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Evaporation Rates:

Assessing the Evaporation Rates of Water, Foam, and Water-enhancers

PROJECT NUMBER: 301014177

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Reduced surface evaporation rates are marketed as a competitive advantage by water-enhancer manufacturers. In this report, a new test method is developed and applied to quantify the evaporation rates of various commercially available water-enhancer products in a controlled environment. These quantified evaporation rates were then compared to the evaporation rate of water which served as the benchmark.

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Background

In aerial wildfire suppression, water-enhancing products offer an alternative to water and foam, which have been more frequently utilised by wildfire agencies for direct-attack operations. Currently, several water-enhancing products are commercially available. Each of these products function differently to achieve the same desired outcome—to enhance the performance of water as a suppressant. This enhancement has been marketed by water-enhancer manufacturers in several different ways, such as improved performance, increased recovery rates, and superior drop characteristics.

A key challenge for wildfire agencies has been to figure out where, precisely, the competitive advantage of water-enhancers lies. This challenge stems from the products functioning differently from each other. Owing to differences in formulation, each product has different physical and chemical properties. Designing experiments to test the efficacy of these products is therefore difficult since causal changes in experiment outcomes are challenging to attribute to one of several potentially influential parameters.

Several recent studies have taken the approach of examining these variables in isolation: the crib test, which focused on performance testing (Refai and Paskaluk, 2021); rheometric studies that targeted the effect of mix ratio and water hardness on viscosity (Refai et al., 2021a and 2021b); and drop tests that aimed to quantify recovery rates (Refai and Hsieh, 2021). In the theme of examining variables in isolation, the study described in this report focused on the evaporation rates of water-enhancing products in a controlled environment, specifically, the mass loss exclusively due to surface evaporation. This study did not focus on the evaporative losses that occur during a drop from an airtanker.

Value Added to Existing Literature

We reviewed the existing literature on the subject of evaporation rates of wildfire chemicals:

- *Influence of moisture on effectiveness of fire retardants* (Rothermel and Hardy, 1965)
- *Exploring a method to evaluate the longevity of fire-control agents under field conditions* (de Bruijn and Mooney, 2010)

These two studies had objectives similar to this current study (i.e., quantifying and comparing the evaporation rates of water-enhancers). However, each study had specific pieces of information that could be updated or improved upon. The following two subsections outline the aspects of each study that were identified as items to update or improve upon in this report, thus adding value to existing literature.

Influence of moisture on effectiveness of fire retardants

This study by Rothermel and Hardy was conducted in 1965. The products tested in that study—namely, Gelgard, Algin-gel, Bentonite, Phos-Chek 202, and Fire-Trol—are not the same products that are of interest in 2021. All five products were classified as retardants; there was no distinction between water-enhancers and retardants at the time. The products were classified as either short-term (relying on entirely on the water they containing to prevent combustion) or long-term (containing water plus a chemical the prevents flaming combustion even after the water has evaporated). Gelgard, Algin-gel, and Bentonite were classified as short-term products, while Phos-Check 202 and Fire-Trol were classified as long-term products.

In their study, Rothermel and Hardy conducted a series of drying tests on fuel beds comprised of dry ponderosa pine needles. While the use of forest fuels can somewhat replicate the natural environment in which these products are used, they can introduce variability because of how they are arranged. Fuel arrangement can affect product penetration, especially when water-enhancer products have different absorption and adhesion characteristics. The arrangement of fuels, specifically the packing factor, can also impact the drying factor, as outlined in the report.

Updating the list of products tested for evaporation rates as well as removing fuel arrangements as a variable in experiments offers more current and accurate information on this topic.

Exploring a method to evaluate the longevity of fire-control agents under field conditions

This study by de Bruijn and Mooney was conducted in 2010. The objective of this study was to test a field method of evaluating the evaporation rates of fire-control agents. The evaporation rate tests done in this study had the product names masked. In addition, only one water-enhancing product was tested. This resulted in a knowledge gap to help differentiate between the evaporation rates of various products.

The tests done in this study did not conduct multiple replications. To confirm replicability, multiple iterations of the same test under the same ambient conditions must be done.

In this study, exposure to natural environment conditions meant that:

a. Replications with the same natural environment conditions are challenging to achieve.

b. All products have to be tested simultaneously in order to expose them to the same ambient conditions. While this task is certainly possible, it can be logistically challenging to execute when testing a large number of products.

Disclosing product names as well as conducting multiple replications under controlled conditions will add to the transparency and scientific rigour of the evaporation rate tests.

Methods

A new test method was developed to execute evaporation rate tests in a controlled laboratory environment using mass-loss data loggers.

Test setup and equipment

The tests were conducted in a temperature and humidity-controlled room at the Protective Clothing and Equipment Research Facility (PCERF) in the Department of Human Ecology at the University of Alberta. The temperature in the room was set to 25°C and the relative humidity was set to 15%.

A set of six load cells were connected to aluminium platforms, as shown in Figure 1. These platforms served as a base on which 4-inch diameter plastic cups were placed. The plastic cups contained mixed samples of the products to be tested.

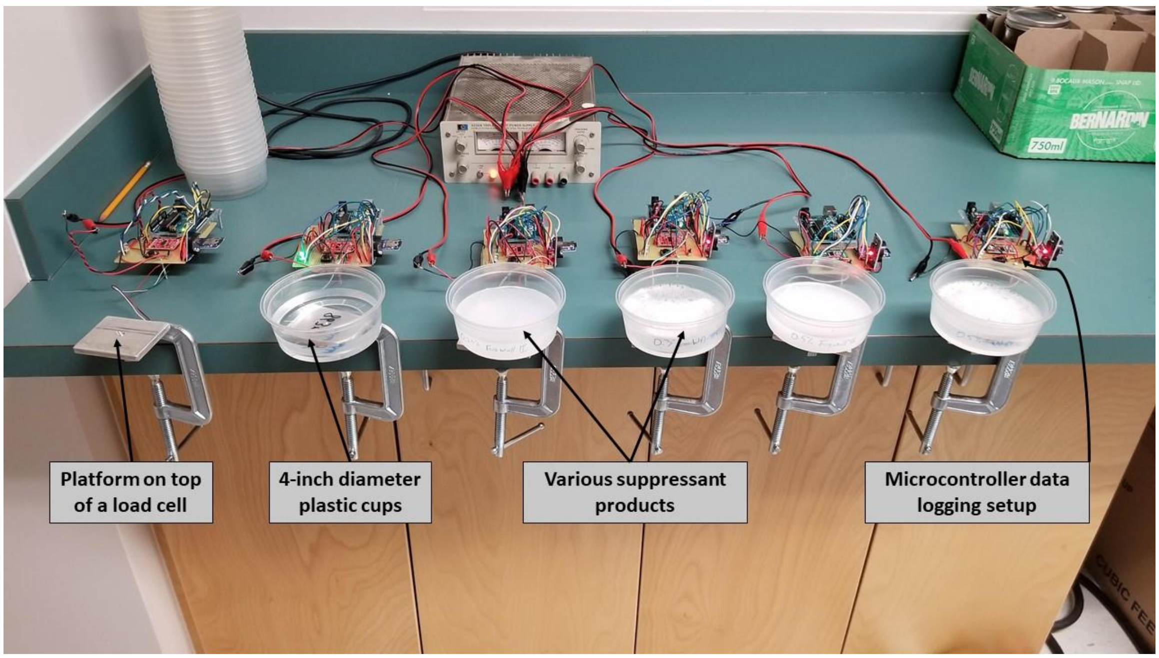

Figure 1. Evaporation rate test equipment setup.

The data logger used in this study was a custom-built mass-loss logging device. A close-up of the data logger is presented in Figure 2. The setup comprised of the following key components:

1. **Microcontroller (Arduino Uno)** – Used to program the mass-loss tracking function (through the Arduino Integrated Development Environment, or IDE).

2. **Real-time clock module (DS3231)** – Used to keep time during data logging operations.

3. **Mirco SD card module** – Used for on-board data storage.

4. **Amplifier module (HX711)** – Used to amplify the signal from the load cell.

5. **Load cell (0–760 g, CZL616C by Phidgets Inc.)** – Used for mass measurements.

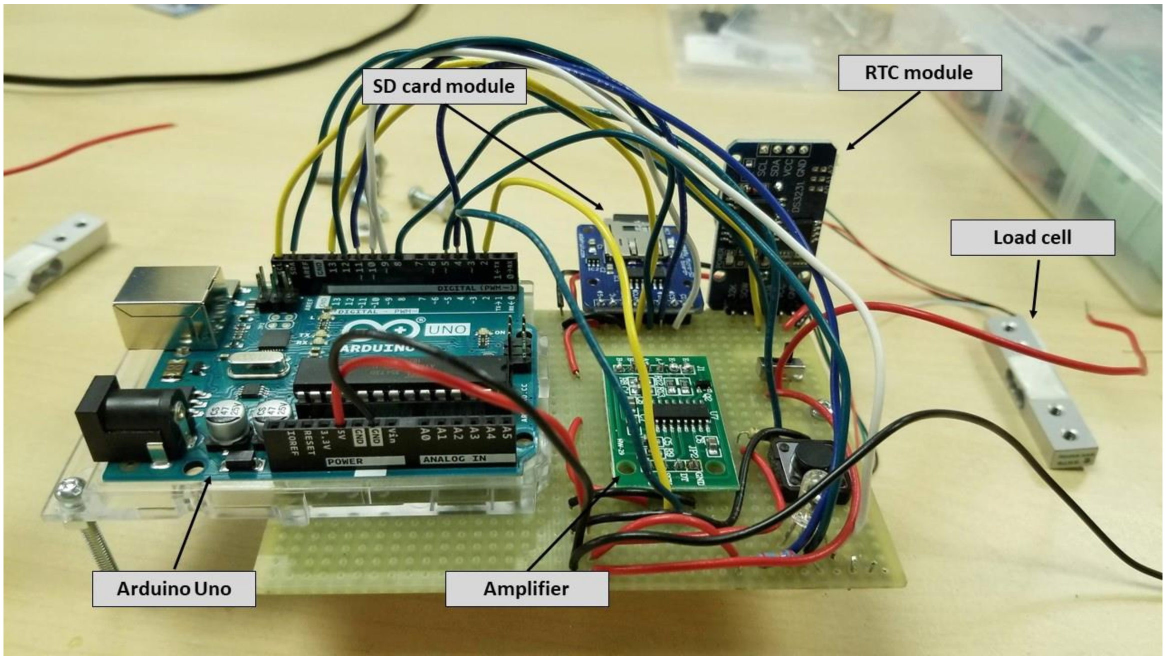

Figure 2. Custom-built mass-loss data logger.

Sample preparation

Six water-enhancing products were selected for this study. The products and their mix ratios are presented in Table 1. The mix ratios for these products were selected based on (in order):

1. The USDA Forest Service's qualified product list (QPL). This list qualifies products and mix ratios for use based on factors such as mammalian toxicity and aircraft corrosion (USDA Forest Service, 2019).

2. Recommendations for operational viscosity ranges by Refai et al. (2021a) from their study on the rheology of wildfire suppressants. These recommendations were found to be practical during empirical performance tests conducted by Refai and Paskaluk (2021).

All samples were prepared using City of Edmonton tap water, which had a water hardness of 150 to 160 ppm. Products that had liquid concentrate were mixed by volume, whereas products that had solid (powdered) concentrate were mixed by weight.

Table 1. Water-enhancer products and mix ratios tested in this study.

Product	QPL Mix-Ratio Range	Mix Ratios Tested		
Water	-	-	-	-
WD881C	0.1% - 1.0%	0.3%	0.5%	-
BlazeTamer 380	0.65%	0.65%	-	-
Firewall II	0.25% – 3%	0.25%	0.5%	1.0 %
FireIce 561	1.4% – 2.1%	1.4%	-	-
Thermo-Gel 200L	0.5% - 3.0%	0.5%	-	-

Test Procedure

Samples of approximately 150 ml were exposed to ambient room conditions for 24 hours. During this period, mass loss was recorded by a data logger to obtain the mass loss over time (i.e., evaporation rate). Each mix ratio for each product was tested three times.

Results

Figure 3 presents the average evaporation rates for the products tested. Mass loss is in grams per unit time (hour) and unit area (m^2) and the error bars represent standard deviation. Note: the evaporation rates presented here are negative values, indicating mass loss over time.

To facilitate the comparison of evaporation rates between the products, the evaporation rate of water was selected as a benchmark. For a product to have a significant difference in evaporation rates, a 10% difference from the evaporation rate of water was selected as a threshold.

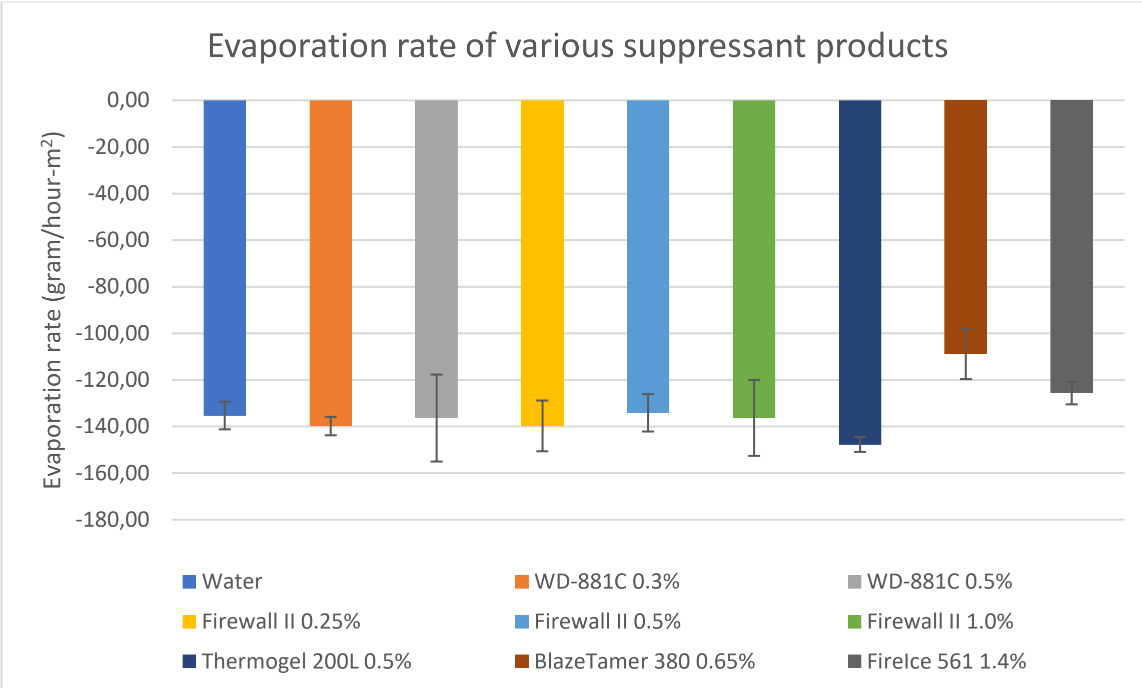

Figure 3. Average evaporation rates per unit time (hour) and per unit area (m^2) of six water-enhancer products.

Applying this 10% threshold, it was found that only one product, BlazeTamer 380 at 0.65%, had a noticeably lower evaporation rate than that of water. All other products had evaporation rates within the 10% threshold. Firewall II at 0.5% and FireIce 561 at 1.4% had evaporation rates slightly lower than that of water, whereas WD881C at 0.3%, WD881C at 0.5%, Firewall II at 0.25%, Firewall II at 1.0%, and Thermo-Gel 200L at 0.5% had evaporation rates slightly higher than that of water. Overall, these products were found to have evaporation rates similar to that of water. Table 2 presents the average evaporation rates of the six products tested and the percentage difference relative to water.

Table 2. Evaporation rates of six water-enhancer products.

Product	Average Evaporation Rate (grams / hour-m^2)	Standard Deviation (grams / hour-m^2)	Difference Relative to Water (%)
Water	-135.27	5.95	-
WD881C 0.3%	-139.78	4.01	3.33
WD881C 0.5%	-136.34	18.66	0.79
Firewall II 0.25%	-139.74	10.91	3.30
Firewall II 0.5%	-134.15	7.98	-0.83
Firewall II 1.0%	-136.30	16.28	0.76

Product	Average Evaporation Rate (grams / hour-m^2)	Standard Deviation (grams / hour-m^2)	Difference Relative to Water (%)
Thermo-Gel 200L 0.5%	-147.63	3.24	9.14
BlazeTamer 380 0.65%	-108.98	10.73	-19.44
FireIce 561 1.4%	-125.69	4.82	-7.08

Discussion

Evaporation rate differences

Based on the average evaporation rates calculated in this study, it was found that, with the exception of BlazeTamer 380 at 0.65% mix ratio, the products tested had evaporation rates similar to that of water. These results suggest that surface evaporation rates of water-enhancers, with the exception of Blazetamer 380 at 0.65% mix ratio, do not provide a meaningful competitive advantage over water. The similarity in evaporation rates between water-enhancers and water is consistent with the findings of Rothermel and Hardy (1965) and de Bruijn and Mooney (2010).

Operational applicability

To understand the practical application of the estimated evaporation rates calculated in this study, let us consider the coverage level of a product. Coverage level 1 is defined as 1 US gallon/100 ft^2, or 407 grams/m^2. If the evaporation rate of water is -135.27 grams/m^2 per hour, then approximately 33% of coverage level 1 would be lost by surface evaporation after one hour of exposure to the ambient conditions used in this study.

Addition of wind conditions

In this study, the controlled environment presented near-zero wind conditions. Mass loss due to surface evaporation was found to be steady and linear for the duration of the tests. In practice, wind conditions will play a significant role in increasing the surface evaporation rate of products. Both Rothermel and Hardy (1965) and de Bruijn and Mooney (2010) included wind as a parameter in their studies. Their results suggested that wind conditions change the rate of mass loss from a linear trend to a non-linear trend; that is, evaporation accelerated due to wind conditions. Therefore, the estimated evaporation rates in this study can be considered conservative.

Conclusion

The objective of this study was to evaluate evaporation rates of currently available water-enhancer products. First, existing literature on this topic was reviewed to identify areas of information that required updating. In addition, certain knowledge gaps in pre-existing test methods were identified. A new test method based on mass-loss due to surface evaporation was developed to address these knowledge gaps. The test method involved mass-loss logging of various suppression products in a controlled environment to ensure minimal impact from external variables as well as the benefit of replicability.

The tests done on various suppressant products found that, with the exception of BlazeTamer 380 at 0.65% mix ratio, all suppressant products assessed in this study were found to have evaporation rates similar to that of water (the benchmark). BlazeTamer 380 at 0.65% was found to have a reduction in evaporation rate of 19% in comparison to that of water. It was concluded that in general, surface evaporation rates of water-enhancing products do not offer a noticeable competitive advantage over water.

References

De Bruijn, P. & Mooney, C. (2010). *Exploring a method to evaluate the longevity of fire-control agents under field conditions*. FPInnovations Wildfire Operations Research.

Refai, R. & Hsieh, R. (2021). *Drop footprint mapping of suppressants using heavy helicopters* (Project No. 301014177). FPInnovations Wildfire Operations Research.

Refai, R. & Paskaluk, S. (2021). *Performance assessment of wildfire suppressant products using the Crib Test methodology* (Project No. 301014177). FPInnovations Wildfire Operations Research.

Refai, R., Yang, J., & Tsai, A. (2021a). *Wildfire suppressant rheology: Mapping viscosity as a function of product mix ratios* (Project No. 301014177). FPInnovations Wildfire Operations Research.

Refai, R., Yang, J., & Tsai, A. (2021b). *Wildfire suppressant rheology: Impact of water quality on water-enhancer viscosity* (Project No. 301014177). FPInnovations Wildfire Operations Research.

Rothermel, R.C. & Hardy, C.E. (1965). *Influence of moisture on effectiveness of fire retardants*. USDA Forest Service Research Paper INT-18.

USDA Forest Service. (2019). *Water enhancers for wildland fire management: Qualified by US Forest Service in accordance with Forest Service Specification 5100-306B's qualified product list*. Retrieved from https://www.fs.fed.us/rm/fire/wfcs/documents/2019%20qpl_we_2019-July.pdf

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