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IDENTIFICATION AND DEVELOPMENT OF A GELLED FUEL THROUGH THE USE OF LIQUID GELLING AGENTS

PREPARED FOR THE UNITED STATES FORESTRY SERVICE

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13. ABSTRACT (Maximum 200 words)

The United States Forestry Service (USFS) currently uses solid powder gelling agents to create gelled gasoline for controlled burns. Because these gelling agents are difficult to mix with gasoline, nonhomogeneous solutions result. The inconsistency in the gelled gasoline results in larger quantities of it being used for controlled burns and also worsens the safety hazards associated with gel dispersion. Therefore, the project objective was to solve these problems by producing a better, thickened or gelled gasoline using liquid gelling agents. Laboratory tests were performed and a number of products were recommended for field test and evaluation.

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FOREWORD

Solid powder gelling agents that the United States Forestry Service (USFS) currently uses to create gelled gasoline for controlled burns are difficult to mix with gasoline, which results in nonhomogeneous solutions. The inconsistency in these solutions makes it necessary to use larger quantities for controlled burns, and also makes gel dispersion more hazardous. The objective of this project was to solve these problems by producing a thickened or gelled gasoline using liquid gelling agents. Laboratory tests were performed and a number of products were recommended for field testing and evaluation.

This report has been reviewed by Matthew J. Hornbaker, Head, CBR Concepts and Experimentation Branch, and Michael Purello, Head, CBR Defense Division.

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EXECUTIVE SUMMARY

The United States Forestry Service (USFS) currently uses solid powder gelling agents to create gelled gasoline for controlled burns. These gelling agents are difficult to mix with gasoline, which results in nonhomogeneous solutions. The inconsistency in the gelled gasoline requires not only that larger quantities of gelled gasoline be used for controlled burns, but also leads to increased safety hazards associated with gel dispersion. Therefore, the project objective was to solve these problems by producing a thickened or gelled gasoline using liquid gelling agents.

Phase I of the project included identification, test, and evaluation of commercially available gellant technologies, while Phase II involved binary gellant systems and the potential for synthetic development of new gelling agents. Due to successes in Phase I, the development of novel gelling agents in Phase II was not pursued. The following products are recommended for field testing by the USFS:

- Halliburton's My-T-Oil^{SM} system (MO-85M and MO-86M) at 0.5% by weight of each component for gasoline without ethanol and 1.0% by weight of each component for gasoline with ethanol,
- Alco-Brite's Gelled Alcohol Fuel,
- Magna Chemical's Viscopro S.F. at 8% by weight Viscopro S.F. and 32% by weight water, and
- Fire-Trol Canada's Flash21 System at 0.94% by volume of each component for gasoline with ethanol.

GLOSSARY

CONUS	Continental United States
DoD	Department of Defense
DTIC	Defense Technical Information Center
NSWCDD	Naval Surface Warfare Center, Dahlgren Division
USFS	United States Forestry Service

1.0 INTRODUCTION

1.1 Background

The United States Forestry Service (USFS) currently uses thickened or gelled gasoline to conduct controlled burns. There are three primary reasons for using gelled gasoline over regular gasoline.

- Gelation prevents propelled fuels, from sources such as flamethrowers and helitorches, from dissipating before reaching the target.
- Gelled fuel sticks to vegetation while liquid fuel follows the contour of the land.
- Gelled fuels burn longer than nongelled fuels.

However, the current commercially available gelling agents used by the USFS, especially those that are solids, have several associated problems due to their nonhomogeneity, inconsistencies between batches, and difficulties in mixing. These problems are listed below.

- The helitorch pilot must fly closer to the ground to ignite vegetation.
- More gelled gasoline has to be used when the batch is nonhomogenous.
- Helicopter flight time must be increased.
- Flaring at the fuel discharge point can damage equipment.

Each of these problems can be associated with reduced safety and increased cost. Consequently, the USFS became interested in investigating or developing other gelation technologies. Liquid gelling agents were targeted as the best possible candidates to replace the current solid powder products, mainly due to their potential for easier, more efficient mixing.

1.2 Project Objectives

The primary objective of this project was to evaluate commercially available gellant technologies, including those developed for other industries, to gel gasoline. More specifically, the project was to produce a thickened or gelled gasoline without the current gelation system's issues associated with mixing and stability. After test and evaluation, Naval Surface Warfare Center, Dahlgren Division (NSWCDD) would recommend gelling agents or gellant systems, and associated vendor contact information, for field testing to be conducted by the USFS. The project was organized into two phases. Phase I included identification, test, and evaluation of available gellant technologies; Phase II involved binary gellant systems and the potential for synthetic development of a new gelling agent. Due to successes in Phase I, the development of novel gelling agents in Phase II was not pursued.

1.3 Approach

Four approaches were taken simultaneously to identify potential gel technologies to satisfy the requirements of the USFS. The approaches taken were as follows:

- Market survey,
- Literature survey,
- Alternative solutions, and
- Binary gelant systems.

The first approach, a market survey, was performed to identify commercially available chemicals that thicken or gel gasoline or other hydrocarbon liquids. The survey included but was not limited to products specifically designed to gel fuels. An effort was made to avoid sole-source situations and thus multiple vendors across multiple industries were included. Product specifications (e.g., target liquids, stability, temperature sensitivity, required concentration, and price) were analyzed to aid in down selection prior to testing and evaluation. The identified products were tested and evaluated relative to the following:

- Their ability to gel gasoline (with and without ethanol) and diesel fuel,
- The concentration required to produce a gel or thickened liquid,
- The rate of gelation,
- Viscosity, and
- The cost of the gelling agent.

The second approach, a literature survey, investigated published research from industry, academia, and government focusing on methods for increasing the viscosity or gelling fuels and hydrocarbon liquids. Potential specifications (e.g., complexity, availability, and price) were characterized to aid in down-selection prior to testing and evaluation. The identified products were tested and evaluated relative to the following:

- Their ability to gel gasoline (with and without ethanol) and diesel fuel,
- The concentration required to produce a gel or thickened liquid,
- The rate of gelation,
- Viscosity, and
- The cost of the gelling agent.

The third approach, alternative solutions, surveyed commercially available gelled fuels, other than gasoline (e.g., gelled alcohols), that are currently used in industry. These products were to be comparatively analyzed with their counterparts from the market and from literature surveys as well as identified binary gelling agents.

The fourth and last approach was to investigate or develop a binary gelant system. The basic idea was that two liquids that normally form a gel when mixed could be added to gasoline, one at a time, and form a gel incorporating the gasoline or targeted chemical. Usually, for this approach to work, at least one of the chemicals must be soluble in the targeted solvent—gasoline in this case. This investigation was based on available literature and the experience of researchers at NSWCDD. The identified products were tested and evaluated relative to the following:

- Their ability to gel gasoline (with and without ethanol) and diesel fuel,
- The concentration required to produce a gel or thickened liquid,
- The rate of gelation,
- Viscosity, and
- The cost of the gelling agent.

2.0 EXPERIMENTAL PROCEDURE

2.1 Supplies and Equipment

- Brookfield Digital Viscometer Model DV-II
- 8-ml screw cap glass vials
- Volumetric pipettes
- Serological pipette
- Balance
- Stainless steel scoops

2.2 Chemicals

- Gasoline
- Gasoline with approximately 10% ethanol
- Diesel fuel
- Carbopol EZ
- Armeen CD
- Carbopol EZ II
- Ninol 11-CM
- MO-85M
- MO-86M
- Imbiber Beads
- Aluminum stearate
- Hexanol
- Octonal
- Decanol
- Fire gel
- Flash 21

- Magna Viscopro S.F.
- Swiss fire gel
- Sterno gelled fuel

2.3 Experimental Procedure

All experiments were conducted in certified laboratory chemical fume hoods at ambient temperature and pressure. All mixing was accomplished via hand-shaking of the 8-ml glass vials. Components were added to the vials either by weight (solids) or volume (solids and liquids) in predetermined ratios. Order of addition was either an experimental variable or dictated by the manufacturer's instructions. Viscosities were measured following the equipment instruction manual.

2.4 Data Evaluation

Gelation and viscosity increases were visually observed and approximate times were recorded and data tabulated. Photographic records of successful gelling agents or thickeners were created. The arithmetic means of the measurable viscosities along with their standard errors were calculated and tabulated.

3.0 PHASE I RESULTS AND DISCUSSION

3.1 Market Survey

A comprehensive survey of commercially available gellant technologies was conducted. The World Wide Web was the main resource utilized to search the market for readily available solutions designed to gel gasoline or other hydrocarbon fuels. Delineations were not made across industries and the search was not limited to the gelation of fuel for purposes similar to that of the USFS. One of the primary objectives was to provide multiple products, associated with multiple companies, to eliminate the problem of dependency on a sole-source supplier. The USFS was aware of and familiar with Fire-Trol Canada and its products, including the following:

- Fire-Trol Canada – SureFire™: This product is a solid gelling agent already in use by the USFS. The primary goal is to overcome the following difficulties associated with this product: (1) difficulties when blending into fuel, (2) inconsistencies from batch to batch, and (3) creation of dust during mixing.

- Fire-Trol Canada – Petrol Jel™: This product is a liquid gelling agent designed to thicken fuels. There are known problems such as nonhomogeneity of the mix and separation of the product from the fuel over time (i.e., settling).

- Fire-Trol Canada – Flash21™: This product is a two- part liquid gelling agent. It is undergoing field testing in the United States, Canada, and Australia. Initial test results look promising, although it was unclear if this product will work with commonly available gasoline containing ethanol.

In addition to these products supplied by the current vendor, Fire-Trol Canada, three others were identified during the market survey. The first of these products is a two-part chemical system that Halliburton developed for use in oil wells. Halliburton operates in nearly 70 countries and offers a broad array of products and services to upstream oil and gas customers. This company typically works in two major business segments across the lifecycle of oil and gas reservoirs—drilling and evaluation, and completion and production. The My-T-Oil℠ V Service Oil-Based Gel System product, offered by Halliburton, had the potential to satisfy the requirements of the USFS. This product is discussed below:

- Halliburton – My-T-Oil℠ V Service Oil-Based Gel System (MO-85M and MO-86M): Test and evaluation of this product, conducted by Halliburton scientists, indicated positive results. One percent by mass (0.5% each part) created a stiff but pourable gel with gasoline. Again, it was unclear if this product will work with commonly available gasoline containing ethanol.

The second option identified during the market survey is a product made by Magna Chemical Canada, Inc., Viscopro S.F. Magna Chemical Canada is part of the global Magna Chemical Group of Companies. Viscopro S.F. had the potential to satisfy the requirements of the USFS. This product is discussed below:

- Magna Chemical Canada, Inc. – Viscopro S.F.: This product is a liquid specialty surfactant used to make water- and solvent-based gels and pastes. An advantage of this product is that gelled mixtures contain approximately 30% by mass of water and gelation occurs instantly upon addition of that water. Furthermore, test and evaluation of this product by Magna showed that Viscopro S.F. can gel gasoline and that the gel still burns even though the gel is 30% water. Again, it was unclear if this product will work with commonly available gasoline containing ethanol.

The third option is a product of the Lubrizol Corporation, Carbopol EZ 3. The Lubrizol Corporation is a specialty chemical company serving the global transportation, industrial, and consumer markets. Carbopol EZ 3 also had the potential to satisfy the requirements of the USFS, except that it is a solid polymer. This product is discussed below:

- Lubrizol – Carbopol EZ 3: This product is a patented, self-wetting, crosslinked polyacrylic acid polymer (solid) that can be used to transform many liquid products into a gel. It is suggested for use as an all-purpose thickener and rheology modifier, oil-in-water emulsion stabilizer, and in making gelled fuel among other uses. Examples were given of its use to produce gelled alcohol fuels with both ethanol and methanol.

Another product that was identified in the market survey is a product of Messina Chemicals, OilAid. Messina Chemicals' gelation system is stable from 80^{o}F to 300^{o}F. This temperature range does not fit the requirements of the USFS and, therefore, OilAid was not purchased for testing.

3.2 Literature Survey

Comprehensive information and literature searches of a number of databases were conducted, including the Defense Technical Information Center (DTIC) of Science and Technology. Although the gelation of hydrocarbon fuels was specifically documented in multiple sources during this literature survey, the results were limited. They are categorized below:

Defense Technical Information Center (DTIC) Reports:

1. A. R. Schleicher, *Rapid Gelling of Aircraft Fuel*, **AD629765**.
2. W. G. Setser, *Fuel Gelling for Ballistic Protection of Aircraft Fuel Tanks*, **AD382874.**
3. R. E. Erickson, *Chemical and Physical Study of Fuels Gelled with Hydrocarbon Resins*, **AD728305**.
4. James Teng, *Chemical and Physical Study of Fuels Gelled with Carbohydrate Resins*, **AD730513**.
5. L. Maurice Shaw, *Safety Evaluation of Emulsified Fuels*, **AD729330**.
6. James P. Waller, *A Study of Rapid Solidification of Hydrocarbon Fuels*, **AD426127**.

Scientific Journal Articles, Books, and Conference Proceedings:

1. William W. Banister, Applications of Amine Gelling Agents in Fire Technology, *Plant/Operations Progress*, Volume 8, No. 2, April 1989, pages 80-81.
2. Volume Editor: Frederic Fages, Low Molecular Mass Gelators: Design, Self-Assembly, Function, Springer-Verlag, **Volume 256**, 2005.
3. Yair Solomon, *Combustion of Gel Fuels based on Organic Gellants*, 42nd AIAA Joint Propulsion Conference and Exhibit, July 2006.

From these sources, potential gelation systems were identified and logically evaluated for down-selection for laboratory test and evaluation. The systems investigated are listed here:

- Amine carbamates
- Cocoamine (C12-C14) and sebacoyl chloride
- Dodecyl amine and a mixture of toluene-2,4-diisocyante and toluene-2,6-diisocyanate
- Olely (C18) amine and a mixture of toluene-2,4-diisocyante and toluene-2,6-diisocyanate
- Benzene and polystyrene
- Aluminum soaps (e.g., aluminum stearate)
- Alcohols plus laundry detergent (aluminum soaps)

Although all systems above possess the potential to gel gasoline for use by the USFS, there are associated drawbacks that make the majority of the identified possibilities infeasible. The amine carbamates required gaseous carbon dioxide to be passed through the fuel for successful gelation. This requirement increases the mixing difficulties currently experienced and is impractical for field use. The diisocyanates are only readily available in gram quantities at a cost of approximately $50 per gram, thus making them cost-prohibitive. Furthermore, a mixture of gasoline, benzene, and polystyrene creates Napalm B. Napalm B requires very high temperatures for ignition and thus is impractical for field use by the NSFS with the currently fielded ignition mechanisms (e.g., flamethrowers, helitorches). Therefore, the aluminum soaps presented the only practical option and, thus, neat aluminum stearate and that mixed with hexanol, octonal, or decanol was selected for laboratory test and evaluation.

3.3 Phase I Laboratory Test and Evaluation Results and Discussion

Test and evaluation of Phase I products can be divided into three parts:

1. Visual inspection of the fuel / gelling agent mixture for gelation or thickening
2. Recording the approximate time required for observed gelation or thickening
3. Measuring the viscosity of the solution using a Model DV-II Brookfield Digital Viscometer

Presented in this section are photographs of successful gelation products along with commentary on each product's behavior and potential for use in the field by the USFS. In Appendix A, a table of complete project results is available and includes the unsuccessful gelling agents tested.

Figures 1 through 4 depict gels created using one of the familiar Fire-Trol products, SureFire. Laboratory mixtures were scaled down to 5-ml vials, but the gelling agent concentration simulated field scenarios where either 3 or 4 pounds of SureFire is added to 55 gallons of fuel. The purpose of making these gels was to gain first-hand experience with the problems experienced by the USFS when using this gelant product, such as inconsistencies, and to evaluate the differences in gelation when ethanol is present in the gasoline. Initially, viscosity data was obtained using the Model DV-II Brookfield Digital Viscometer but that data was eventually abandoned due to observed inconsistencies between batches and within the mixtures. In both simulations, the gasoline containing ethanol resulted in a nonhomogeneous mixture of gel and viscous liquid while the ethanol-free gasoline was a nearly homogeneous, thickened liquid. Gel formation was completed within 2 to 4 hours in all cases. As FireGel is currently unsatisfactory to the customer, is inconsistent, and does not create a uniform gel when ethanol is introduced, FireGel is not recommended for field testing and continued use by the USFS.

Figure 1. FireGel in Gas Containing Ethanol 3-lb Simulation

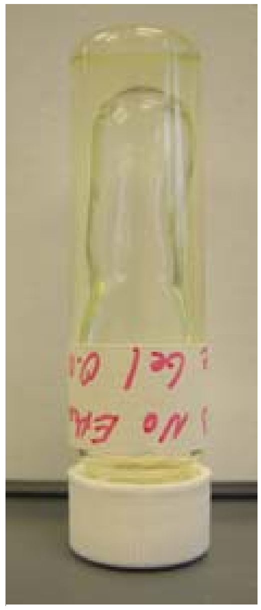

Figure 2. FireGel in Gas Without Ethanol 3-lb Simulation

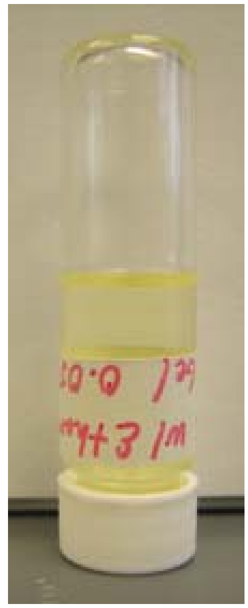

Figure 3. FireGel in Gas Containing Ethanol 4-lb Simulation

Figure 4. FireGel in Gas Without Ethanol 4-lb Simulation

Figures 5 through 8 depict gels created using another of the familiar Fire-Trol products, the company's newly released Flash21. Laboratory mixtures were scaled down to 5 ml, but simulated field scenarios where either 1 liter or 2 liters of each of the components of the Flash21 system is added to 55 gallons of fuel. The purpose of making these gels was to evaluate the differences in gelation when ethanol is present in the gasoline and to serve as a baseline for comparison of the experimental products from the market survey and the literature survey. Additionally, the goal was to specifically identify the viscosity of these gels because the USFS deemed Flash21 as acceptable during field trials. Identification of the desired viscosity range was important as it was to be the metric that determined whether a gel or gelation system is deemed acceptable for use by the USFS. After much effort, viscosity was deemed not a suitable metric as many of the products, including the baselined Flash 21, produced gels exhibiting viscosities outside of the range of the instrument. The viscosity data also exhibited a large degree of variability in the viscosity measurements that *were* within the instrument's range.

Figure 5. Flash21 in Gas Containing Ethanol 2-L Simulation

Figure 6. Flash21 in Gas Without Ethanol 2-L Simulation

Figure 7. Flash21 in Gas Containing Ethanol 4-L Simulation

Figure 8. Flash21 in Gas Without Ethanol 4-L Simulation

In both simulations, the gasoline without ethanol resulted in thicker liquid than when ethanol was present in the gasoline. When the amount of Flash 21 was doubled (i.e., in the 4-L simulation), the resulting liquids were thicker and thus the thickness is directly proportional to the amount of Flash21 added to gasoline with or without ethanol. The viscosity change was complete in less than 30 seconds in all cases and in no case was a completely solidified gel formed using Flash21. Because Flash21 shows considerably improved characteristics and the potential for use when ethanol is present in the gasoline, Flash21 using 2 L of each component is recommended for additional field testing and has the potential for use by the USFS with both types of gasoline.

During these initial tests, the commercially available, solid, absorbent Imbiber Beads were tested as well. The results are shown in Figures 9 and 10 below. Imbiber Beads are an absorption technology advertised as useful for cleaning chemical spills. The Imbiber Beads were included as NSWCDD experience shows that they are typically useful for organic solvents. The addition of 10% Imbiber Beads resulted in complete absorption and solid material in both types of gasoline, with and without ethanol. Absorption was complete in less than 5 minutes in all cases. As a result, NSWCDD repeated the test with 1% Imbiber Beads. At 1%, a gel does not form and, in fact, only minimal absorption of gasoline is observed. Because Imbiber Beads are solid themselves and at best create solidified gels that would be impossible to pump or disperse as necessary, Imbiber Beads are not recommended for field testing or use by the USFS.

Figure 9. 10% Imbiber Beads in Gasoline Containing Ethanol

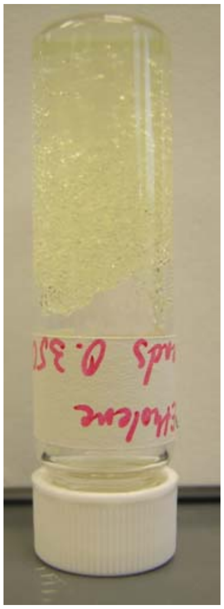

Figure 10. 10% Imbiber Beads in Gasoline Without Ethanol

Figures 11 through 13 depict gels created using Halliburton's My-T-Oil^{SM} V Service Oil-Based Gel System at 1% of the total weight (i.e., 0.5% MO-85M and 0.5% MO-86M). For gasoline without ethanol and diesel fuel, gelation was the result. When the components were added to gasoline containing approximately 10% ethanol, the result was a thickened liquid that slowly flowed down the side of the vial when inverted. The viscosity change or gelation was complete in less than 30 seconds in all cases. There was no noticeable change upon the addition of MO-85M to the fuels. Thickening and gelation occurred upon the addition of the second component MO-86M. Therefore, the possibility exists to premix MO-85M with the fuels for convenience. The use of 0.5% of each component is recommended for additional field testing and has the potential for use by the USFS with diesel fuel and both types of gasoline.

Figure 11. 0.5% Each MO-85M and MO-86M in Gas Containing Ethanol

Figure 12. 0.5% Each MO-85M and MO-86M in Gas Without Ethanol

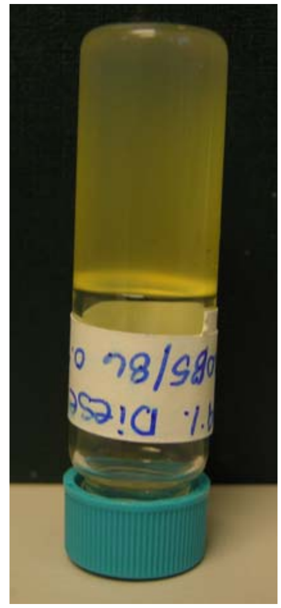

Figure 13. 0.5% Each MO-85M and MO-86M in Diesel Fuel

Figures 14 through 16 depict gels created using Halliburton's My-T-Oil[SM] V Service Oil-Based Gel System at 2% of the total weight (i.e., 1% MO-85M and 1% MO-86M). For gasoline without ethanol and diesel fuel, gelation occurred and a firm gel was the result. When the components were added to gasoline containing approximately 10% ethanol, the result was a gel that resembled those obtained with lower percentages in gasoline without ethanol and diesel fuel. The gelation was complete in less than 30 seconds in all cases. There was no noticeable change upon the addition of MO-85M to the fuels. Thickening and gelation occurred upon the addition of the second component MO-86M. Therefore, the possibility exists to premix MO-85M with the fuels for convenience. The use of 1% of each component is recommended for additional field testing and has the potential for use by the USFS with gasoline containing ethanol. The gels obtained with gasoline without ethanol and diesel fuel are likely too rigid to pump and disperse via the methods currently employed by the USFS.

Figure 14. 1% Each MO-85M and MO-86M in Gas Containing Ethanol

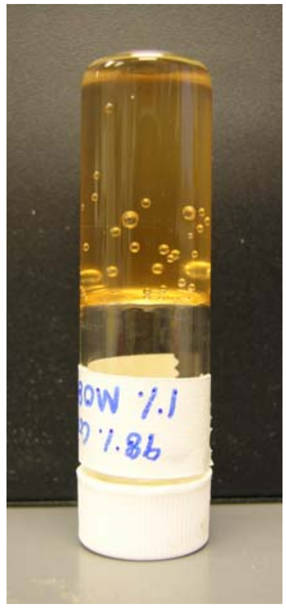

Figure 15. 1% Each MO-85M and MO-86M in Gas Without Ethanol

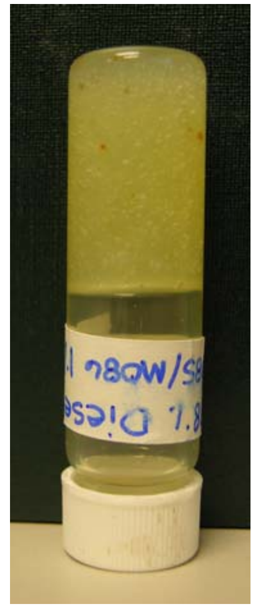

Figure 16. 1% Each MO-85M and MO-86M in Diesel Fuel

Figures 17 through 19 depict gels created using Magna Chemical's Viscopro S.F. and tap water mixed according to the manufacturer's instructions. The gels seem independent of the fuel type used and in all cases are likely too thick to pump and disperse via the methods currently employed by the USFS. In addition, there was no noticeable change upon the addition of Viscopro S.F. to the fuels other than color due to the incorporation of the brown Viscopro S.F. into the transparent yellow fuel. Thickening and gelation occurred locally immediately upon the addition of the second component, water, and became homogenous upon hand-shaking. Therefore, the possibility exists to premix Viscopro S.F. with the fuels for convenience. The use of this gelation system in the proportions tested here is not recommended for additional field testing. Also, the quantities required for field testing (i.e., the mix is 55% fuel by weight) and subsequent use by the USFS may make the Viscopro S.F. system impractical for use.

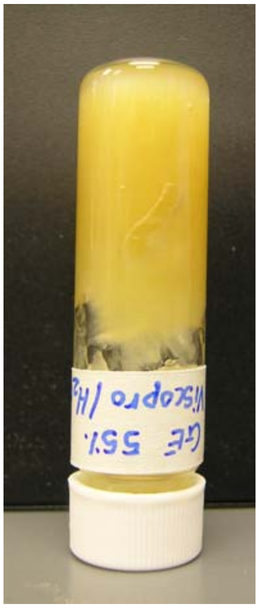

Figure 17. 16% Viscopro S.F. and 29% Tap Water in Gas Containing Ethanol

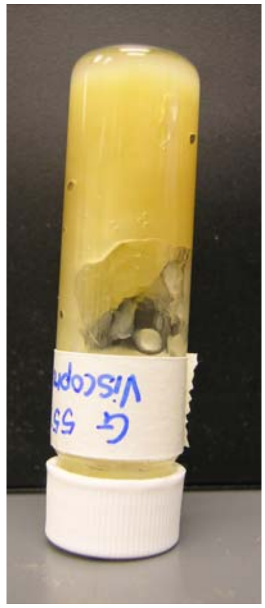

Figure 18. 16% Viscopro S.F. and 29% Tap Water in Gas Without Ethanol

Figure 19. 16% Viscopro S.F. and 29% Tap Water in Diesel Fuel

Figures 20 through 22 depict gels created using Magna Chemical's Viscopro S.F. and tap water mixed using less Viscopro than the manufacturer's recommendations. Through experimentation it was determined that the relative proportions of Viscopro S.F. and water were crucial to the proper functionality of the gelation system. Therefore, the gels created are likely a framework constructed via linkages between Viscopro S.F. and water molecules with fuel occupying the free spaces. For this reason, the ratio of Viscopro S.F. to water suggested in the manufacturer's mixing instructions was preserved in these mixtures. At these proportions, there was no noticeable difference between gels of gasoline and gasoline containing approximately 10% ethanol. The mixture with diesel fuel was a thickened liquid that flowed easily down the sides of the vial when inverted. In addition, there was again no noticeable change upon the addition of Viscopro S.F. to the fuels other than color, due to the incorporation of the brown Viscopro S.F. into the transparent yellow fuel. Thickening and gelation occurred locally immediately upon the addition of the second component, water, and became homogenous upon hand-shaking. Therefore, the possibility exists to premix Viscopro S.F. with the fuels for convenience. The use of this gelation system in the proportions tested here is recommended for additional field testing with gasoline both with and without ethanol. It must be noted that the quantities required for field testing (i.e., the mix is 60% fuel by weight) and subsequent use by the USFS may make the Viscopro S.F. system impractical for use. Testing at these proportions in not recommended for diesel fuel as gelation was unsuccessful. As a follow-on to this testing, diesel fuel alone was tested with 10% Viscopro S.F. and 31% water. The result was much like that for the gasoline tested above with 8% Viscopro S.F.

Figure 20. 8% Viscopro S.F. and 32% Tap Water in Gas Containing Ethanol

Figure 21. 8% Viscopro S.F. and 32% Tap Water in Gas Without Ethanol

Figure 22. 8% Viscopro S.F. and 32% Tap Water in Diesel Fuel

3.4 Alternative Solutions

A comprehensive survey of commercially available gelled fuels was conducted. The World Wide Web was the main resource utilized to search the market for readily available products across all markets and industries. This survey resulted in three products primarily intended for consumer use:

- Alco-Brite (gelled alcohol)
- Flamenco Gel Fuel (gelled alcohol)
- Swiss Fire Gel (gelled alcohol)

The products listed above are commercial and readily available in small, prepackaged quantities at a cost of approximately $10 per quart. In addition, it is unknown if these products will have the required burn characteristics. Therefore, these commercial gelled alcohols remain a possibility, but most are likely cost-prohibitive. NSWCDD scientists measured the viscosity of two of the three gelled fuels listed above and the results are listed in Table 1.

Table 1. Viscosity Data for Commercially Available Gelled Fuels (Gelled Alcohols)

(The upper limit of the measurable range of viscosities is 10,000 cps for the Model DV-II Brookfield Digital Viscometer.)

Commercial Gelled Fuel				
	II	III	AVG	ERR
Swiss Fire Gel	6710	6510	6610	82
Sterno Canned Cooking Fuel	$>10^5$	$>10^5$	$>10^5$	-

Swiss Fire Gel was less viscous than the majority of the gelation systems tested during this project. Sterno Cooking Fuel was paste-like and is likely hard to distribute through a pump system as is currently employed by the USFS. Again, these products are typically sold in small quantities and may prove cost-prohibitive unless a bulk vendor can be identified.

This cost problem may be overcome by the product manufactured by Alco-Brite, Inc. It be purchased in 55-gallon drums, and the burn properties and viscosity can be adjusted for the intended use. Alco-Brite's gelled alcohol is currently used by the railroad industry to heat the metal when repairing or replacing track. Assuming the USFS is able to procure this product, its primary advantage is that it is premixed and the by-products of combustion are water and carbon dioxide, making it a green fuel. The opportunity exists to alter the current formulation to produce a special product for the USFS, although certain additives can create additional by-products and increase the environmental impact. However, it is likely that this option is still better for the environment than burning gasoline in any form. The price of the Alco-Brite gelled fuel is dependent on the quantity and the type of gelled fuel purchased.

A second alternative solution investigated was commercially available gelled aircraft fuels. The literature survey uncovered research into gelling aircraft fuels for improved safety. NSWCDD contacted various companies in the petroleum industry to determine the availability of such products. At this time, gelled aircraft fuel is not commercially available, and there was no indication that it will be in the future. Therefore, purchasing gelled aircraft fuels was not a viable option and will not be pursued further.

4.0 PHASE II RESULTS AND DISCUSSION

4.1 Binary Gelant Systems

An investigation of a potential binary system that could form gels with gasoline was conducted. This investigation was based on available literature and the experience of researchers at NSWCDD. Over the past five years, NSWCDD has worked to develop surfactant technologies for use the by the Department of Defense (DoD). One of these technologies is phase-tailored explosives, meaning the development of products that allow a warfighter to make solid, liquid, or gelled explosives as determined by the operational need. During this research, NSWCDD scientists learned that compounds containing nitrate groups often form gels when mixed with compounds that contain alcohol groups. These chemicals are commercially available from a variety of sources and thus the potential for a binary gelation system utilizing nitrate and alcohol functional group surfactant chemistry was investigated. Two compounds of interest are shown in Figure 23.

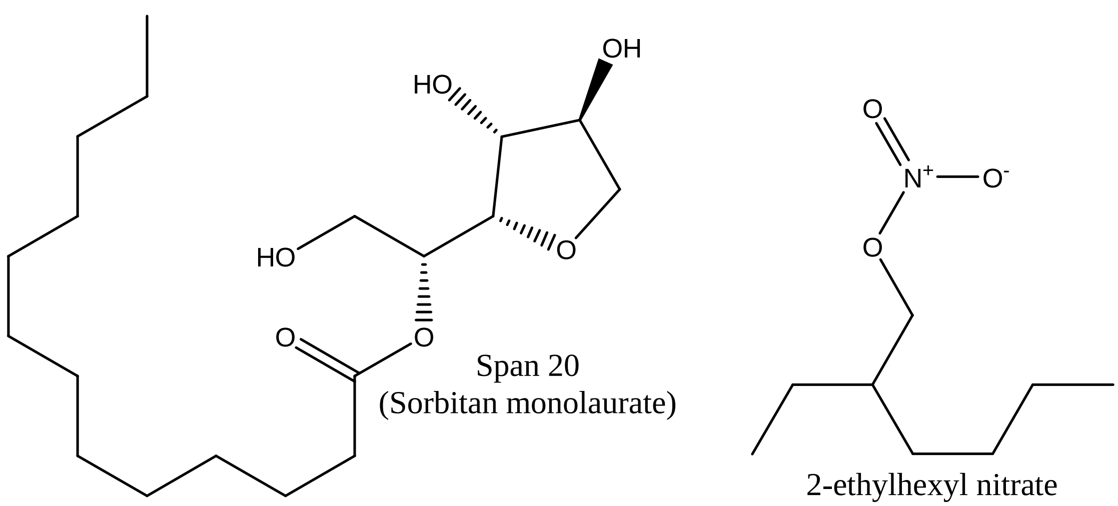

Figure 23. Two Compounds of Interest for Use in a Binary Gelation System

Drawing from this information, the following potential binary gelation systems were identified and tested:

- 2-ethylhexyl nitrate and Span 20
- 2-ethylhexyl nitrate and Span 80
- 2-ethylhexyl nitrate and Ninol 11-CM

Equally proportioned volumetric mixtures of 2-ethylhexyl nitrate with the surfactants listed above did not create gels. Systematic increases in the percentage of surfactant were unsuccessful in gelation as well. All mixtures thickened, probably due to higher viscosities of the surfactants. Because of the lack of successful gelation, the use of these chemical combinations as binary fuel gelling agents was discounted.

In addition, drawing from and adding to the comprehensive information and literature searches conducted in Phase I, the following potential binary gelation system was identified and tested:

- Cocoamine (Armeen® CD) and alkanolamide (Ninol 11-CM)

An equally proportioned volumetric mixture of Armeen® CD and Ninol 11-CM created a solid gel in less than 1 hour. However, a volumetric mixture of 90% gelants and 10% fuel was soluble but did not create a gel. Although it is possible that increasing percentages of the binary gelant mixture would create a gel, this avenue was not pursued as it was not deemed operationally practical or cost effective to utilize gelling agent contents higher than 10% by volume.

5.0 CONCLUSIONS, RECOMMENDATIONS, AND FUTURE WORK

5.1 Conclusions and Recommendations

While there are a limited number of commercially available products useful for gelling gasoline (with and without ethanol) and diesel fuel, a few do exist and provide alternatives for use by the USFS. Halliburton's My-T-Oil^{SM} V Service Oil-Based Gel System and Magna Chemical's Viscopro S.F. surfactant do satisfy the customer's need to avoid the dependency of a sole-source supplier. The potential to use Alco-Brite's gelled alcohol fuel eliminates the need for mixing, thus reducing labor and logistics requirements and making immediate response to an event (e.g., forest fire) easier.

NSWCDD recommends the following products for field testing by the USFS with gasoline with and without ethanol:

1. Halliburton's MO-85M and MO-86M Oil-Based System
    a. 0.5% by weight of each component for gasoline without ethanol
    b. 1.0% by weight of each component for gasoline with ethanol
2. Alco-Brite's Gelled Alcohol Fuel
3. Magna Chemical's Viscopro S.F.
    a. 8% by weight Viscopro S.F. and 32% by weight water
4. Fire-Trol Canada's Flash21 System
    a. 0.94% by volume of each component for gasoline with ethanol

5.2 Future Work Considerations

A time-course study on the gelation systems that are successful in pending field testing would be prudent. The shelf-life and storage temperature requirements for the gelled fuels are valuable information. NSWCDD has environmental chambers suitable to simulate a variety of real-world environments for a variety of temperatures and humidity levels.

APPENDIX A

RESULTS TABLE

Table A-1. Results Table

Key:
Grey = Not Tested
% = weight % unless otherwise noted
IS = Insoluble
S = Soluble
G = Gel
T = Thickener
EEE = Exceeded machine limits
X = Not tested because gelation unsuccessful or solidified
NA = not applicable

Gelling Systems	Gasoline including 10% Ethanol	Viscosity (CPS)					Gasoline including 0% Ethanol	Viscosity (CPS)					Diesel Fuel	Viscosity (CPS)				
		I	II	III	AVG	ERR		I	II	III	AVG	ERR		I	II	III	AVG	ERR
Carbopol EZ 0.5% Carbopol, 24% water, 75% Fuel, 0.5% Armeen CD	IS	X	X	X	X	NA	IS	X	X	X	X	NA	IS	X	X	X	X	NA
Carbopol EZ II 0.5% Carbopol, 24% water, 75% Fuel, 0.5% Ninol 11-CM	IS	X	X	X	X	NA	IS	X	X	X	X	NA	IS	X	X	X	X	NA
Halliburton Oil Based System 99% Fuel, 0.5% MO-85M, 0.5% MO-86M	T	9020	10100	9320	9480	322	G	$>10^5$	$>10^5$	$>10^5$	$>10^5$	NA	G	$>10^5$	$>10^5$	$>10^5$	$>10^5$	NA
Halliburton Oil Based System 98% Fuel, 1% MO-85M, 1% MO-86M	G	47400	50100	51800	49767	1281	G	$>10^5$	$>10^5$	$>10^5$	$>10^5$	NA	G	$>10^5$	$>10^5$	$>10^5$	$>10^5$	NA
Imbiber Beads 90% Fuel, 10% Imbiber beads	G[2]	X	X	X	X	NA	G[2]	X	X	X	X	NA	G[2]	X	X	X	X	NA
Imbiber Beads 99% Fuel, 1% Imbiber beads	IS	X	X	X	X	NA	IS	X	X	X	X	NA	IS	X	X	X	X	NA
Aluminum Stearate + Alcohol 90% Fuel, 5% Al Stearate, 5% Hexanol	IS	X	X	X	X	NA	IS	X	X	X	X	NA	IS	X	X	X	X	NA
Aluminum Stearate + Alcohol 90% Fuel, 5% Al Stearate, 5% Octonal	IS	X	X	X	X	NA	IS	X	X	X	X	NA	IS	X	X	X	X	NA
Aluminum Stearate + Alcohol 90% Fuel, 5% Al Stearate, 5% Decanol	IS	X	X	X	X	NA	IS	X	X	X	X	NA	IS	X	X	X	X	NA
Aluminum Stearate 90% Fuel, 10% Aluminum Stearate	IS	X	X	X	X	NA	IS	X	X	X	X	NA	IS	X	X	X	X	NA
Fire Gel 3 lbs in 55 gal fuel simulation	G	3730					G	185				NA						NA
Fire Gel 4 lbs in 55 gal fuel simulation	G	2000					G	8900				NA						NA
Flash 21 (vol %) 98% Fuel, 1% Part A, 1% Part B	G	21400	19900	19500	20267	578	G	$>10^5$	$>10^5$	$>10^5$	$>10^5$	NA	G	$>10^5$	$>10^5$	$>10^5$	$>10^5$	NA
Flash 21 (vol %) 99% Fuel, 0.5% Part A, 0.5% Part B	G	1790	2150	2200	2047	129	G	$>10^5$	$>10^5$	$>10^5$	$>10^5$	NA	G	$>10^5$	$>10^5$	$>10^5$	$>10^5$	NA
Magna Viscopro S.F. 55% fuel, 16% Viscopro, 29% water	G[1]	X	X	X	X	NA	G[1]	X	X	X	X	NA	G[1]	X	X	X	X	NA
Magna Viscopro S.F. 60% fuel, 8% Viscopro, 32% water	G[3]	33200	33200	35400	33933	733	G[3]	$>10^5$	$>10^5$	$>10^5$	$>10^5$	NA	T	4810	4610	1640	3687	1025
Ninol 11-CM + Armeen CD (vol%) 90% fuel, 5% Ninol 11-CM, 5% Armeen CD	S	X	X	X	X	NA	S	X	X	X	X	NA	S	X	X	X	X	NA

1. Gel appears similar to household petroleum jelly in consistency
2. Gel is completely solidified
3. Gell appears similar to household hand cream

ERR = Standard Error
AVG = Average

APPENDIX B

VENDOR CONTACT INFORMATION

APPENDIX B—VENDOR CONTACT INFORMATION

Halliburton Energy Services, Inc.
(My-T-Oil^{SM} V Service Oil-Based Gel System MO-85M and MO-86M)

Address:
Halliburton Energy Services, Inc.
Corporate Office
Suite 2400
1401 McKinney St
Houston, TX 77010

Sales Contacts:
Curtis Cheetham: (307) 473-8282
Jay Watson: (307) 473-8205
Website: www.halliburton.com

Pricing:
Pricing is dependent on quantity purchased. Products can be packaged as required by USFS.

Alco-Brite, Inc.
(Gelled Alcohol)

Address:
Alco-Brite, Inc.
P.O. Box 840926
Hilldale, Utah, 84784

Sales Contact:
(435) 874-1025
Website: alco@forestwd.com

Pricing:
Pricing is dependent on quantity purchased.

Magna Chemical Canada, Inc.
(Viscopro S.F.)

Address:
Magna Chemical Canada, Inc.
15 Bowman Avenue, P.O. Box 534
Matheson, ON POK 1NO
Canada

Sales Contacts:
James Cheng
Phone: (705) 273-3353
Fax: (705) 273-3352
Website: www.vappro.com
http://www.vappro.com/sub/viscopro-surfactant.jsp

Pricing:
$9.40 per liter (available in 20-liter pails)

Fire-Trol Canada (ASTARIS Canada LTD)
(Flash21)

Address:
Fire-Trol Canada (ASTARIS Canada LTD)
3060 Airport Rd
Kamloops, BC
V2B 7X2

Sales Contacts:
PH: (250) 554-3530
Fax: (250) 554-7788
Website: http://www.firetrolcanada.com

Pricing:
$174.00 per case (12 1-liter bottles per case, $14.50 per liter)

APPENDIX C

MIXING INSTRUCTIONS FOR A 55-GALLON FUEL DRUM

APPENDIX C—MIXING INSTRUCTIONS FOR A 55-GALLON FUEL DRUM

Halliburton Energy Services, Inc. (My-T-Oil[SM] V Service Oil-Based Gel System)

For 55 gallons of gasoline without ethanol (99% fuel mix):

1. Add 825 ml MO-85M (1.81 lb) and mix until homogeneous.
2. When ready for gelation, add 608 ml MO-86M (1.81 lb) to the preceding mixture and mix thoroughly to create gel.

For 55 gallons of gasoline containing approximately 10% ethanol (98% fuel mix):

1. Add 1670 ml MO-85M (3.65 lb) and mix until homogeneous.
2. When ready for gelation, add 1230 ml MO-86M (3.65 lb) to the preceding mixture and mix thoroughly to create gel.

For 55 gallons of diesel fuel (99% fuel mix):

1. Add 973 ml MO-85M (2.13 lb) and mix until homogeneous.
2. When ready for gelation, add 717 ml MO-86M (2.13 lb) to the preceding mixture and mix thoroughly to create gel.

Magna Chemical Canada, Inc. (Viscopro S.F.)

For 55 gallons of gasoline without ethanol (60% fuel mix):

1. Add 5.66 gallons of Viscopro S.F. (47.7 lb) and mix until homogeneous.
2. When ready for gelation, add 22.9 gallons of water (191 lb) under agitation to the preceding mixture and mix thoroughly to create gel.

For 55 gallons of gasoline containing approximately 10% ethanol (60% fuel mix):

1. Add 5.66 gallons of Viscopro S.F. (47.7 lb) and mix until homogeneous.
2. When ready for gelation, add 22.9 gallons of water (191 lb) under agitation to the preceding mixture and mix thoroughly to create gel.

For 55 gallons of diesel fuel (59% fuel mix):

1. Add 8.49 gallons of Viscopro S.F. (71.6 lb) and mix until homogeneous.
2. When ready for gelation, add 26.6 gallons Water (222 lb) under agitation to the preceding mixture and mix thoroughly to create a gel.

Fire-Trol Canada (ASTARIS Canada LTD) (Flash 21)

For 55 gallons of gasoline containing approximately 10% ethanol (98% fuel mix):

1. Add 2000 ml Flash21A and mix until homogeneous.
2. When ready for gelation, add 2000 ml Flash21B to the preceding mixture and mix thoroughly to create gel.

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