info@fpinnovations.ca
www.fpinnovations.ca

Wildfire suppressant rheology:

Impact of water quality on water-enhancer viscosity

PROJECT NUMBER: 301014177

Razim Refai, E.I.T.
Junyi Yang, E.I.T.
Dr. Peichun Amy Tsai, P. Eng.

October 2020

An important characteristic of the majority of the water-enhancing products on the wildfire suppression market is their ability to increase the viscosity of water. This increase in viscosity is linked to their performance. While performance of these products is key, there are several external variables that can influence how these suppressants physically behave. One such external variable is water quality, which is anecdotally known to impact water-enhancing products.

This study aimed to understand how water quality—in particular, hardness—affects the viscosity of various water-enhancing products at different mix ratios. Understanding how water quality affects the viscosity of these products can offer insight into (1) which products are highly sensitive to water quality changes, and (2) how the target viscosity of a mixed product can be affected by water quality.

Project number: 301014177
Technical Report TR 2020 N52
ACKNOWLEDGEMENTS
FPInnovations would like to thank Dr. Andre McDonald and members of the Tsai Lab for their help and guidance throughout this project.

This project was financially supported by NSERC Alliance.

APPROVER CONTACT INFORMATION
Michael Benson

REVIEWERS
Alexander Maclean
Senior Wildfire Officer – Aviation
B.C. Wildfire Service

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

Background

In current practice, aerial wildfire suppression operations can be classified into two general categories: direct-attack and indirect-attack operations. Direct-attack operations involve dropping water or foam directly on an actively burning wildfire. Indirect-attack operations often rely on dropping long-term retardants ahead of a fire front. The market for suppressant products used in direct-attack operations has evolved over the years. There has been an increase in the commercial availability of water-enhancing products, which aim to provide an alternative to water and foam. These water-enhancing products are almost always proprietary, and so little information is available about their constituents and their physical and chemical properties.

An important characteristic of most water-enhancing products is their ability to increase the viscosity of water. Manufacturers claim that this increase in viscosity offers improved performance. There are studies underway to explicitly answer questions about the performance of these products. But while performance of these products is key, there are several external variables that can influence how these products physically behave. Variables such as ambient temperature, water temperature, water quality, and mixing methods can affect the viscosity of these products. Given the proprietary nature of these products, limited information exists on how exactly these external variables impact these suppressant products.

This study aimed to understand how water quality affects the viscosity of various water-enhancing products at different mix ratios. Direct-attack operations often rely on the closest available water source to minimize the time between refilling buckets/tanks and dropping payloads. Water sources often vary in dissolved particulate matter, or hardness. This variability is influenced by several factors, such as seasonality, nearby agricultural run-off, and natural mineral content. Understanding how water quality, hardness in particular, affects the viscosity of suppressant products can offer insight into (1) which products are highly sensitive to water quality changes, and (2) how the target viscosity of a mixed product can be affected by water quality. This information can influence which products are preferred for operational use.

FPInnovations collaborated with the Tsai Lab of Fluids and Interfaces, a fluid dynamics laboratory that is part of the Department of Mechanical Engineering at the University of Alberta, to undertake this study. All data presented in this report was collected by members of the Tsai Lab.

Methods

Equipment

To obtain viscosity data for various water-enhancer products, a rheometer (Model: Anton Paar MCR 302) was used (Figure 1). Details about how a rheometer works and how data on viscosity, first normal stress difference, and storage and loss modulus was collected can be found in the original technical report (Yang and Tsai 2020).

The rheometer required only a small amount of working fluid, so 10 mL of mixed solution was prepared for each product at each mix ratio. The shear rate range was capped from 0.1 to 100 (1/s) based on standard rheometric practice. An ambient temperature of 20^{0}C was maintained throughout the experiment.

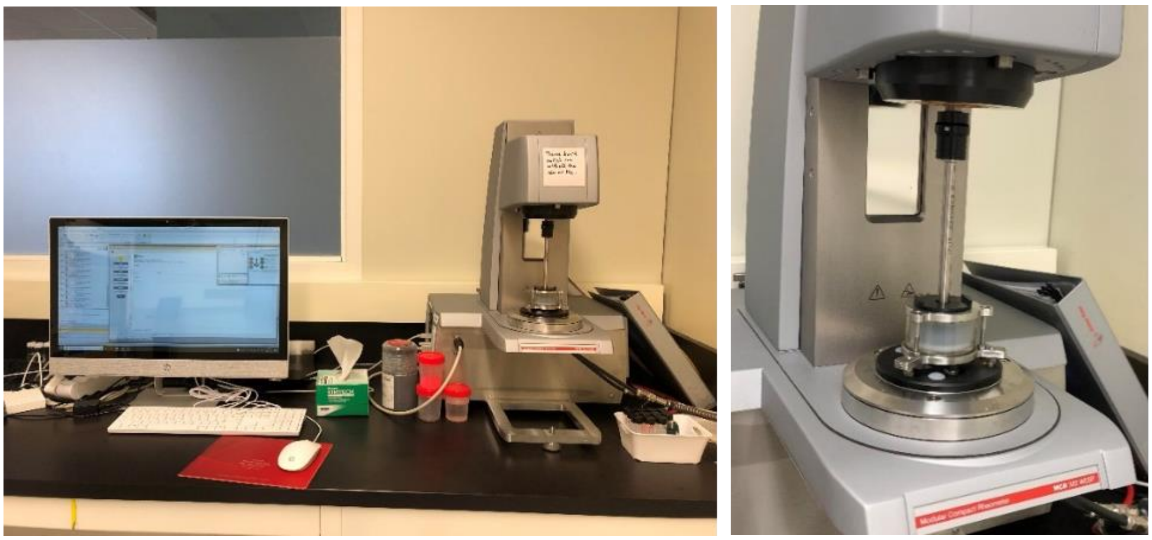

Figure 1. Anton Paar MCR 302 with a particle image velocimetry cell and a concentric cylinder.

Water quality

While water quality is defined by its physical, chemical, biological, and radiological characteristics, only its physical characteristics were of interest in this study—in particular, hardness. Water hardness is of interest because it has been anecdotally known to affect the viscosity of water-enhancing products.

Three different water sources were used in this study: deionized water (DI), tap water, and well water. These three water sources were selected because they provided a large range of dissolved particulate matter, or hardness. A total dissolved solids (TDS) meter, capable of measuring 0–9999 parts per million (ppm), was used to estimate the hardness of the three water sources selected for this study (Table 1). For reference, widely accepted water hardness classifications are presented in Table 2.

Table 1. Estimated water hardness for the different types of water used in this study.

Water Source	Estimated Water Hardness (ppm)
Deionized (DI) water	0
Tap water	170
Well water	1400

Note: TDS, parts per million(ppm), and mg/L are interchangeable units of dissolved particulate matter in water.

Table 2. Classification of water hardness levels (Environment Canada 1977 and Thomas 1953).

Degree of Hardness	Parts per Million (ppm)
Soft	0 to <60
Medium hard	60 to <120
Hard	120 to <180
Very hard	180 and above

Since aircraft battling wildfires often collect water from natural water bodies and have little to no mechanical filtration, it is reasonable to assume that the water used would fall in either the *hard* or *very hard* degree of hardness classification (Table 2).

Sample preparation

Four water-enhancer products were tested in this study: BlazeTamer 380, Firewall II, FireIce 561, and Thermo-Gel 200L. Each product was tested at five different mix ratios that were within the range specified on the qualified product list (QPL) (USDA 2020). The one exception was BlazeTamer 380 because it currently has only one approved mix ratio (0.65%). Table 3 presents the mix ratios tested in this study. Products that had liquid concentrate were mixed by volume, whereas products that had solid (powdered) concentrate were mixed by weight. Each mix ratio was prepared with the three water types.

Table 3. Mix ratios for the suppressant products tested in this study.

Product	QPL Mix-Ratio Range	Mix Ratios Tested				
BlazeTamer 380	0.65%	0.3%	0.4%	0.5%	0.6%	0.65%
Firewall II	0.25% – 3%	0.25%	0.9%	1.6%	2.3%	3.0%
FireIce 561	1.4% – 2.1%	1.4%	1.6%	1.8%	2.0%	2.1%
Thermo-Gel 200L	0.5% - 3.0%	0.5%	1.1%	1.7%	2.4%	3.0%

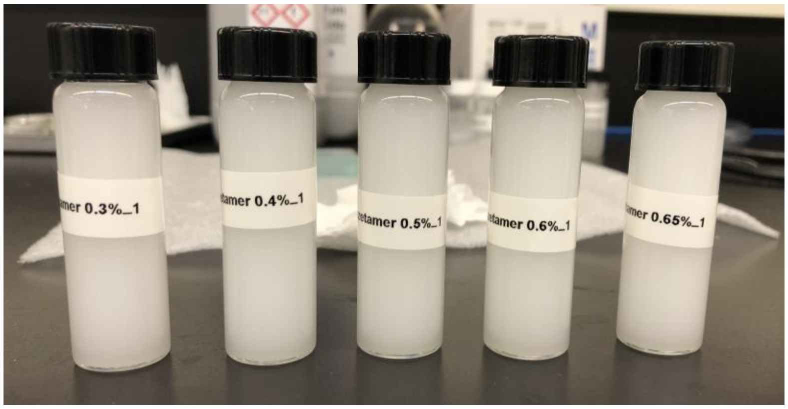

Figure 2. BlazeTamer 380 samples of varying mix ratios prepared with tap water.

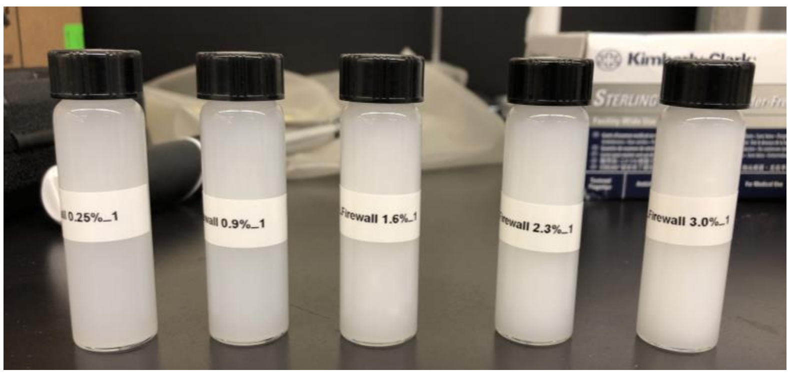

Figure 3. Firewall II samples of varying mix ratios prepared with tap water.

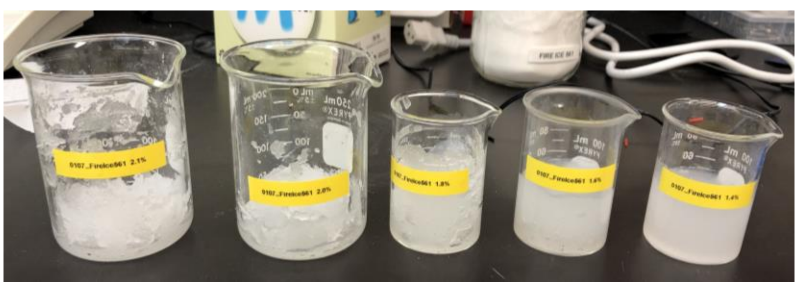

Figure 4. FireIce 561 samples of varying mix ratios prepared with tap water.

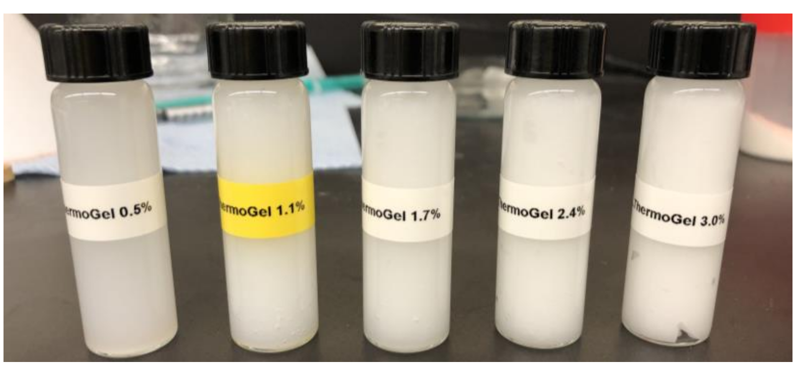

Figure 5. Thermo-Gel 200L samples of varying mix ratios prepared with tap water.

Results

Findings from the rheometric tests carried out on the four water-enhancing products to see how their viscosity was affected by water hardness are presented below. A few important notes about the graphs:

- **Varying scales:** The products tested each have different achievable viscosities based on their mix ratios. Therefore, the scale of the y-axis is different for each product. This variation in scale will make it difficult to use the graphs to make relative comparisons of the viscosity data.
- **Log scale:** Due to the large range of achievable viscosities for the products tested, the y-axis is in logarithmic scale base 10. The difference between each horizontal line is an order of magnitude.
- **Replicates:** Each data point in the graphs represents the average of three replicates.

Viscosity is measured in centipoise (cP). To give context to this measurement, Table 4 provides the viscosity values in cP for several common items.

Table 4. Viscosities of common items.

Material	Viscosity (cP)
Water at 21°C	1 – 5
Blood or kerosene	10
Antifreeze or ethylene glycol	15
Motor oil SAE 10 or corn syrup	50 – 100
Motor oil SAE 30 or maple syrup	150 – 200
Motor oil SAE 40 or castor oil	250 – 500
Motor oil SAE 60 or glycerin	1,000 – 2,000
Karo corn syrup or honey	2,000 – 3,000
Blackstrap molasses	5,000 – 10,000
Hershey’s chocolate syrup	10,000 – 25,000
Heinz ketchup or French’s mustard	50,000 – 70,000
Tomato paste or peanut butter	150,000 – 2,000,000
Crisco shortening or lard	1,000,000 – 2,000,000
Caulking compound	5,000,000 – 10,000,000
Window putty	100,000,000

**Viscosity comparison chart retrieved from http://www.cstsales.com/viscosity.html*

BlazeTamer 380

Figures 6 to 10 present the viscosity results of BlazeTamer 380 at five different mix ratios and three water hardness levels.

Impact of water quality

In general, well water lowered the viscosity of the product (except when mixed at 0.65%), while the viscosity remained approximately the same for DI water and tap water. This suggests that very high particulate matter can affect the viscosity of this product.

Extent of impact

The magnitude of reduction in viscosity in well water was very small for all mix ratios. This suggests that BlazeTamer 380 is not susceptible to drastic viscosity changes as water hardness varies. In addition, BlazeTamer 380 had low viscosities across all mix ratios. Minor changes in viscosity are not anticipated to result in any operational challenges.

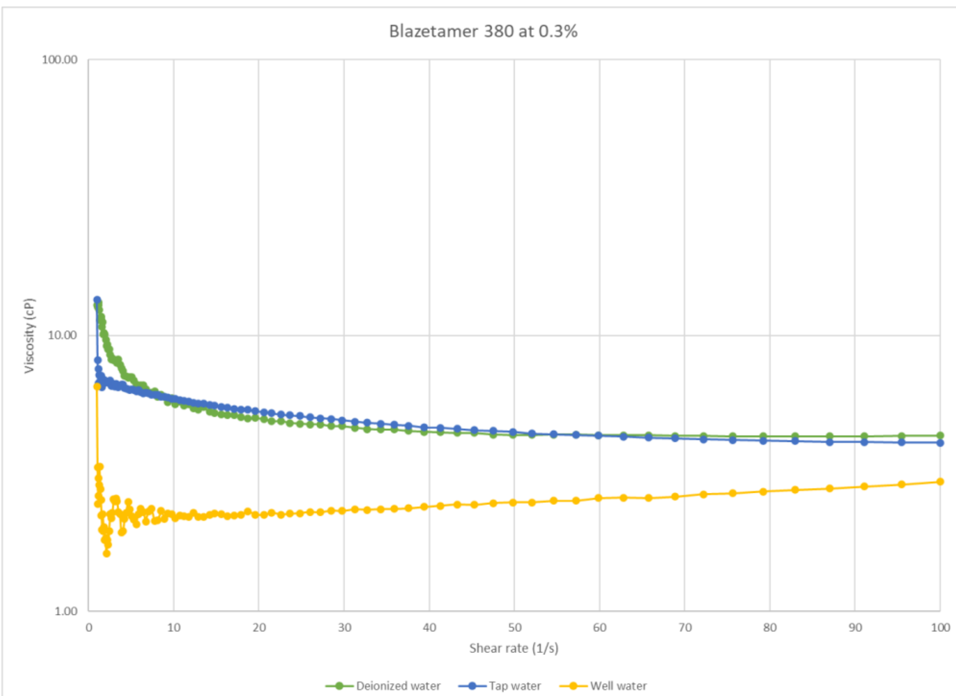

Figure 6. Viscosity of BlazeTamer 380 at 0.3% at three water hardness levels.

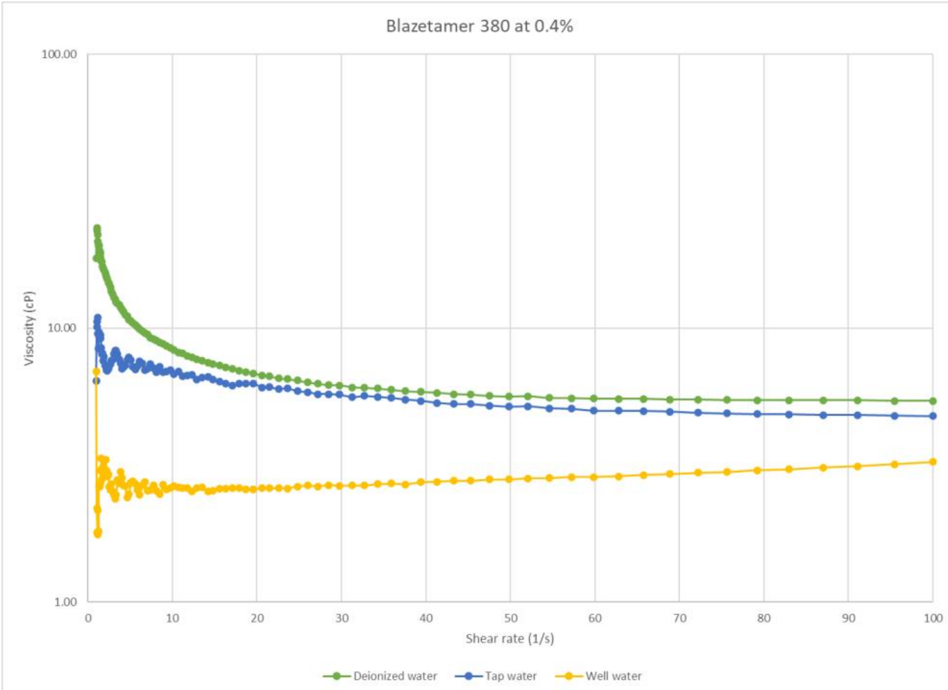

Figure 7. Viscosity of BlazeTamer 380 at 0.4% at three water hardness levels.

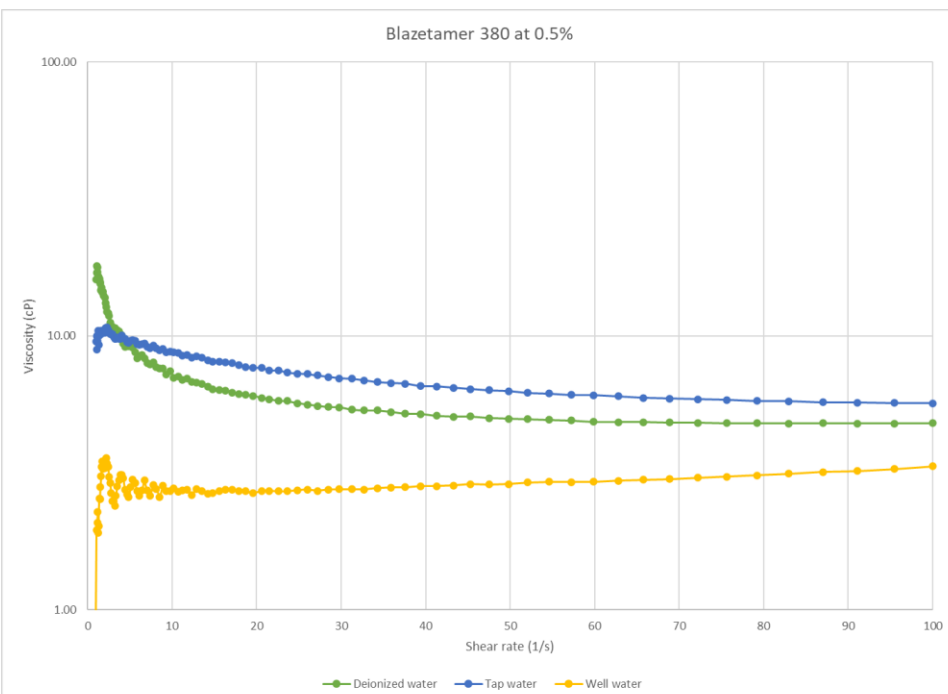

Figure 8. Viscosity of BlazeTamer 380 at 0.5% at three water hardness levels.

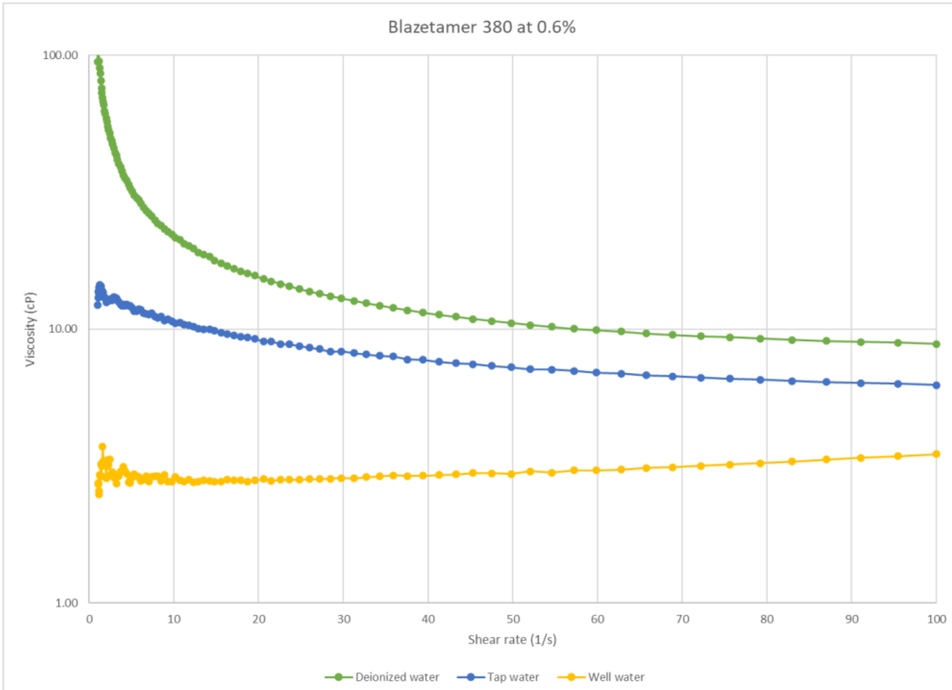

Figure 9. Viscosity of BlazeTamer 380 at 0.6% at three water hardness levels.

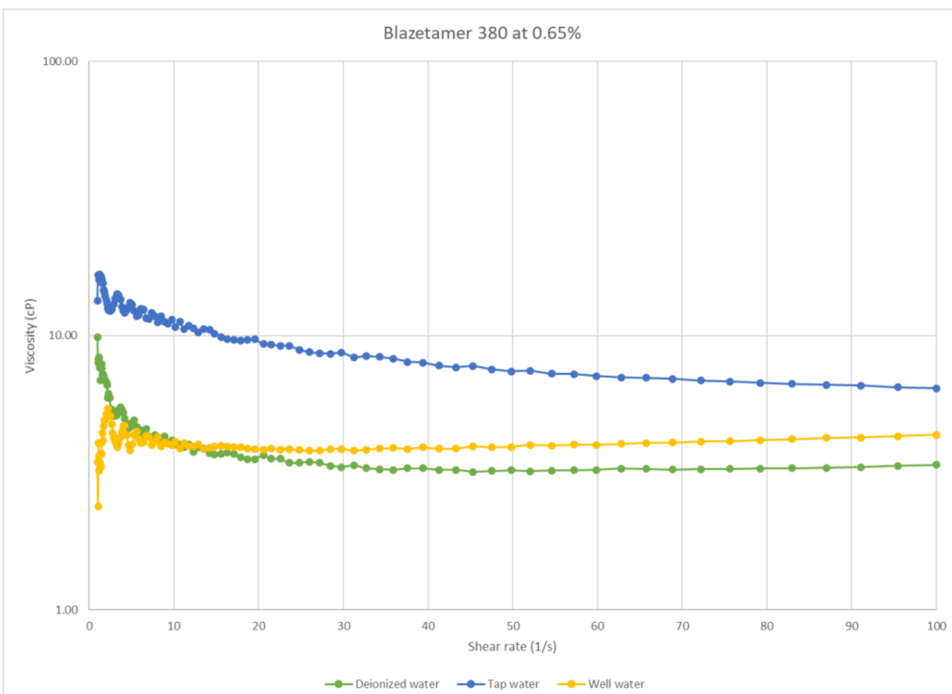

Figure 10. Viscosity of BlazeTamer 380 at 0.65% at three water hardness levels.

Firewall II

Figures 11 to 15 present the viscosity results of Firewall II at five different mix ratios and three water hardness levels.

Impact of water quality

The results show that an increase in water hardness results in a decrease in viscosity. This is most pronounced at Firewall II's lowest mix ratio (i.e., 0.25%) and least pronounced at its highest mix ratio (i.e., 3%).

Extent of impact

The magnitude of reduction in viscosity with an increase in water hardness is likely not significant enough to cause operational issues. The largest decrease in viscosity is observed at 0.25%; however, the viscosity values obtained are still usable. The data presented here suggests that, in general, Firewall II is not susceptible to drastic viscosity changes as water hardness varies.

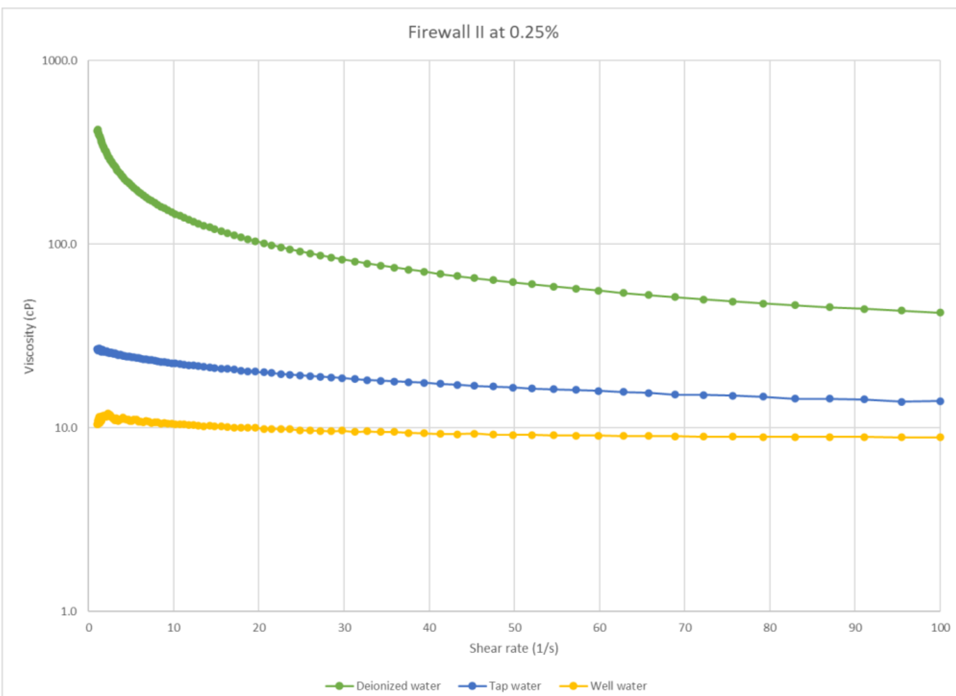

Figure 11. Viscosity of Firewall II at 0.25% at three water hardness levels.

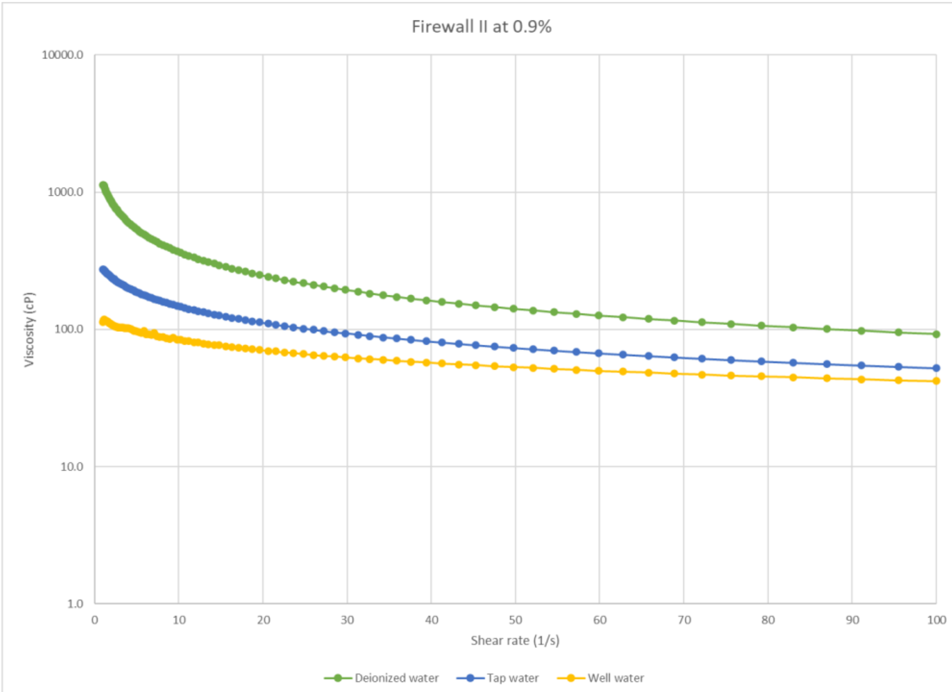

Figure 12. Viscosity of Firewall II at 0.9% at three water hardness levels.

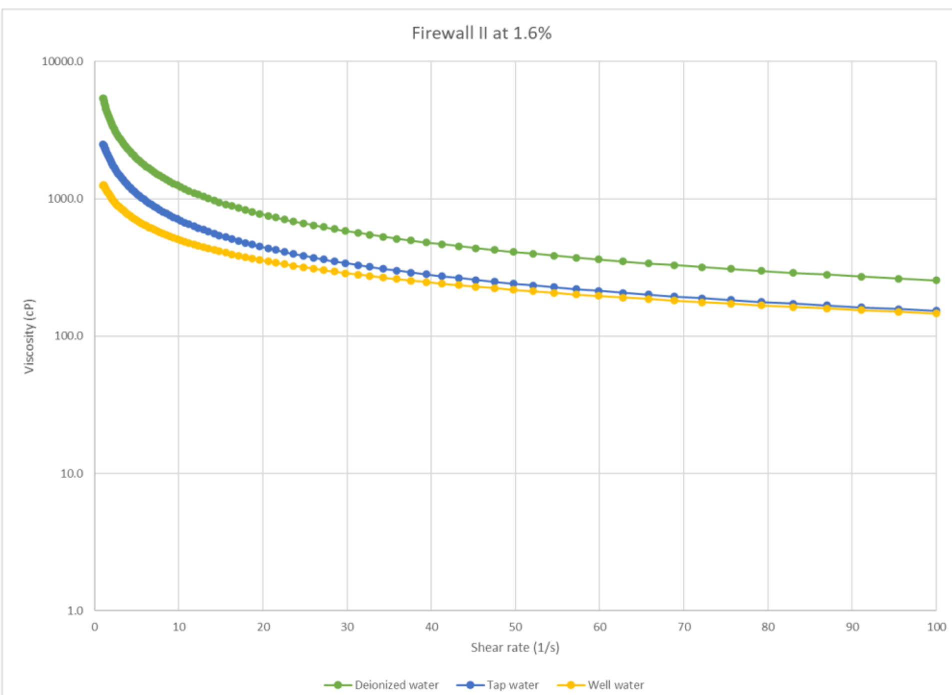

Figure 13. Viscosity of Firewall II at 1.6% at three water hardness levels.

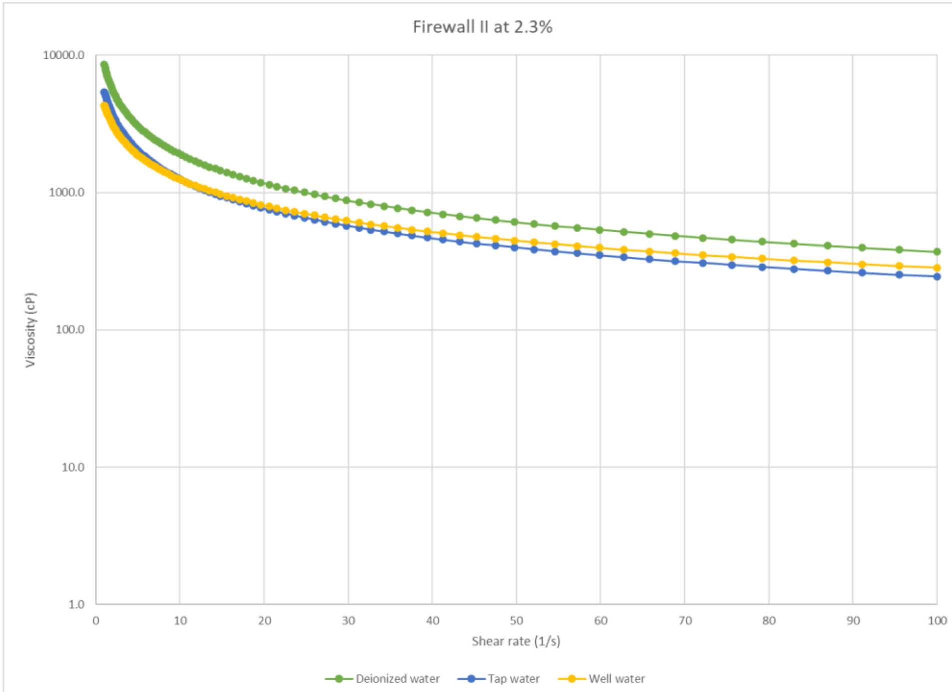

Figure 14. Viscosity of Firewall II at 2.3% at three water hardness levels.

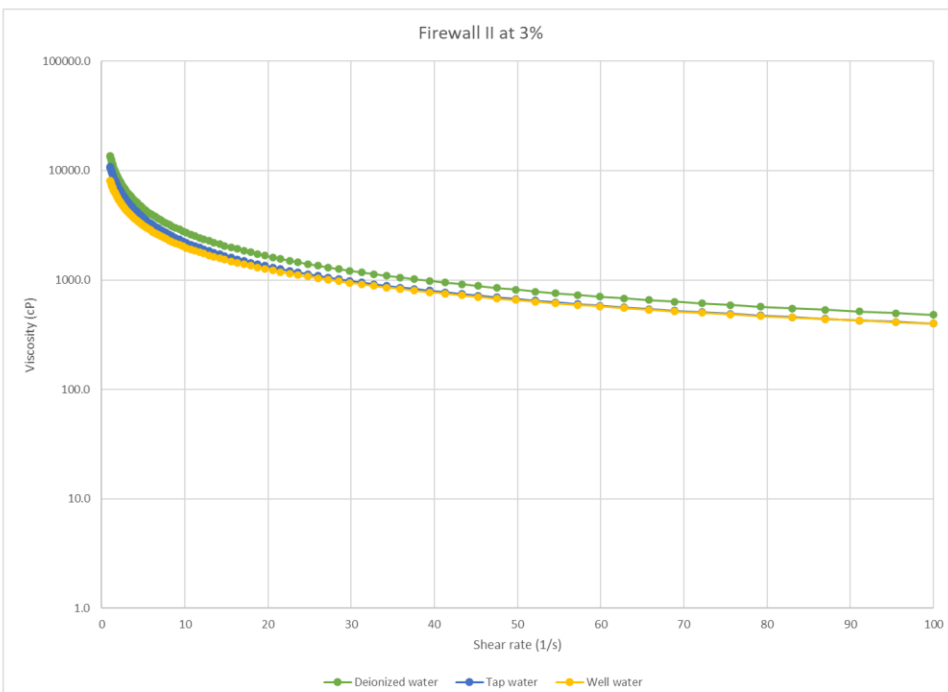

Figure 15. Viscosity of Firewall II at 3% at three water hardness levels.

FireIce 561

Figures 16 to 20 present the viscosity results of FireIce 561 at five different mix ratios and three water hardness levels.

Impact of water quality

The results show that FireIce 561 is susceptible to changes in water hardness, with viscosity decreasing as hardness increases. The data suggests that at lower mix ratios, viscosity values can decrease as low as an order of magnitude, while at higher mix ratios viscosity values can decrease slightly less than an order of magnitude.

Extent of impact

Given this product's high viscosity values when no shear force is applied, the impact of water hardness could result in challenges during operational use. Unlike BlazeTamer 380 and Firewall II, the combination of high viscosity values and susceptibility to water hardness can result in unpredictable viscosity. This could affect drop characteristics, thereby affecting the drop's efficacy.

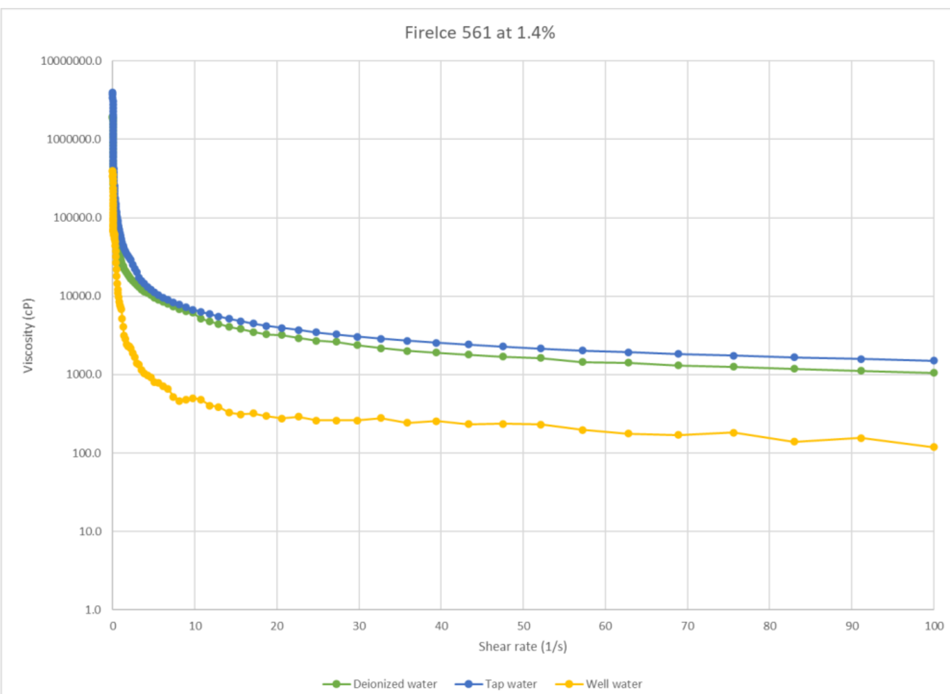

Figure 16. Viscosity of FireIce 561 at 1.4% at three water hardness levels.

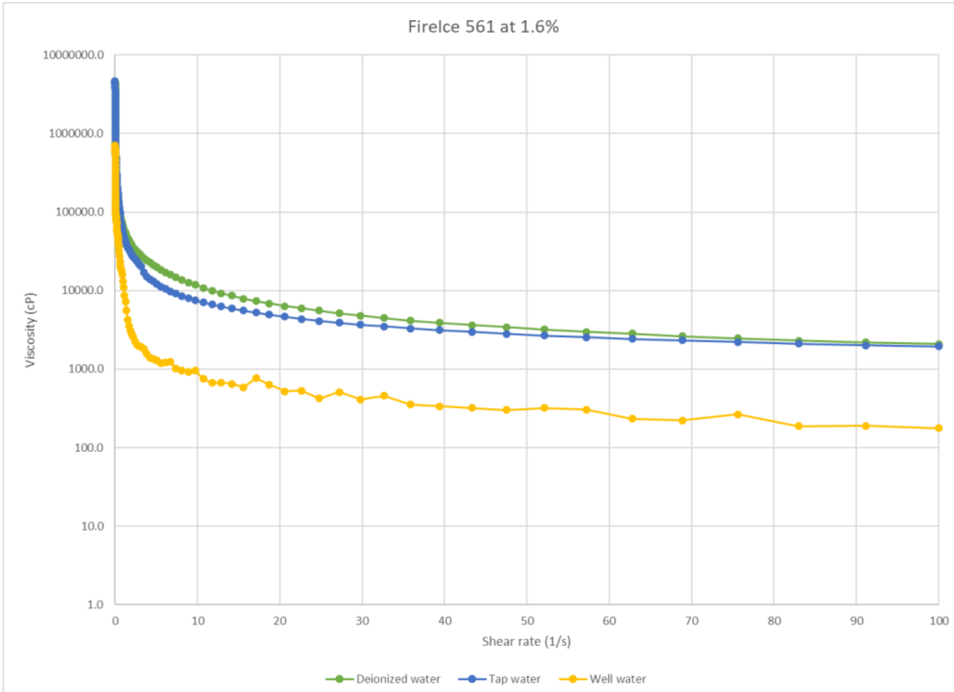

Figure 17. Viscosity of FireIce 561 at 1.6% at three water hardness levels.

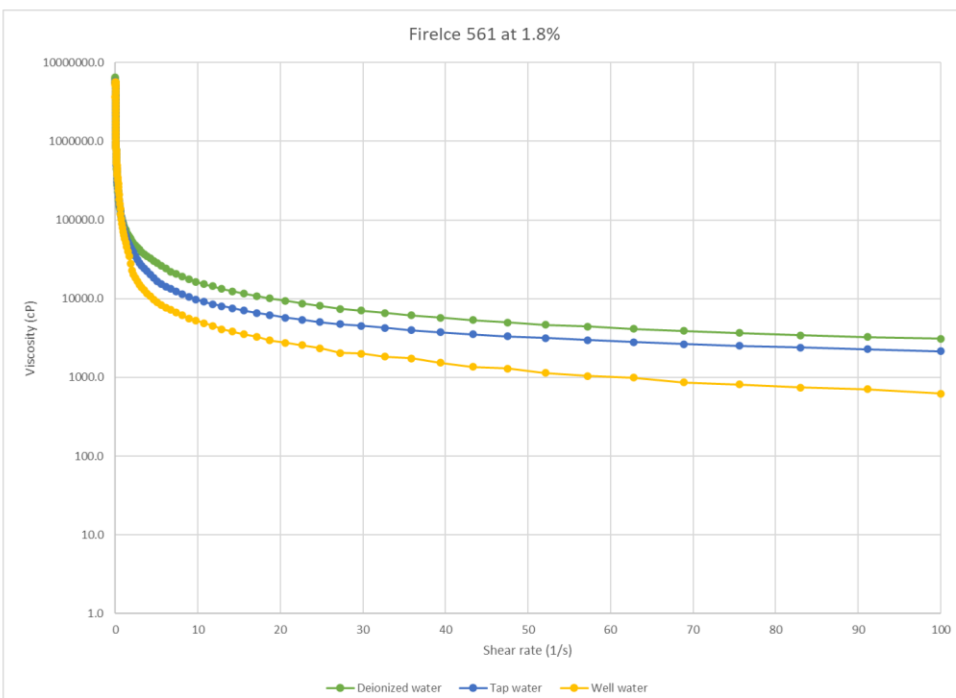

Figure 18. Viscosity of FireIce 561 at 1.8% at three water hardness levels.

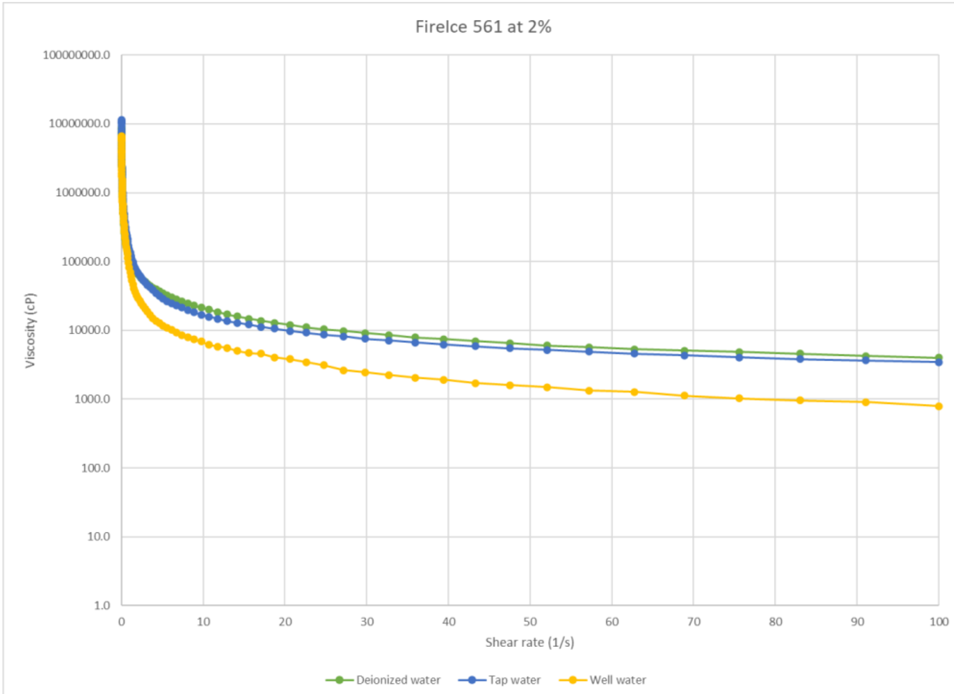

Figure 19. Viscosity of FireIce 561 at 2% at three water hardness levels.

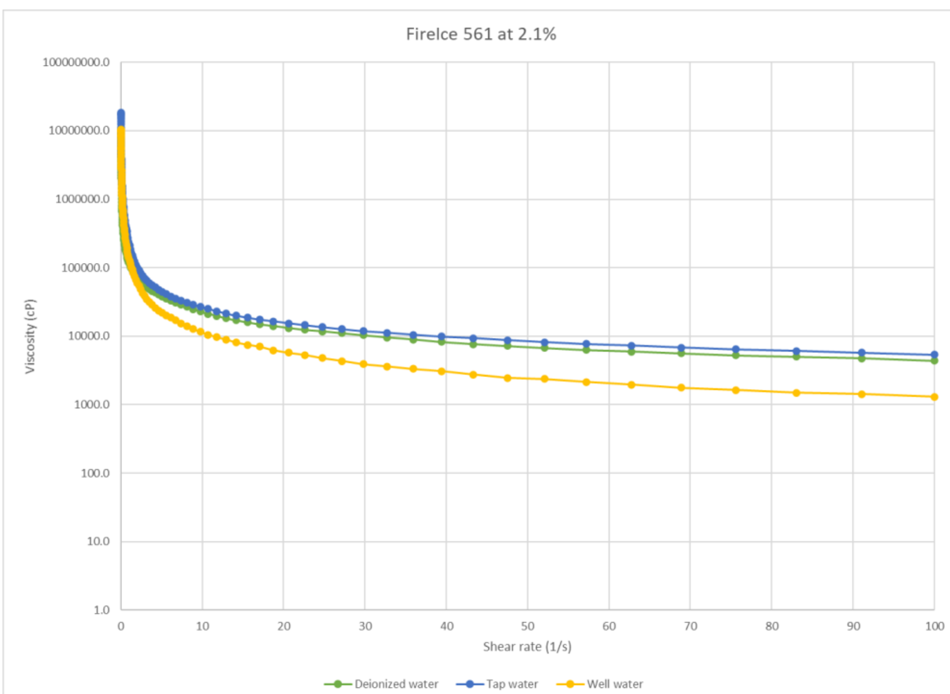

Figure 20. Viscosity of FireIce 561 at 2.1% at three water hardness levels.

Thermo-Gel 200L

Figures 21 to 25 present the viscosity results of Thermo-Gel 200L at five different mix ratios and three water hardness levels.

Impact of water quality

The results show that Thermo-Gel 200L is susceptible to changes in water hardness, with viscosity decreasing as hardness increases. The data suggests that at lower mix ratios, the reduction in viscosity is greater than an order of magnitude while at high mix ratios, it is less than an order of magnitude. Thermo-Gel 200L was also found to have noticeable differences in viscosities between DI and tap water at low mix ratios.

Extent of impact

Given the variability in viscosities even at low mix ratios, it can be challenging to predict what the viscosity will be when the product is mixed. Thermo-Gel 200L, like FireIce 561, can achieve very high viscosity values. The combination of high viscosity values and susceptibility to water hardness could result in unpredictable drop characteristics.

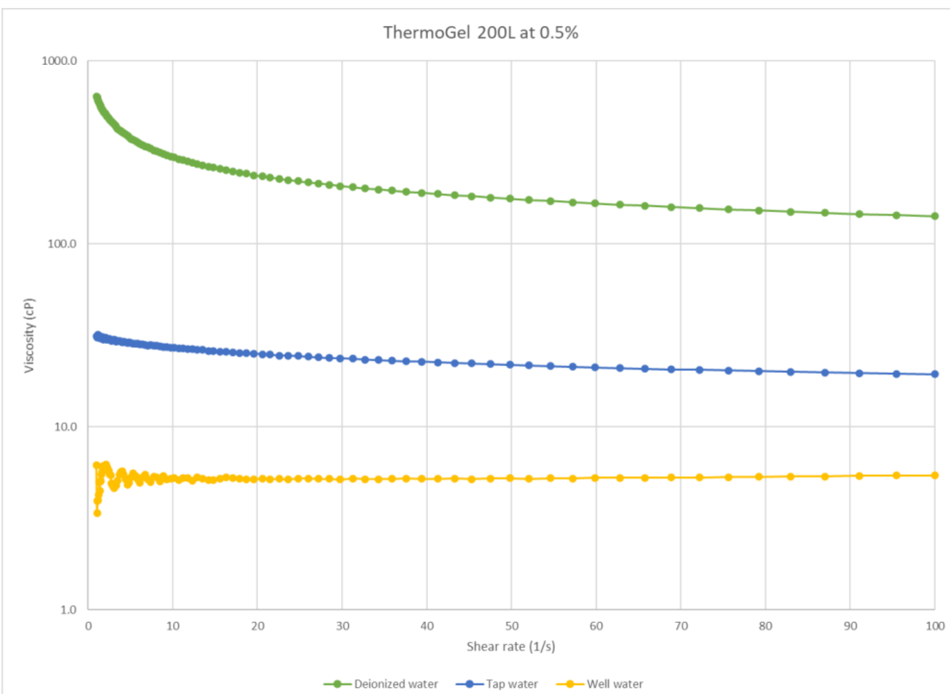

Figure 21. Viscosity of Thermo-Gel 200L at 0.5% at three water hardness levels.

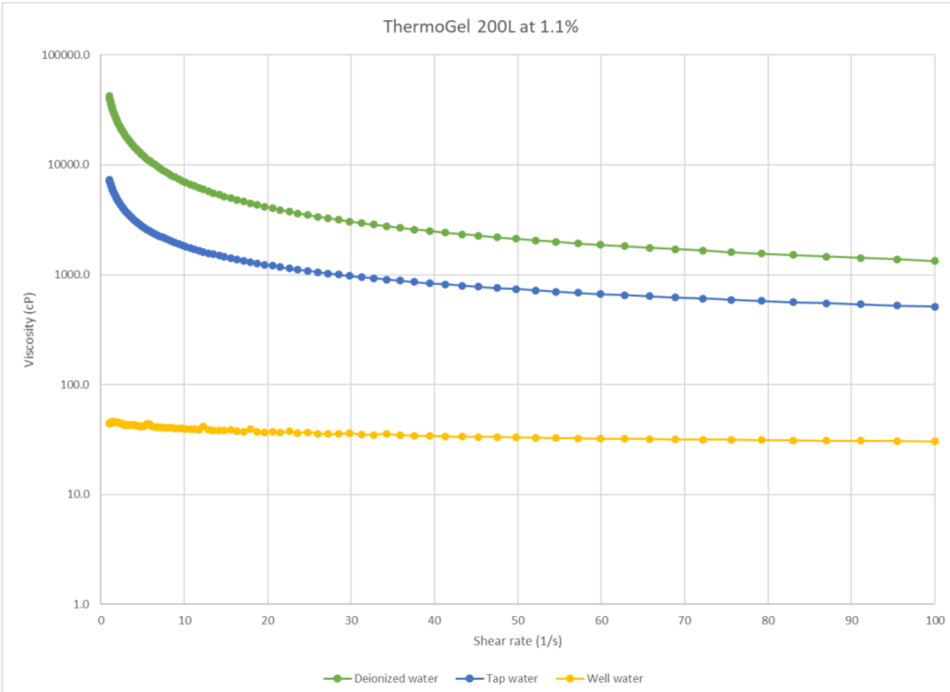

Figure 22. Viscosity of Thermo-Gel 200L at 1.1% at three water hardness levels.

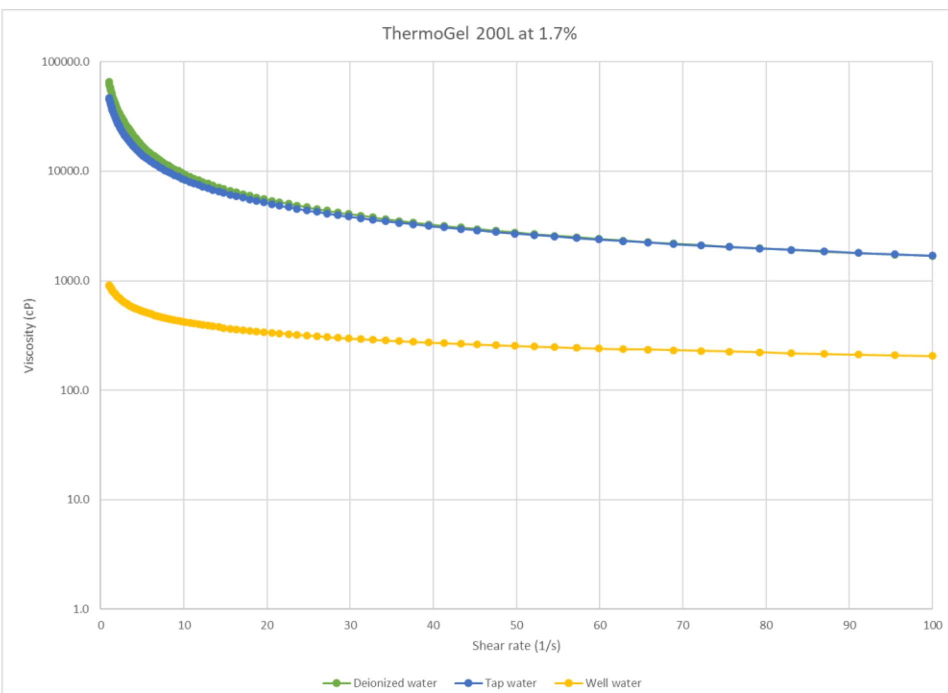

Figure 23. Viscosity of Thermo-Gel 200L at 1.7% at three water hardness levels.

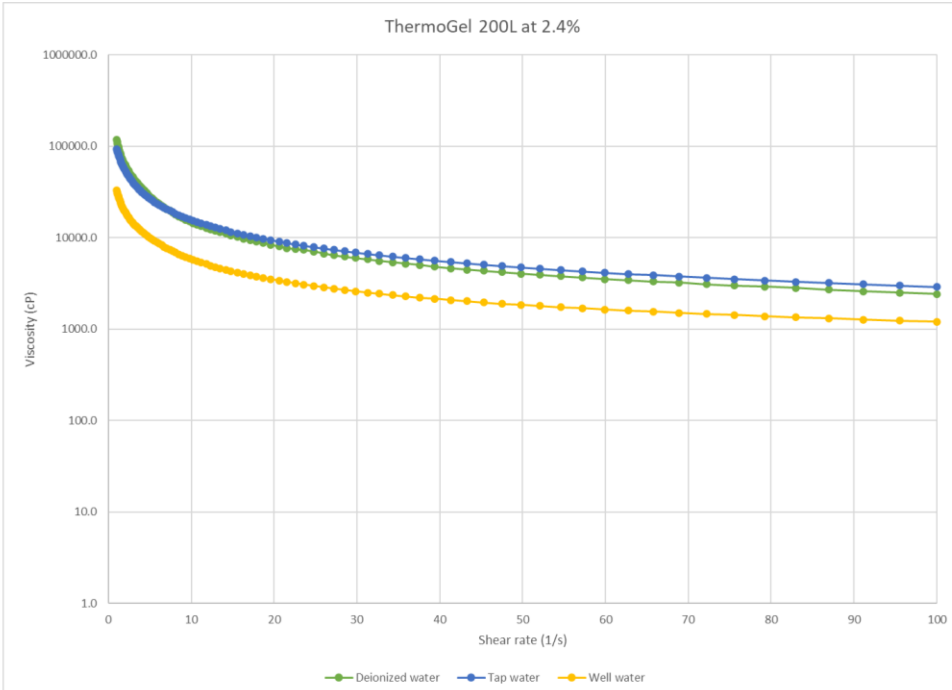

Figure 24. Viscosity of Thermo-Gel 200L at 2.4% at three water hardness levels.

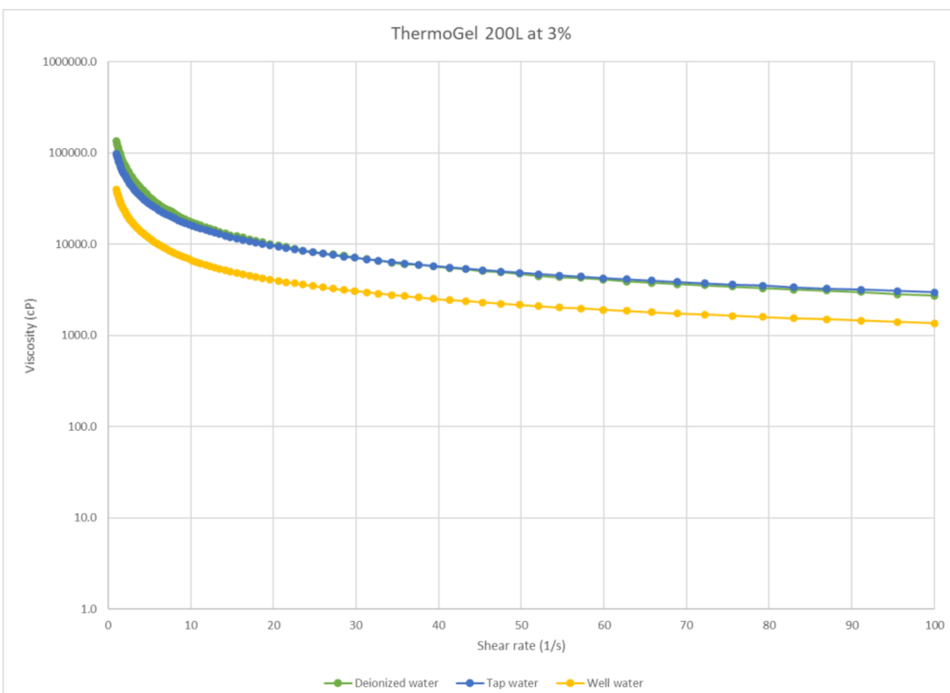

Figure 25. Viscosity of Thermo-Gel 200L at 3% at three water hardness levels.

Discussion

Water hardness

Two of the three selected water hardness levels used in this study are extreme cases of total dissolved solids in the context of drinking water. However, there are several naturally occurring sources of water that come close to these extremes.

- **DI water** – It is likely that a water source similar to DI water (0 ppm) will never be encountered during aerial wildfire operations; however, the purpose of using DI water in this study was to show viscosity changes with low amounts of particulate matter. A study from the U.S. Department of Interior suggests that "water in contact with granite, siliceous sand, well-leached soil, or other relatively insoluble materials is usually below 30 ppm" (Rainwater and Thatcher, 1960). In areas with Precambrian rock, such as the Canadian Shield, water hardness can be as low at 65 ppm (Garrison 1977).
- **Well water** – The well water used in this study recorded a particulate matter of 1400 ppm. While this TDS value may seem high, studies have shown that TDS values in regions with sedimentary rock (Palaeozoic and Mesozoic) can range from 195 to 1100 ppm (Garrison 1977). In addition, streams and lakes in arid western regions of Canada have recorded TDS values as high as 15,000 ppm (Dufour and Becker 1972). With this context, 1400 ppm well water used in this study is not unrepresentative of naturally occurring bodies of water.
- **Common sources of water** – To provide improved context for water hardness values from common water sources, it may be of value to obtain seasonal water hardness values from commonly used water bodies such as Okanagan Lake, Slave Lake, etc. as an addendum to this report.

Granularity in water hardness data

The water hardness levels selected in this study were not equally segmented levels of ppm (i.e., hardness values between well water and tap water is approximately seven times greater than the hardness values between tap water and DI water). In future studies, adding hardness levels in equal segments would offer additional insight into how exactly water hardness affects viscosity data (i.e., linear versus non-linear relationship).

Takeaways from results

The data from this study showed that BlazeTamer 380 and Firewall II were least susceptible to water quality impacts. FireIce 561 and Thermo-Gel 200L were susceptible to water quality impacts that could affect the reliability of drop characteristics. In addition, FireIce 561 and Thermo-Gel 200L both achieve very high viscosities at relatively lower mix ratios. A combination of high viscosities and susceptibility to water hardness could result in greater operational challenges relative to BlazeTamer 380 and Firewall II.

Conclusion

This study aimed to understand how various water-enhancing products are affected by water hardness. Water hardness was selected as the primary variable because it is anecdotally known to affect the viscosity of water-enhancing products. To undertake this study, FPInnovations collaborated with The Tsai Lab of Fluids and Interfaces.

Samples of various water-enhancing products were prepared and run through a rheometer to obtain viscosity data. Each product was tested at five different mix ratios and three water hardness levels. The products tested were BlazeTamer 380, Firewall II, FireIce 561, and Thermo-Gel 200L.

The results from this study showed that two products, BlazeTamer 380 and Firewall II, were the least susceptible to water hardness variations and therefore offer comparatively more reliability in the mixed product’s viscosity irrespective of the water source. Conversely, FireIce 561 and Thermo-Gel 200L showed greater susceptibility to water hardness variations that could result in challenges during operational use.

References

Environment Canada. (1977). *Surface water quality in Canada -- an overview*. Water Quality Branch, Inland Waters Directorate.

Durfor, C.J. and Becker, E. (1972). *Constituents and properties of water*. In: Water quality in a stressed environment: readings in environmental hydrology. W.A. Pettyjohn (ed.). Burgess Publishing Company, Minneapolis, MN.

Garrison Investigative Board. (1977). *Water quality report* (Appendix A). Garrison Diversion Study, report to the International Joint Commission.

Rainwater, F.H. and Thatcher, L.L. (1960). *Methods for collection and analysis of water samples*. Geological Survey Water-Supply Paper, U.S. Department of the Interior. U.S. Government Printing Office, Washington, DC.

Thomas, J.F.J. (1953). *Industrial water resources of Canada*. Water Survey Report No. 1. Scope, procedure, and interpretation of survey studies. Queen's Printer, Ottawa.

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

Yang ,J. and Tsai P.A. (2020). *Firefighting chemicals water testing*. Technical report submitted to FPInnovations September 2020.

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