EMULSION BREAKING IGNITERS: RECENT DEVELOPMENTS IN OIL SPILL IGNITER CONCEPTS

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ABSTRACT

This paper summarized results from a series of laboratory and field experiments carried out to refine an emulsion breaking igniter (EBI) concept. This igniter, composed of a mixture of gelled fuels (gasoline, diesel and Bunker C) and an emulsion breaker (Alcopol 060) was developed for the ignition of stable water-in-oil (w/o) emulsions. The EBI differs from the so-called break-and-burn approach (i.e.: the pre-burn of an emulsion breaker to the slick followed by deployment of an igniter) in that it offers a one-step approach to the ignition, by both breaking and igniting an oil slick in a single step.

Recent experimental work has resulted in the development of a tool capable of igniting 50% water-in-oil emulsions of Statfjord crude oil. This igniter was deployed from a Helitorch onto emulsion slicks ranging in size from 7 to 80 m² in area. A burn efficiency of 80% was obtained for an initial slick volume of 100 L, while efficiencies of up to 75% were observed with 4 000 L slicks burning uncontained. The results obtained show the potential of a one-step approach to igniting w/o emulsions.

INTRODUCTION

SINTEF Applied Chemistry has been working in the area of in-situ burning of water-in-oil (w/o) emulsions since 1990. A research programme to study the feasibility of in-situ burning as a response method for spills in broken ice was initiated by NOFO (Norwegian Clean Seas) as part of a wider NOFO programme, "Oil spill contingency in Northern and Arctic waters" (ONA). It became clear, early on in this in-situ burning programme, that the ignition and burning of water-in-oil emulsions was more difficult and involved a more complex process than burning fresh or evaporated oils (Bech *et al.* 1991 and 1992). Existing ignition methods, such as gelled gasoline, which were known to be effective with unemulsified oils, were found to be increasingly less effective with increasing emulsion water content (Spiltec 1987 and Bech *et al.* 1992). Alternative ignition sources were investigated. Early experiments demonstrated that increasing the heat source, such as substituting diesel or crude oil for the gasoline, could improve the effectiveness of an igniter. The addition of an emulsion breaker to the gelled fuel was also suggested.

These concepts were further investigated during the 1993 emulsion burning project. Findings from extensive laboratory work done 1993 also helped identify some of the processes governing the ignition and burning of emulsions, which in turn helped define criteria for an emulsion breaking igniter (Guénette *et al.* 1994 and 1995). For instance, it was verified that water must be removed from an emulsion

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before ignition can occur; water is removed mainly through evaporation; and that the maximum temperature in a water-in-oil emulsion is the boiling point of water. To ignite an unemulsified crude oil slick, the igniter must supply enough heat to raise the slick surface to above the oil's fire point. In order to ignite a water-in-oil emulsion, enough water must first be remove from the slick, to produce a layer of water free oil on the surface of the emulsion slick. It is this oil layer which can then be vaporize and ignited. Water removal from an emulsion layer can be achieve by either providing sufficient heat to the slick surface to vaporize the water from the emulsion or by chemically breaking the emulsion, thus releasing free oil. An igniter for emulsions must therefore be capable of first, producing a water free oil layer from the emulsion and second, raising the surface temperature of the oil to its fire point. Sustained burning of an emulsion slick requires that the heat provided by the igniter or ignited portion of the slick be sufficient to continue evaporating the water from the emulsion and producing a water-free oil slick on the emulsion surface.

Based on these findings, improvements to existing igniter technology (namely gelled gasoline deployed from a Helitorch) were investigated as part of the 1993 programme, including the use of gelled oil, and the use of demulsifiers and flame-spread/combustion promoting chemicals. Two concepts were explored. One was to combine the chemical additives with the crude oil igniter, while the other was to apply the additives to the slick first, followed by the deployment of gelled fuel igniters. Both concepts showed promise and further work in this area was recommended. Figure 1 shows an experiment carried out to compare the effect of emulsion breaker concentration on the effectiveness of a gelled crude oil igniter. These igniters were tested on a 50% w/o emulsion of 25% evaporated Statfjord crude oil. A range of emulsion breaker concentration, from 0.5% to 20% had been evaluated. It was concluded that an emulsion breaker concentration of approximately 4 to 5% by volume in gelled Statfjord crude was found to be the most effective

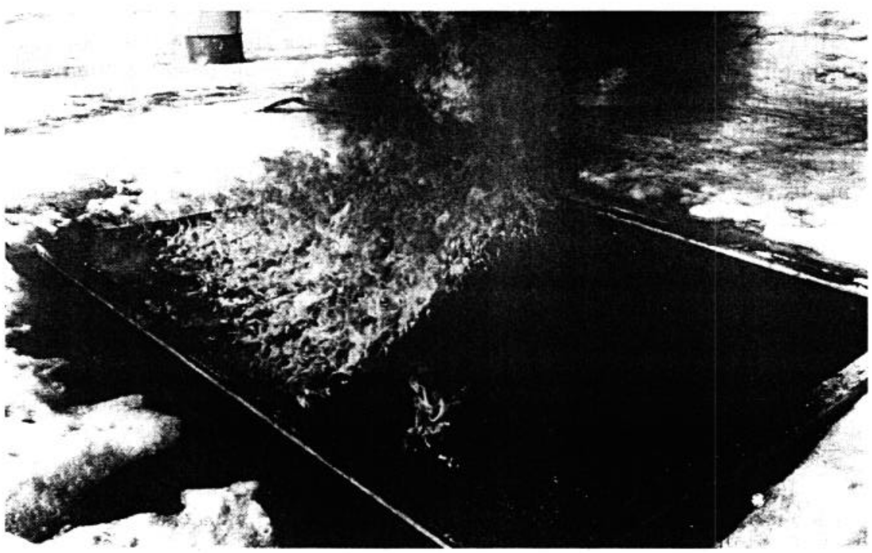

Figure 1. 1993 crude oil igniter experiments with and without emulsion breakers

The purpose of the present work was to refine a gelled crude oil igniter concept, initiated during the previous emulsion burning projects (Guénette and Sveum 1995). While the concept of making a pre-burn application of emulsion breaker to the slick had shown promise in the 1993 experiments, as well as in recent experiments carried out on a larger scale (Buist *et al.* 1995), it was decided that the focus on the present research would be on developing a one-step type approach to igniting emulsions because of the simpler logistics this method would offer.

More specifically, the goal was to develop an emulsion breaking igniter (EBI) deployable from a Helitorch for the ignition of heavily emulsified oils. This objective was met by conducting the following types of experiments:

- laboratory experiments to optimize potential igniter fuel combinations based on their maximum flame temperatures and ignition rates
- small scale emulsion burns to investigate the effect of chemical additives (demulsifier, combustion promoter and anti-foams) on the effectiveness of a crude oil based igniter
- small and large scale experiments to test the effectiveness of selected igniters concepts deployed using a Helitorch.

MATERIALS AND METHODS

Test oils and emulsions. The following table gives some of the physical-chemical properties of the oils and emulsions used to evaluate the emulsion breaking igniters. Stafjord crude oil was used in all experiments. Fresh oil was evaporated by sparging a know volume of oil with air until the desired degree of evaporation was obtained. Stable water-in-oil emulsions were created by mixing the evaporated oil with natural seawater with a high capacity pump. Density and viscosity were measured using an Anton Paar densitometer and Brookfield digital viscometer respectively, measured according to standard ASTM methods.

Table 1. Physical-chemical properties of Statfjord crude oil

Evaporation (vol. %)	Water content (vol. %)	Density (g/cm^3)	Viscosity (cP)	Shear rate (s^{-1})
0	0	0.838 at 21°C	82 at 15°C	12.24
25	0	0.871 at 25°C	1250 at 13°C	4.0
25	51	0.959 at 20°C	4500 at 13°C	4.0
25	66	0.974 at 20°C	6800 at 20°C	4.0
250$^+$ cut	70	0.989 at 37°C	46900 at 13°C	4.0

Experimental design. Statfjord crude oil was used as the igniter fuel during the initial investigations into the crude oil igniter conducted in 1993. While this fuel performed well as an igniter, it was considered logistically impractical to develop an igniter based on one specific crude oil, for two reasons: different oils may behave differently with the various additives and gelling agents, therefore any formula developed would not be consistent from one oil to another; the particular oil chosen for these experiments, or one with similar properties, may not be readily available in the event of a spill. It was therefore decided that a mixture of gasoline, diesel and Bunker C would be more suitable as the igniter fuel.

Table 1 gives the components included in the development of the emulsion breaking igniter. The experiments were carried out using combinations of these variables based on standard statistical designs for multi-variant experimentation. The proportions of these fuel were varied and optimum ratios selected for further optimization of additives, based on the ease of ignition and flame temperatures. The addition of the chemical additives Alcopol, ferrocene, glycerol and silicone, singly or combined, to the igniter fuels was evaluated. A total of 27 sets of experiments were conducted, each consisting of a matrix of 4 to 11 fuel ratios and additive combinations.

The development of the emulsion breaking igniter was achieved by conducting three series of experiments. This research was carried out during winter and summer of 1994 field sessions, as part of a larger emulsion burning project, at the SINTEF Applied Chemistry field research facilities in Sveagruva, Spitsbergen.

I) Experiments in metal pans to optimize fuel ratios and chemical additives
II) Basin burns with emulsions for of igniter formulae
III) Deployment and testing of the most promising igniters using a Helitorch

Table 2. Experimental parameters for optimization of the igniter composition

Fuels	Ratio (vol. %)	Additives	Amount (%)
Gasoline	0 to 100	Alcopol 060 (emulsion breaker)	0 to 5
Diesel	0 to 100	ferrocene (combustion promoter)	0 to 4
*Statfjord crude 250+ cut	0 to 90	glycerine (anti-foaming agent)	0 to 1.0
Bunker C	0 to 50	silicone (anti-foaming agent)	0 to 0.25

* A 250+ fraction of Statfjord crude oil was used instead of Bunker C during the winter experiments as it was not available in Sveagruva at that time.

Series I experiments. The first series of experiments was conducted outdoors in aluminum pans containing 100 ml of gelled igniter fuel. The fuel ratios ranged from 0 to 100 percent for each component (gasoline, diesel and Statfjord 250+ cut or Bunker C) of the igniter formula. Type K thermocouples were placed approximately 2 cm above the fuel surface to record flame temperatures during these experiments. The fuels were ignited using a propane torch, as with a Helitorch. Four to eight burns were carried out at one time, with the temperatures logged simultaneously using a Squirrel logger. The set-up for these experiments is shown in Figure 2.

The first sets of experiments in this series were dedicated to optimizing the fuel ratios. Based on their burning characteristics, specific fuel ratios were selected and used to optimize the chemical additive composition of the igniter.

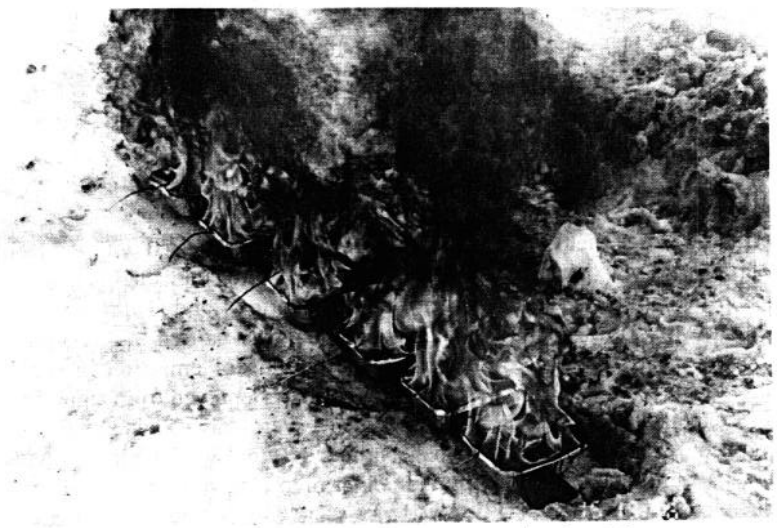

Figure 2. Fuel and additive optimization experiments in aluminium pans

Series II experiments. This next series of experiments was carried out to evaluated and compare the capabilities of the selected igniters formulae of igniting water-in-oil emulsions. Gelled fuel igniters, contained in plastic bags, were placed directly onto the slick surface and ignited using a propane torch. During the winter field session, experiments were conducted in 1 m^2 basins cut into the ice. During the fall, these experiments were carried a lagoon across from Sveagruva in a floating steel ring measuring 3 m in diameter. The set-up for these experiments is shown in Figure 3. The surface area in the ring was approximately 7 m^2. Initial slick thicknesses of approximately 1 to 2 cm were used for these experiments. Emulsions with water contents of 50%, 66% and 70% were used to test the igniters.

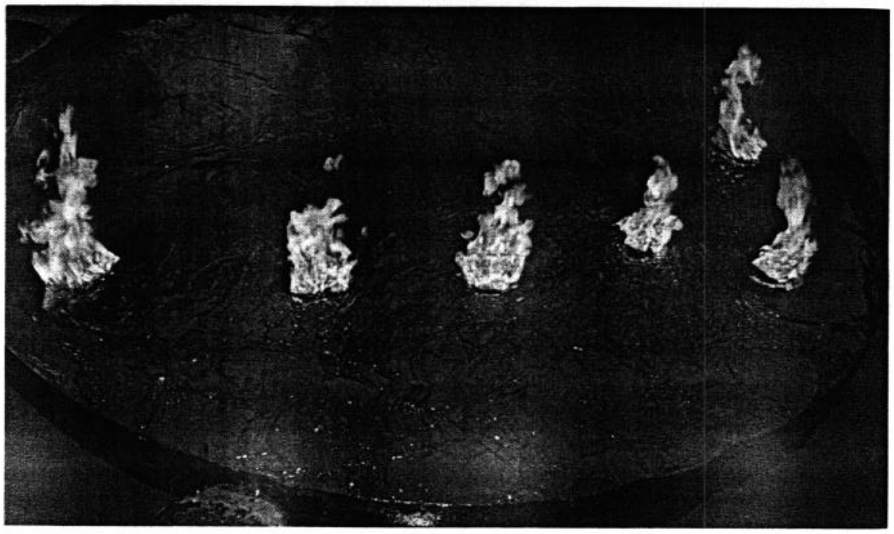

Figure 3. Summer igniter optimization experiments

Series III experiments. Selected igniter formulae were tested with the Helitorch in the third series of experiments. These experiments were conducted both during the winter and the summer on Spitsbergen following series I and II type experiments. The winter testing of the Helitorch deployed igniters was carried in a 15 m diameter basin cut into the frozen fjord, as part of the burning of emulsion in broken ice section of this project. The Helitorch was powered and deployed from a power shovel for these experiments. The summer experiments were carried out in a salt water lagoon in conjunction with uncontained burning of emulsions studies. Small scale experiments were done by deploying the igniter onto emulsion slicks contained in a 3 m diameter floating ring, while the large scale experiments were carried with emulsions contained in a 10 m diameter floating ring. The crane on a work boat was used to deployed the Helitorch during the summer tests. The capabilities of the igniters were tested with 20 and 50% w/o emulsions.

Properties of gelled igniter fuels. During the 1993 igniter development experiments, it was observed that gelled crude oil had a different consistency than that of gelled gasoline. It was therefore assumed that the gelled crude oil igniter would behave differently than gelled gasoline in the Helitorch, which consequently, could affect the deployment of this type of igniter. In order to better understand of the properties and behaviour of the new igniter formulae, several simple experiments were carried out.

Gel properties of the various fuels combinations and the effect of the chemical additives to the fuel were investigated. The parameters considered included the gelling time, gelling agent concentration, effect of stirring, and the effect of Alcopol, ferrocene silicone concentrations on the viscosity and flow properties of the final gelled fluid. Gelled gasoline, the fuel most commonly deployed from the Helitorch, was used as a reference against which these observations were made.

RESULTS AND DISCUSSION

Evaluation and selection of fuel ratios. Gelled fuel deployed from a Helitorch is ignited by a propane flame located directly below the nozzle from which the fuel is released. The contact time between the gelled fuel and the flame is very short. The gelled fuel therefore needs to be quite flammable. While high burn temperatures are an important criteria for the selection of a successful igniter fuel for use with emulsions, the ignition time is an important logistic factor when considering deployment of the igniter from the Helitorch. The gelled fuel should reach a high temperature quickly and begin burning rapidly in a very short time. When the igniter is released from the Helitorch, it must remain ignited as it falls through the air.

The following table summarizes some of the results obtained from these experiments, conducted to evaluate potential fuel ratios for the emulsion breaking igniter. The selection criteria for the gelled fuel igniters were the following:

- quick ignition of the gelled fuel upon contact with a propane flame
- short time to high or maximum temperature (approximately 700°C)
- continued burning at a high temperature for several minutes

Table 3. Ignition times and flame temperature for selected igniters

Fuel ratio (gasoline:diesel:250+ cut)	Ignition time (s)	T_{MAX} (°C)	Time to reach T_{MAX} (s)	Duration of T >500°C (s)
100:0:0	0-2	625	264	72
50:50:0	0-1	681	18	48
50:0:50	0-1	694	33	51
25:25:50	1	788	27	348
25:25:50	3-5	743	63	288

It can be seen from this table that while a high fraction of gasoline in the igniter fuel results in very quick ignition, the heavy fuel (250+) provides a higher temperature flame. In addition, the fuel mixtures containing higher fraction of heavy fuels maintained a higher temperature for a longer period of time.

Temperatures recorded in the flames during experiments which compared igniter fuels with maximum heavy fuel concentrations of 50% are shown in Figure 4 while Figure 5 shows ignition and initial burning stages during these experiments. The fuel mixture containing only gasoline and diesel, quickly reached a temperature of about 700°C. The flame temperatures periodically increased and decreased over the course of the burn, presumably as fractions of fuel were burned off. The igniter mixture with a fuel ratio of 50:0:50 also showed a similar trend, except that the temperatures remain higher for a longer period of time after the second peak. The remaining three igniter mixtures, composed of higher concentrations of heavy ends, maintained a consistently high temperature, for most of the burn period.

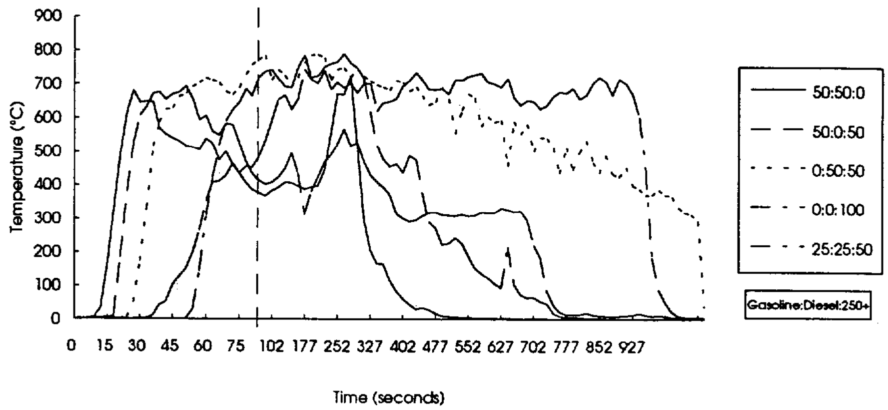

Figure 4. Flame temperatures of fuel mixtures containing 50% or less heavy fuel

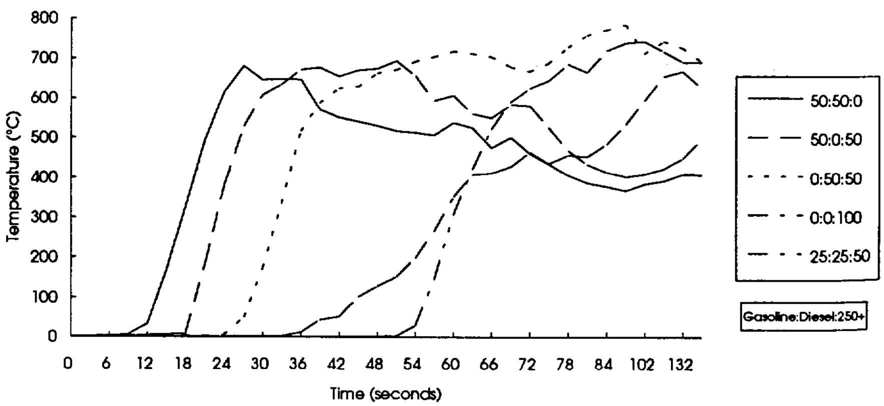

Figure 5. Flame temperatures of during the ignition of fuel mixtures

Gelled gasoline ignited and reached its peak temperature more quickly than the heavier fractions. However, the peak temperature and the duration of the burn at high temperatures were lower than those of the fuel combinations. In general, fuel ratios with greater that 80% heavy fuel maintained flame temperatures in the area of 700°C for at least five minutes. However, with such low fraction of light fuel, these gelled fuel mixtures were more difficult to ignite and required over a minute to reach their maximum temperatures, and were therefore not suitable for use with the Helitorch.

It was concluded that the ideal igniter fuel would consist of a mixture of gasoline, diesel and heavy fuel. This composition would provide the low flash point needed for quick ignition of the gelled fuel, combined with a continuum of crude oil fractions for a long burning period and high temperatures.

Effect and Selection of Chemical Additives. Small pan burns were conducted to study the effect of Alcopol and ferrocene on the ignition time and flame temperatures. Ferrocene appeared to increase flame temperatures and ignition rate of the fuel. Alcopol caused a small decrease ignition rate and the fuel burned at a lower temperature. This is likely due to the fact that Alcopol contains 60% alcohol which cools as it is evaporated. The combination of both Ferrocene and Alcopol seemed to have the greatest impact on the burning characteristic of these fuels, causing a decrease in flame temperatures and ignition rate. Similar results were obtained with other fuel ratios. It had been determined previously that an emulsion breaking igniter is essential for the this type of igniter concept, therefore, despite the cooling effects of Alcopol, it was not omitted from the crude oil igniter. In any case, these effects were quite small.

Winter experiments. The effectiveness of igniters with fuel ratios of 10:25:65 and 25:25:50 with the addition Ferrocene and/or Alcopol was evaluated in a series of small scale emulsion burns carried out during the winter. Igniters which did not contain Alcopol were not effective at all, causing no ignition of the emulsion slicks. Igniters with ferrocene showed a slightly faster flame spreading rate. The igniters with a fuel ratio of 10:25:50 did not remain ignited for more than a few minutes, and those containing Alcopol, while successfully breaking the emulsion, extinguished before the emulsion could be ignited, possibly due to foaming of the slick surface near the igniter. The foaming process has previously been observed to impair flame propagation during the ignition phase of emulsions and to dampen, and eventually extinguish a burning emulsion (Twardus 1980, Guénette *et al.* 1994 and 1995, and Buist *et al.* 1995). Igniters with the 25:25:50 fuel ratio, containing both additives were capable of igniting a 50% w/o emulsion and of causing some flame spreading in the upwind direction. This igniter was also effective with a 66% w/o emulsion, although the burn efficiency was lower. The 70% w/o emulsion made of the 250+ fraction of Statfjord crude could not be ignited with this igniter.

Summer experiments. Following the experiments with the Helitorch in the winter, it was concluded that a higher concentrations of gasoline were required for more effective ignition of the gelled fuel. In order to decrease the ignition time of the igniter, a higher fraction of gasoline was tested in the summer and fall experiments. The igniter fuel containing between 40 and 60% gasoline were tested the summer/fall experiments. Further additive concentration experiments were carried out to include the use of an anti-foaming agent. These products are often used as effective anti-foams in the petroleum industry (Ross and Morrison 1988, Clint 1992, Pape 1993). Three silicone based products selected for testing in combination with the crude oil igniters. Four experimental matrices, which included 30 igniters additive combinations were tested in this series of experiments. The additives evaluated were Alcopol, ferrocene, and the silicone products. The igniter fuels used in these experiments were composed of the fuel ratios 60:25:15 and 60:15:25 (gasoline:diesel:Bunker C). These igniter combinations were evaluated by gelling 200 ml of the igniter fuel and respective additives in a plastic bag, which was then placed directly on the slick surface and ignited using a propane torch. Five to six igniters were compared at one time.

The addition of the silicone products to the igniters resulted in reduced foaming of the emulsion surface near the burning igniter and enhanced flame spreading during the ignition phase of the burn. The most effective igniters were those containing the emulsion breaker and the silicone product Dow Corning 210H fluid. It became apparent during these experiments, that ferrocene did not enhance flame spreading, and in some cases caused the formation of a crust on the surface of the burning igniter, thus preventing it from spreading over the emulsion surface. This had not been observed during the experiments done in the winter. It is possible that ferrocene behaves differently with the modified fuel mixture or when silicone was present.

These experiments also revealed the importance of placing igniters at the upwind end of an emulsion slick. Unlike fresh or evaporated oil, the burning emulsions in these experiments showed very little upwind flame spreading, and limited widthwise spreading of the flames regardless of the igniter used.

Properties of various gelled fuel mixtures and additives. Understanding the properties of the gelled fuel was important for the effective deployment of the igniter using the Helitorch. During some of the experiments carried in 1993 with gelled crude oil it was observed that the gelling characteristics of crude oil, especially with the addition of emulsion breakers, was quite different from that of gelled gasoline. While it was not possible to duplicate the properties of gelled gasoline using the fuels and chemicals considered for this igniter, some of the general characteristics could be simulated.

To be deployable from the Helitorch, the igniter must be fluid enough to be pumped, while at the same time be solid enough to form lumps as it leaves the Helitorch nozzle. At the least, the stream of gelled fuel should eventually break into lumps. A second characteristic of the gelled fuel is that it not spread to thinly after landing on the slick, so as to remain burning sufficiently long enough to cause ignition of the surrounding slick.

Quantities of 3 and 6% by weight of Surefire was sufficient to gel gasoline and crude oil respective in less than 30 minutes. The heavy fraction of Stafjord crude (250+) required much more time (several hours) to reach the point a being gelled. The final consistency of these gelled fuels varied from one to another.

Continuous stirring the fuel following the addition of the gelling agent was found to increase the rate of gelling and the viscosity of the gelled fuel, and also produced a more evenly gelled fuel. Temperature had a significant impact on gelling time. Gelling time for all fuel ratios tested decreased with increasing ambient temperature. These observations are consistent with those made during previous experiments with gelled gasoline (Spiltec 1987). Gelling time also increased with increasing heavy fuel concentration.

The effect of ferrocene and Alcopol on the gelling properties of the fuel ratio 25:25:50 (gasoline:diesel:250+) were investigated. It was discovered that the addition of 3 to 5 % ferrocene resulted in a decrease in viscosity by approximately 15%. The addition of 3% Alcopol by volume caused an order of magnitude decrease in the gelled fuel viscosity.

In summary, crude oil does not gel as firmly as gasoline. In addition, there is a marked decrease in the viscosity and gel firmness of the fuel when Alcopol is added to the fuel prior to gelling. Higher concentrations of gelling agent are therefore required to achieved the similar gelling properties as a fuel containing no Alcopol.

The gelling time was also higher with higher concentrations of crude oil and with the addition of Alcopol.

Effectiveness of the Helitorch deployed crude oil igniter. The Helitorch was tested during the winter experiments of burning emulsions in broken ice. A gelled fuel ratios of 25:25:50 and 40:20:40 (gasoline:diesel:250+) containing 5% Alcopol, 5% ferrocene, and 10% Surefire was selected for testing during the large scale emulsion burns in broken ice. The igniter did not ignite very well, if at all, as it was released from the Helitorch nozzle. This resulted in poorly lighted igniters landing on the emulsion and in very limited flame spreading over the slick.

Part of the reason for poor ignition of the igniter may have been an insufficient power source for the Helitorch during these experiments which may have caused the ignition spark designed to ignite the propane flame of the Helitorch to spark inconsistently. Consequently, the propane flame was not always on when the gelled fuel was pumped through the nozzle, causing gelled fuel to be deployed for several seconds without being ignited. However, the main reason is likely that the time required to ignite the fuel mixture was too high (gasoline fraction too low), and that the fuel may also have been too fluid (not enough gelling agent).

Following further fuel ratio and chemical additive optimization, experiments with the Helitorch resumed during the summer field session. A total of five experiments were conducted with the Helitorch and four variations of the EB igniter, deployed onto 50% w/o emulsions prepared from 25% evaporated Statfjord crude oil. Table 4 summarizes these experiments.

Experiments H1 and H2 were small scale experiments carried out with the Helitorch in the 3 m diameter ring. In the first experiment, the fuel mixture (60:25:15) did not seem to be sufficiently gelled, since the igniter was deployed from the Helitorch in a long viscous stream as opposed to lumps. Not all of the igniter landing on the emulsion slick remained ignited. In the second experiment, the same additive concentrations were used, but this time with the 60:15:25 fuel mixture. This resulted a thicker igniter, which could, for the most part be deployed in discrete lumps. Most of the igniters continued to burn after landing on the emulsion slick. This fuel ratio was therefore chosen for the large scale experiments. Higher gelling agents concentrations were used in order to enhance the formation of lumps and to increase the contact time between the igniter and the propane flame by slowing the release rate of the gelled fuel.

Experiments U4 to U7 were carried out in the 10 m diameter ring. These igniter tests were carried out as part of the uncontained burning of emulsions experiments. In experiment U4, 1200 L of emulsion was used. Due to the higher winds during this experiment, most of the slick was located in the downwind half of the ring. The crane used to deploy the Helitorch from the boat was not long enough to reach the centre of the ring. Some of the igniters which This combined with difficulties manoeuvring the boat near the ring under these wind conditions, resulted in igniters being dropped on only a limited portion of the slick. Some igniter which landed on the water managed to drifted into the slick; however, they did not come into very good contact with the emulsion and were therefore not capable of heating to the immediate slick area to the point of ignition. Only about 10% of the slick surface, near the ring edge, was ignited and remained burning for approximately 5 minutes. The burn efficiency was estimated to be less than 10%.

Table 4. Summary of Helitorch experiments with the EB igniters.

Exp. No.	Igniter composition (gasoline:diesel:Bunker C)	Volume (L)	Initial area (m^2)	Wind speed (m/s)	Burn efficiency (%)
H1	60:25:15 5% Alcopol 10% Surefire	70	7	4.5	80
H2	60:15:25 5% Alcopol, 0.25 Silicone 10% Surefire	80	7	1.0	n.m.
U4	60:15:25 5% Alcopol, 0.25 Silicone 11% Surefire	1200	79	4.1	<10
U5	60:15:25 5% Alcopol, 0.25 Silicone 11% Surefire	2000	79	4.0	65
U7	60:15:25 5% Alcopol, 0.25 Silicone 15% Surefire	4000	79	0.1	75

H = contained burns in 3m diameter ring
U = uncontained burns, 10 m initial diameter
n.m.= not measured

In the next experiment, the same igniter was tested with a 2000 L emulsion slick. The slick covered the entire ring area, and an extension to the crane permitted deployment of the igniter over a greater area of the slick. While the ignition of the slick was successful using this igniter formula, the fuel was found to be still too fluid and difficult to ignite consistently. Approximately 40 L of igniter was deployed onto the slick which burned uncontained with an efficiency of 65%. In the next experiment with 4000 L of emulsion, a gelling agent concentration of 15% was used. The fuel was extremely thick and formed semi-solid clumps as it was pumped out, which slowly detached from the Helitorch nozzle. Almost all of the igniter deployed remained ignited after landing on the emulsion slick. Figure 6 shows the deployment of the igniter during this experiment. Approximately 10 L of igniter was used to ignite this slick which burned uncontained with an efficiency of 75%.

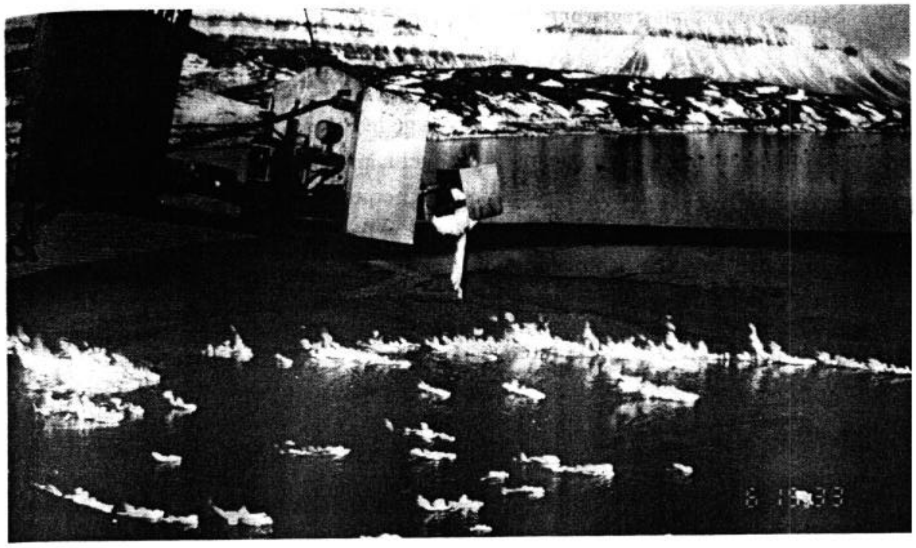

Figure 6. Deployment of an emulsion breaking igniter onto a 50% w/o emulsion

CONCLUSIONS

The experimental work carried out in 1993 and 1994 have led to the development of a Helitorch deployable igniter capable of igniting 50% water-in-oil emulsions of 25% evaporated Statfjord crude oil. It can be concluded that the key elements of an emulsion breaking igniter are the following:

- The igniter must contain an emulsion breaker. An emulsion breaker (Alcopol) concentration of approximately 5% by volume was most effective in igniting 50% water-in-oil emulsions of 25% evaporated Statfjord crude oil.
- The optimal igniter fuel contains a range of light, medium and heavy end of crude oil. The light ends provide quick ignition of the igniter fuel, while the heavy ends provide the heat input required for the ignition of emulsions. The full range of oil components are required to maintain continuous burning of the igniter. A fuel ratio of 60% gasoline, 12% diesel and 28% Bunker C was found to be effective with the emulsions tested.
- Chemicals acting as anti-foaming agents, such as silicone can enhance the flame spreading capabilities of the igniter by reducing foaming in the early stages of ignition which is know to prevent or impede ignition of emulsion.
- Ferrocene increased the burning temperature of the igniter fuels, but did not enhance flame spreading.

Some conclusions regarding the deployment of the emulsion breaking igniter using the Helitorch were also be made:

- The igniter fuel should contain approximately 12% wt./vol. gelling agent (if using SureFire). The fuel must be sufficiently gelled to be pumped out of the nozzle in lumps rather than in a stream. If the fuel is pumped out too quickly, it will not be sufficiently ignited before reaching the emulsion slick. Excess gelling agent may cause difficulties in pumping out the gelled fuel.
- The igniter must be deployed upwind on the emulsion slick. Almost no upwind flame spreading was observed when winds were above approximately 4 m/s.
- At higher wind speed, it is important to deploy the igniters close together as lateral flame spreading is limited.
- The igniter must be deployed directly onto the emulsion slick. Igniters, dropped onto the water surface upwind from an emulsion slick and allowed to drift into the slick did not effectively cause ignition of the slick.

RECOMMENDATIONS

- Further research is recommended to define the limitations of the current igniter formula in terms of environmental conditions, oil type and degree of weathering.
- Further development work of this igniter could be undertaken to include other performance enhancing additives The addition of other additives (soot reducers, bioremediation agents) could also be considered.
- Operational experiments with the Helitorch and the emulsion breaking igniter, deployed using a helicopter are recommended.
- Should a pre-burn application of emulsion breaker to extremely stable emulsions be considered, it might be practical to consider applying other burning aids at the same time, such as combustion promoters, soot reducing agents, or compounds which may enhance the biodegradation or recovery of the remaining residue.

ACKNOWLEDGEMENTS

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