable to that of WD881C at 0.1%. The two products that had the highest rates of initial flame re-growth, and eventual highest normalized flame areas were BlazeTamer 380 at 0.65% and Firewall II at 1%. Firewall II at 1% also had the largest normalized flame area immediately after suppression.

An alternate, simplified way to understand how the products performed after suppression in the flame re-growth stage is using integrated flame re-growth (presented in Figure 27). The integrated flame re-growth data focuses exclusively on the flame re-growth period and highlights how quickly the flames grow after suppression. The lower the end value on the curve, the better a product performed. The integrated flame re-growth data provides one aggregated number for each product to simplify comparison. The final integrated flame re-growth numbers for each product is presented in Table 6.

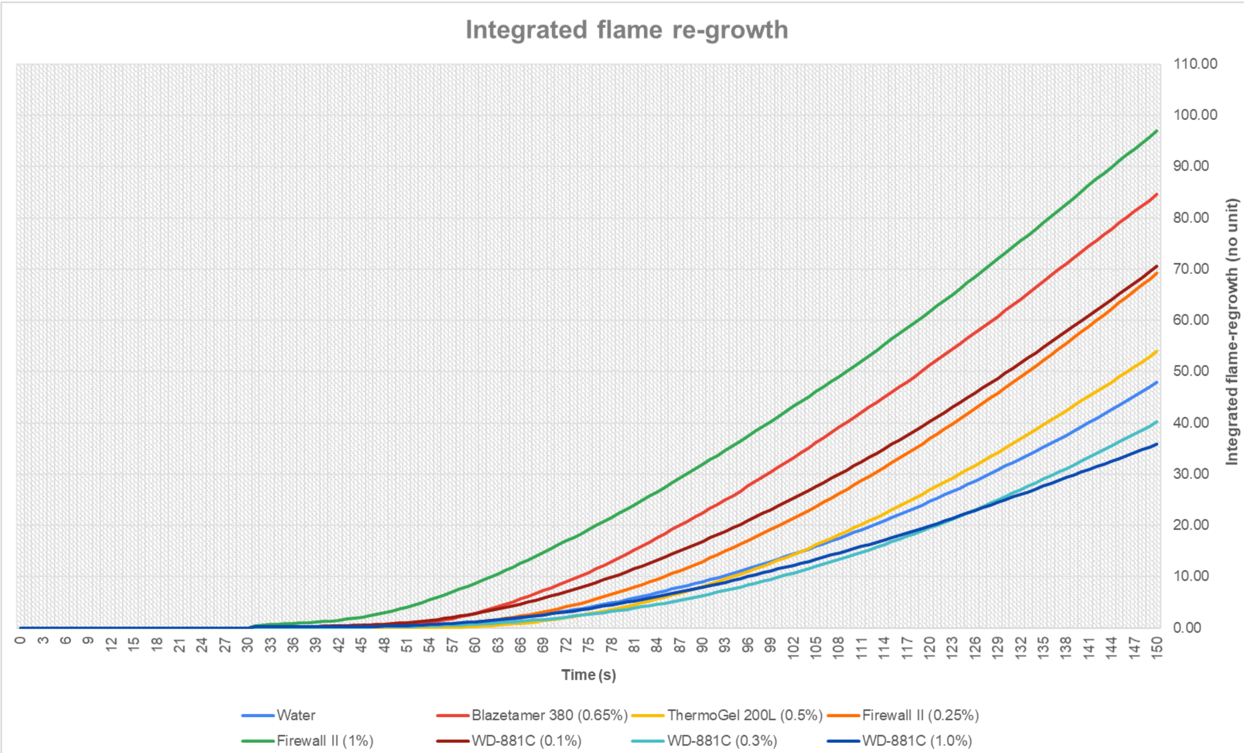


Figure 27. Averaged and normalized flame area during the flame re-growth stage integrated over time.

Table 6. Averaged and normalized integrated flame area at 150 seconds (end of burn).

Suppressant	Averaged and Normalized Integrated Re-growth Flame Area (no unit since normalized)
Water	47.9
BlazeTamer 380 (0.65%)	84.6
Thermo-Gel 200L (0.5%)	54.0
Firewall II (0.25%)	69.2
Firewall II (1%)	97.0
WD881C (0.1%)	70.5
WD881C (0.3%)	40.2
WD881C (1.0%)	35.9

While the performance of WD881C highlighted that having surfactant properties can lead to improved wettability, decreasing surface tension of a product can lead to increased atomization. The crib test, by virtue of being executed at a laboratory scale, cannot capture certain performance influencing variables such as atomization, drift, and recovery rate at scales observed during aerial suppression operations. Despite WD881C at 1.0% showing promising results in the crib test, operationally, it may be more suitable to use a lower mix ratio to reduce drift losses to the environment when dropped. A decrease in surface tension also implies that the product will spread laterally more during a drop. This can lead to a less concentrated drop and may explain the larger variability observed in repetitions with WD881C.

What the crib test did highlight was that there is currently minimal evidence to suggest that water-enhancing products are more effective than water, specifically in their ability to suppress fire in a crib test. Water-enhancing products modify the properties of water (i.e., viscosity). So, a mixed product, despite its increased viscosity, is still fundamentally water and, therefore, offers the same capacity of energy reduction that water offers when applied to fire. The effectiveness of that capacity to reduce energy release may be dictated by other drop variables such as recovery rate, minimal drift, etc. However, those variables and their associated impacts are yet to be studied and proven.

Furthermore, high viscosity water-enhancing products were found to consistently collect on the top surface of the crib, as suggested by the reduced variability between repetitions. While this behaviour produced repeatable results, it also appeared to reduce penetration to the lower levels of the crib structure. The continued burning of the lower levels of the crib was sufficient to cause substantial flame regrowth, despite the large quantity of product on the crib top. This suggests that high viscosity water-enhancing products could get caught higher up in the forest canopy and fail to penetrate the stand within an adequate time frame. Given that water enhancers will be primarily used for direct attack operations, if it were suggested that canopy penetration takes longer, it is certainly worth questioning their immediate effectiveness when mixed at high viscosities. Low viscosity water enhancing products would likely function better at canopy penetration than their high viscosity counterparts. Parallel studies are currently underway to better understand the relationships between water quality, viscosity, and mix ratios.

7 Conclusion

The objective of this study was to develop an improved test method to assess the performance of commercially available wildfire suppression products. This improved test method, called the *crib test*, was expected to more closely resemble direct attack operations on an ignited woody fuel structure. The suppressant products assessed in this study were water, WD881C, BlazeTamer 380, Firewall II, FireIce 561, and Thermo-Gel 200L. Each product was assessed at mix ratios approved by the US Forest Service's Qualified Product List (QPL).

The crib test methodology was found to be capable of producing consistent flame heights and coverage levels; repeatability is necessary to test a variety of suppressant products. The methodology allowed researchers to evaluate the performance of different products based on the data gathered during suppression and the flame re-growth phase.

Only two products, WD881C at 0.3% and 1%, were found to be more effective than water (baseline) at suppressing the ignited crib. Both products had slower flame re-growth rates and smaller normalized flame areas for the time period of interest. All water-enhancing products assessed in this study were found to perform as effective or slightly less effective than water at supressing the ignited crib. The test results highlighted wettability and fuel penetration as important characteristics for a suppressant. Seven high viscosity products could not be tested in this lab-scale setup due to their inability to flow effectively from the drop tank to the target area, and/or their inability to penetrate fuels effectively. It is possible that similar challenges could be observed if high viscosity water-enhancing products were used for aircraft operations.

The crib test methodology also showcased that water-enhancing products, despite having a higher viscosity than water, are still fundamentally water and therefore exhibit a similar ability to suppress fire. The advantages of water-enhancing products may come in other forms, such as a more concentrated drop, less wind drift, improved recovery rates, and better fuel adhesion. However, those parameters were outside the scope of this study.

From this study, it can be concluded that based purely on the ability to suppress fire within the confines of the crib test methodology, water-enhancing products did not offer a noticeable advantage.

8 References

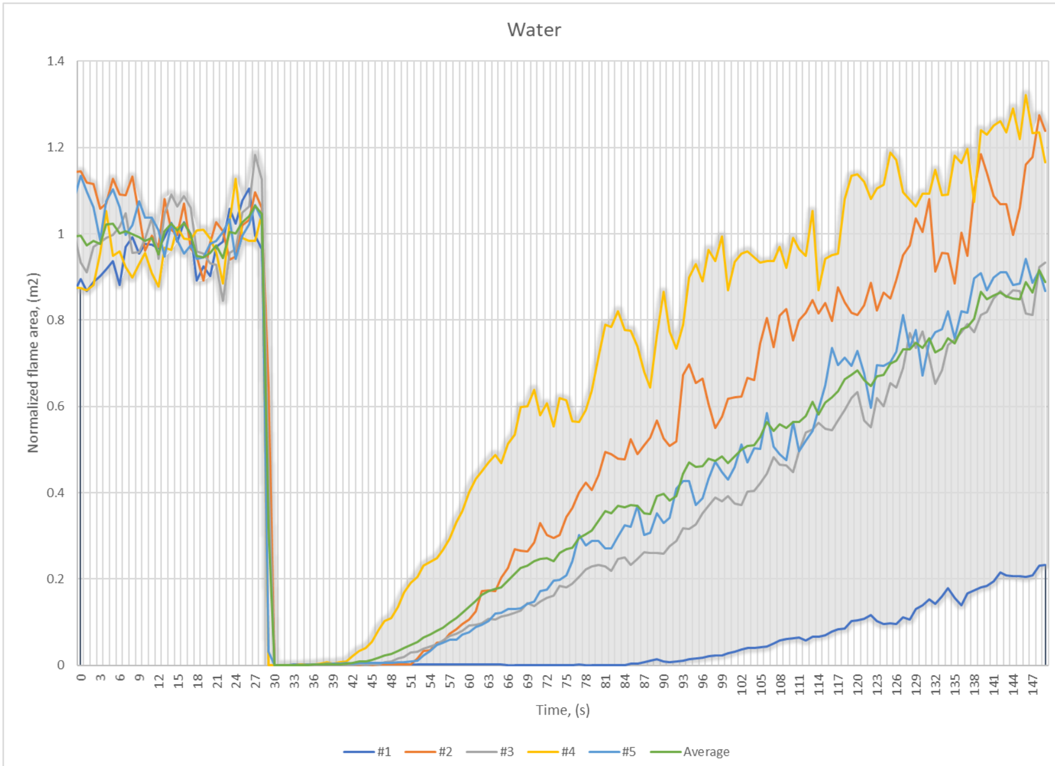
Refai, R., Villa Coronel, E.A., McDonald, A. (2020). Performance evaluation of commercially available wildland fire chemicals using a custom-built thermal canister. FPInnovations Technical Report No. 11 (2020).

USDA Forest Service Fire & Aviation Management (2020). Water Enhancers for Wildland Fire Management. Technical document March 5, 2020. Retrieved from https://www.fs.fed.us/rm/fire/wfcs/documents/2020-0305_qpl_WE..pdf

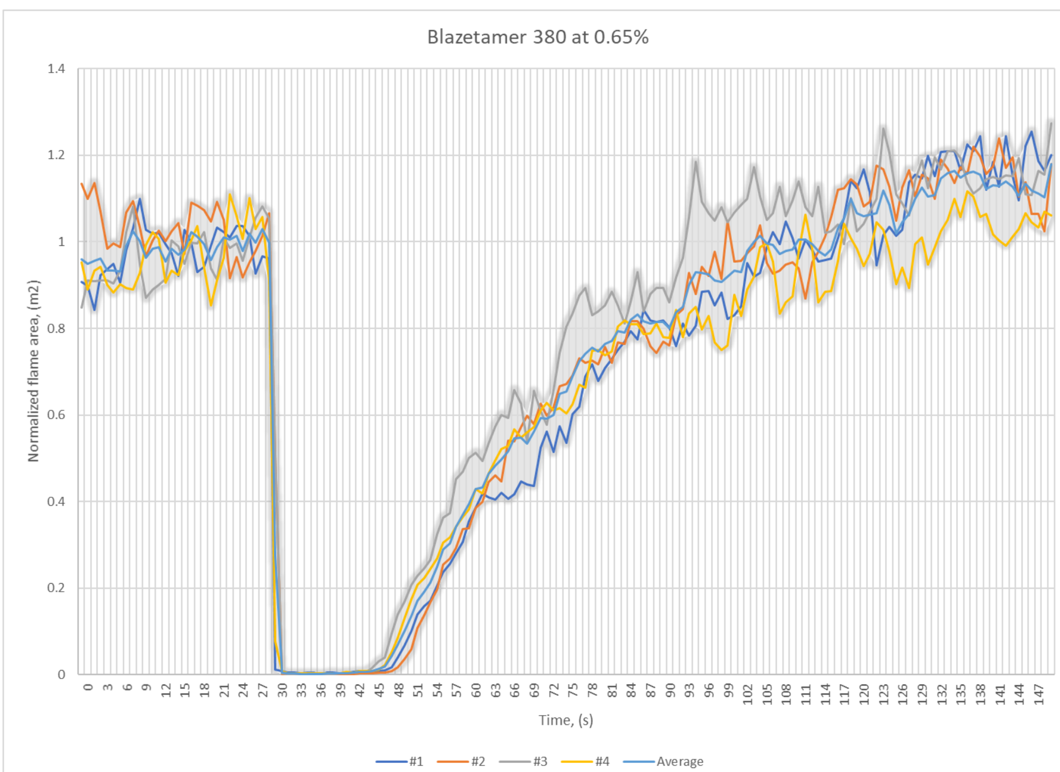
USDA Forest Service Wildland Fire Chemical Systems. (2007, May 30). Evaluation of Wildland Fire Chemicals Standard Test Procedures STP 2.2 – Lateral Ignition and Flame Spread (LIFT). Retrieved from https://www.fs.fed.us/rm/fire/wfcs/tests/stp02_2.htm

USDA Forest Service Technology & Development Center. (2000). Drop Testing Airtankers: A Discussion of the Cup-and-Grid Method. Technical Report TE92P32

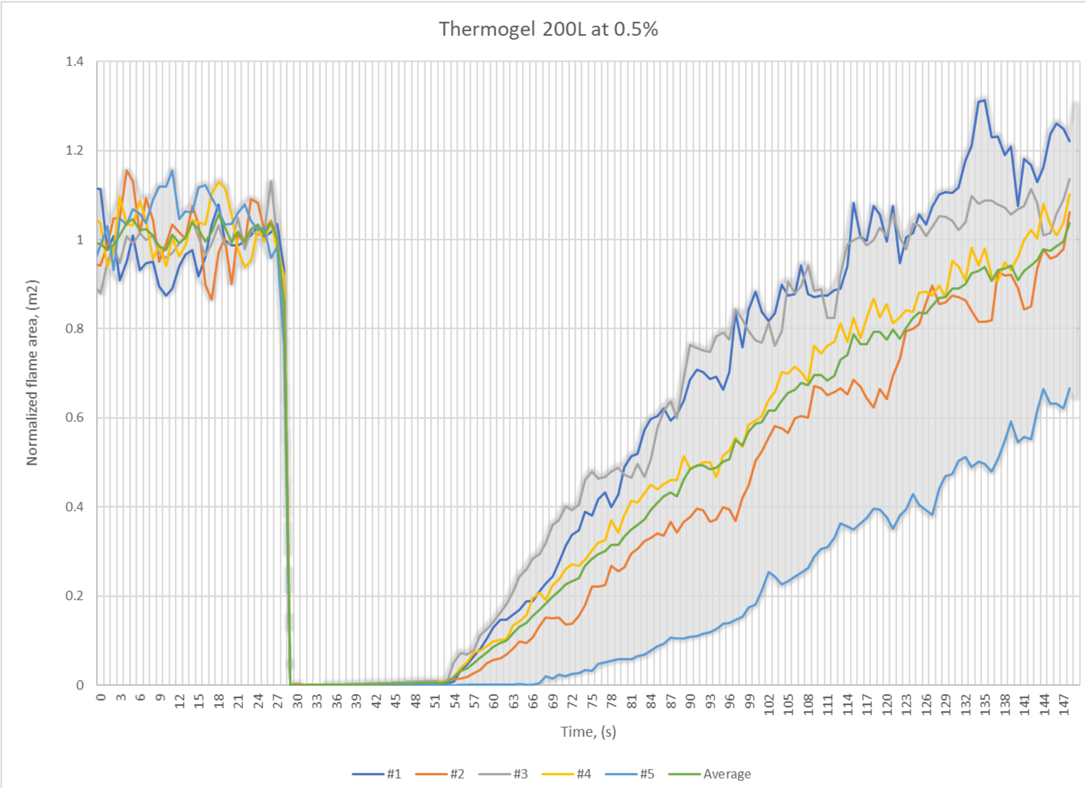
9 Appendix

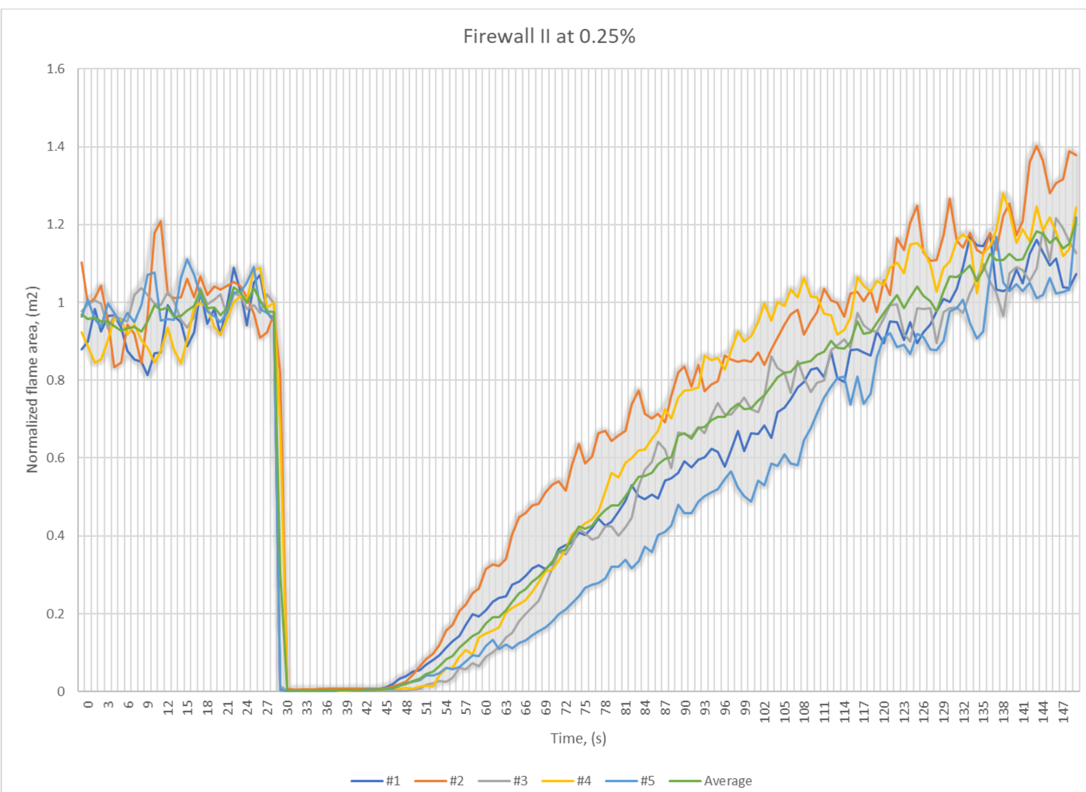


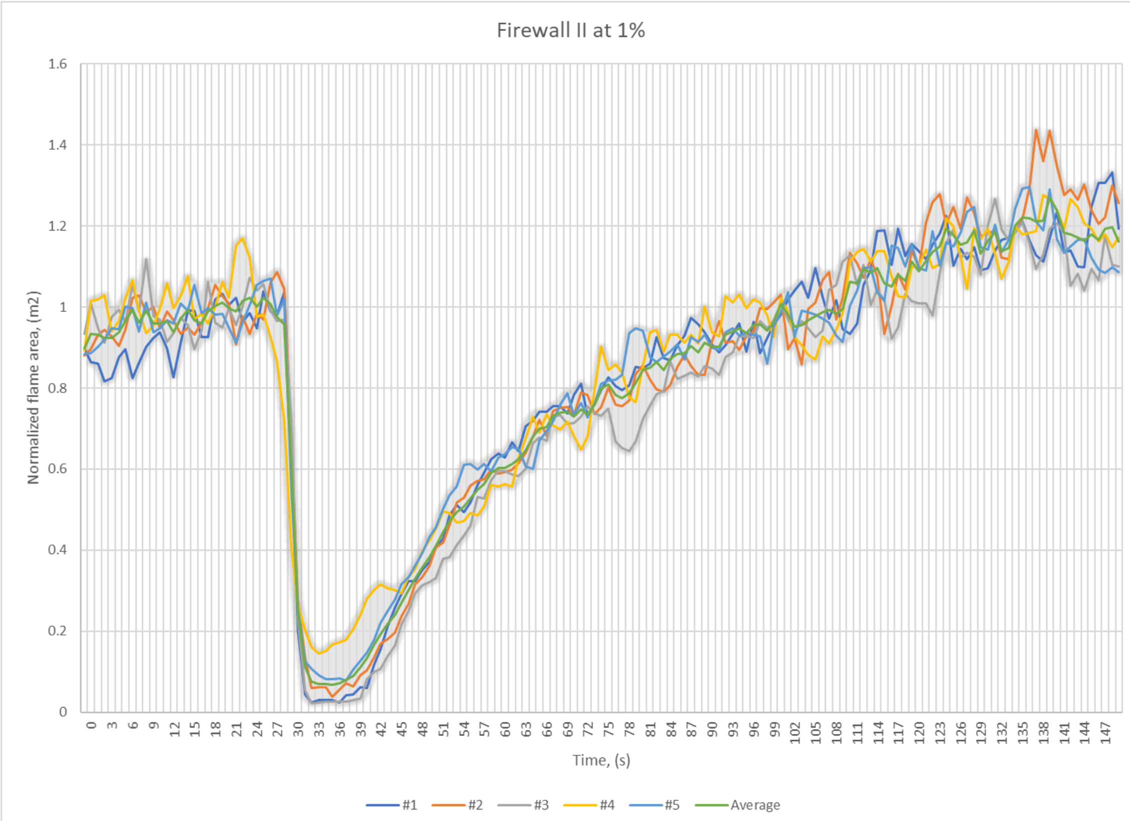
Water
1.4
1.2
1
0.8
0.6
0.4
0.2
0
Normalized flame area, (m2)
0 3 6 9 12 15 18 21 24 27 30 33 36 39 42 45 48 51 54 57 60 63 66 69 72 75 78 81 84 87 90 93 96 99 102 105 108 111 114 117 120 123 126 129 132 135 138 141 144 147
Time, (s)
#1 #2 #3 #4 #5 Average

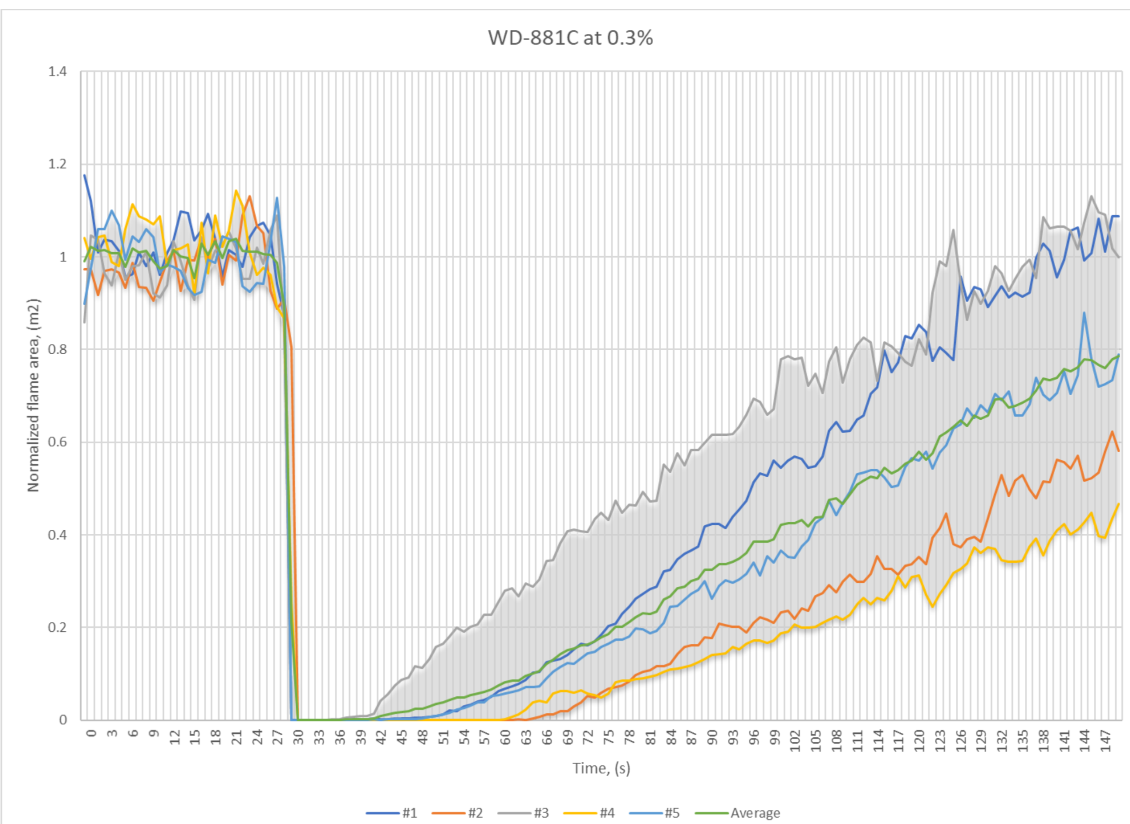


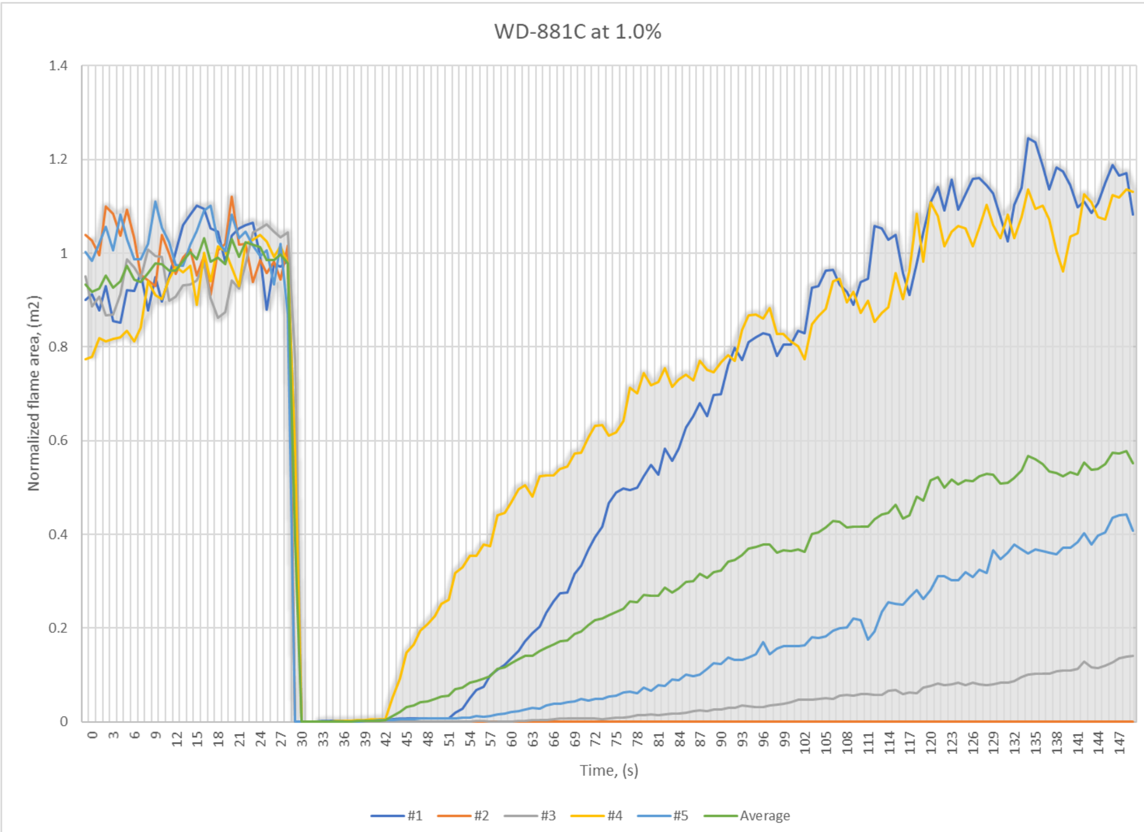
Blazetamer 380 at 0.65%
1.4
1.2
1
0.8
0.6
0.4
0.2
0
Normalized flame area, (m2)
0 3 6 9 12 15 18 21 24 27 30 33 36 39 42 45 48 51 54 57 60 63 66 69 72 75 78 81 84 87 90 93 96 99 102 105 108 111 114 117 120 123 126 129 132 135 138 141 144 147
Time, (s)
#1 #2 #3 #4 Average

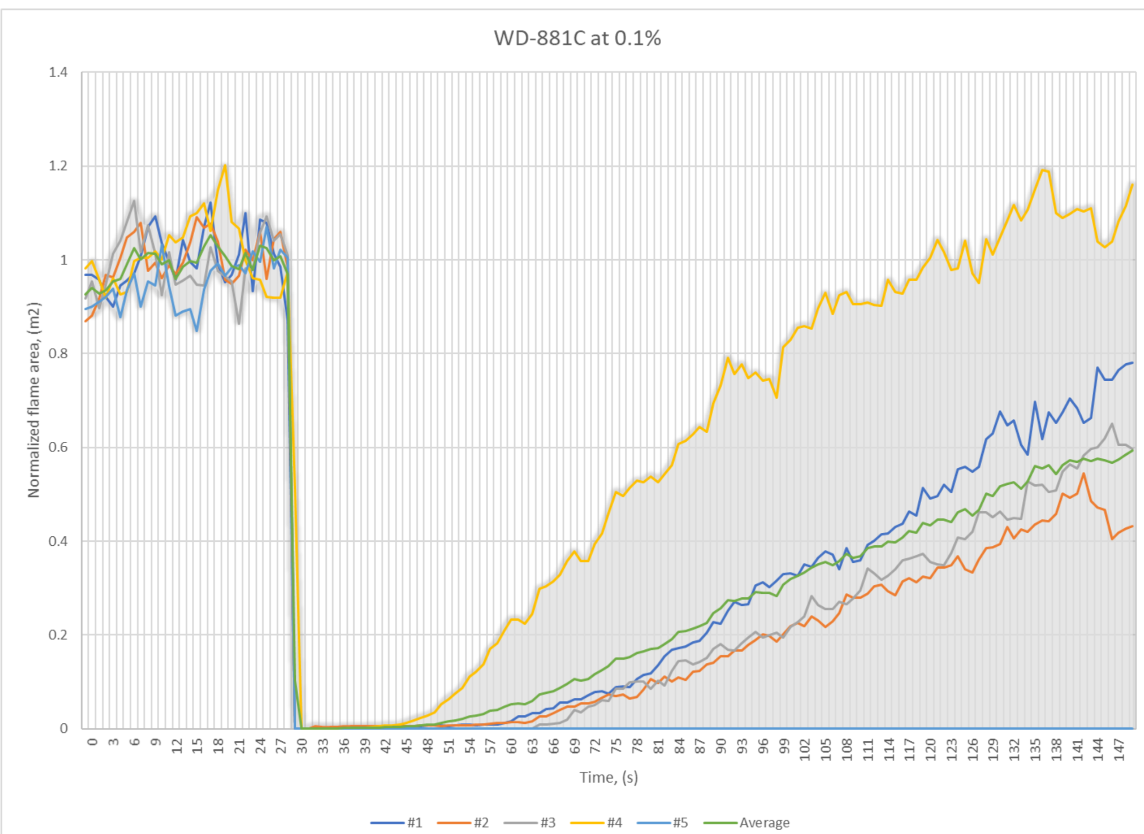

Thermogel 200L at 0.5%
Normalized flame area, (m2)
Time, (s)
#1
#2
#3
#4
#5
Average


Firewall II at 0.25%
Normalized flame area, (m2)
Time, (s)
#1
#2
#3
#4
#5
Average


Firewall II at 1%
Normalized flame area, (m2)
Time, (s)
#1
#2
#3
#4
#5
Average


WD-881C at 0.3%
Normalized flame area, (m2)
Time, (s)
#1
#2
#3
#4
#5
Average


WD-881C at 1.0%
Normalized flame area, (m2)
Time, (s)
#1
#2
#3
#4
#5
Average


WD-881C at 0.1%
Normalized flame area, (m2)
Time, (s)
#1
#2
#3
#4
#5
Average

info@fpinnovations.ca
www.fpinnovations.ca

OUR OFFICES

Pointe-Claire	Vancouver	Québec
570 Saint-Jean Blvd.	2665 East Mall	1055 rue du P.E.P.S.
Pointe-Claire, QC	Vancouver, BC	Québec, QC
Canada H9R 3J9	Canada V6T 1Z4	Canada G1V 4C7
(514) 630-4100	(604) 224-3221	(418) 659-2647