THE EFFECT OF WIND, ICE AND WAVES ON THE IN-SITU BURNING OF EMULSIONS AND AGED OILS

by

Cathe Bech and Per Sveum
SINTEF Applied Chemistry
Trondheim, Norway

and

Ian Buist
S.L. Ross Environmental Research Ltd.
Ottawa, Canada

ABSTRACT

This paper describes a series of small and meso-scale in-situ burning tests conducted on Spitsbergen in 1991 and 1992. The objectives of the tests were:

- *to define the limitations and burn effectiveness of in-situ burning of water-in-oil emulsions in terms of water content, degree of evaporation and film thickness; and,*

- *to study how the presence of ice, waves and wind affect in-situ burning.*

The tests were conducted in basins cut in the ice on a fjord. The size of the basins ranged from 4 m^2 to 300 m^2; the largest basin was fitted with a wavemaker.

The conclusions from these tests were:

- *Evaporated water-free oil is easily ignited and burns with high efficiency. The burn efficiency is not affected by waves.*

- *Highly evaporated oil with 25% water is hard to ignite with gelled gasoline. In the presence of waves (swell), it was not possible to ignite a 12.5% stable water-in-oil emulsion.*

- *The presence of waves reduced the burn efficiency for emulsion with a low water content.*

- *The main problem with in-situ burning of emulsions is flame spreading; emulsions require a large initial burn area for the burn to be self-sustaining.*

- *Small ice-floes and slush did not influence burn efficiency in a negative way.*

- *In-situ burning could not be accomplished in wind speeds above 10 m/sec.*

INTRODUCTION

In-situ burning of spilled oil has been considered as a major response technique for open water, ice infested wasters, in snow and on shorelines. Successful burning in these different spill situations depends on many factors affecting the partitioning and the availability of the oil; the properties of the oil at the time of ignition, and the meterological and oceanographic conditions.

When oil is spilled at sea, weathering processes change both its physical and the chemical properties. The main weathering processes that affect in-situ burning are evaporation and emulsification. In addition, when oil is released on water it spreads naturally to a minimum thickness. These processes combine to define a time "window" in which burning can be successful as a response option.

To ignite the oil, the heat from the ignition source has to be sufficient to evaporate oil at a rate fast enough that the vapours in the air above the slick ignite and burn. Both spreading and weathering affect in-situ burning of oil in a negative way. The oil must be thick enough to insulate itself from heat loss to the underlying water. In ice infested waters the oil may be naturally contained, but on open water the oil probably has to be contained mechanically to maintain a burnable thickness.

As oil's evaporate they lose light ends, become less volatile and, consequently, more difficult to ignite. The rate of evaporation increases with decreasing oil thickness. When oil is spilled on water emulsions can form very quickly. After just a short time the water content can be as high as 70%.

Burning of water-in-oil emulsions differs from the burning of water-free oil. Emulsions have reduced volatility compared to oil and a higher rate of heat loss to the underlying water due to higher thermal conductivity. Thus, emulsions have a higher minimum thickness for ignition than oils. In addition, the water in the emulsions needs to be removed before the oil is volatilized and burned. In fact it may be the removal of this water which controls emulsion burning. Ignition of emulsions in-situ may require more powerful ignition sources than ignition of oils. The water is boiled out and a water-free oil layer is created on top of the emulsion (Bech et al 1992). Heating of the emulsion may also promote breaking of the emulsion. This oil will be volatilized by the radiated heat and when the temperature reaches the parent oil's flash point it will ignite.

Meterological and oceanographic conditions such as ice, wind and waves, in addition to affecting the weathering processes, will also directly influence the burn to some extent.

This paper presents a series of experiments designed to study some aspects of in-situ burning of aged oils and water-in-oil emulsions spilled on Arctic ice-infested waters. The specific objectives of the experiments, which were carried out both in small and meso-scale, field conditions were:

- To define the limitations and burn effectiveness of in-situ burning of water-in-oil emulsions in terms of water content, degree of evaporation and film thickness

- To study how the presence of ice, waves and wind affect in-situ burning.

MATERIALS AND METHODS

The experiments were conducted on the frozen fjord next to the SINTEF laboratory on Spitsbergen. The small scale experiments were conducted in April-May 1991 while the meso-scale experiments were conducted in the spring of 1992. In addition, some pilot tests were conducted in 1992.

SMALL SCALE EXPERIMENTS - 1991

In the small-scale experiments circular basins, each within an area of 4 m^2, were cut in the fjord ice. To maintain a constant water level an overflow system was made for the basins (Figure 1).

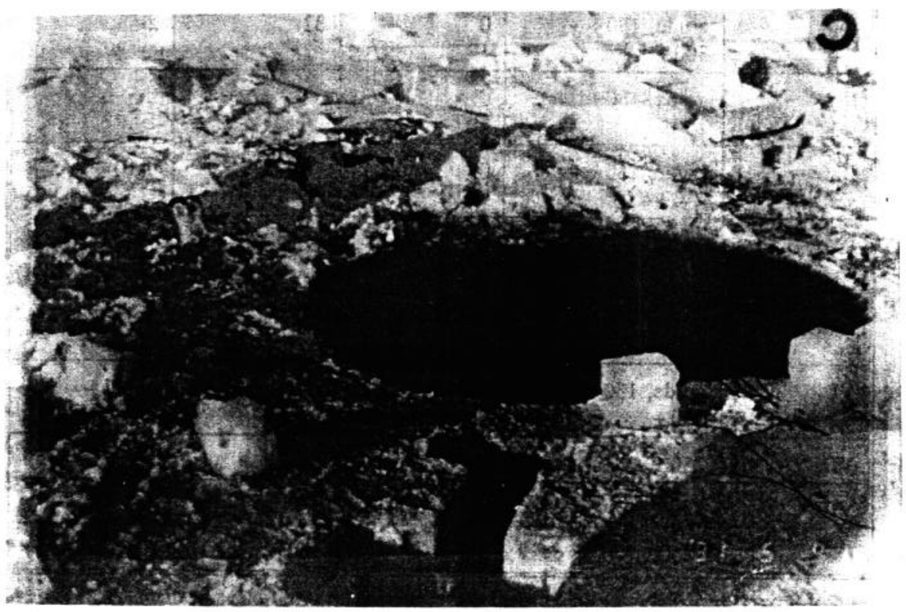

Figure 1. Basins used in the small scale experiments

The oil types burned, water content and amount used in each test are given in Table 1.

SMALL SCALE EXPERIMENTS - 1992

Prior to the meso-scale experiments conducted in 1992 a series of small scale burn experiments were carried out. For some of these tests the same design was used as described above for the small scale tests.

In addition, larger basins were made to study the effects of scale. These experiments were conducted in basins with an area of 20 m^2.

Table 1 - Small Scale Experiment Variables (1991 and 1992)

Experiment	Oil type	Water content [% value]	Amount of oil/emulsions [L]	Wind velocity [m/s]
I	crude, 150+ - 300+	0	32	2-5
II	crude, 150+ - 250+	0	32	2-5
III	crude, 150+ - 250+	0	16	9-10
IV	crude, 150+ - 250+	10	32	7-8.5
V	crude, 150+ - 250+	20	32	10-11
VI	crude, 150+ - 250+	40	32	10-11
VII	250+	0,10	32	5-6
VIII	250+	20, 30, 40	35	5-6,4-7,5-6
IX	"250+"	25	140	

MESO-SCALE EXPERIMENTS

The meso-scale burning experiments were conducted in an open basin cut in the fjord ice. The size of the test basin was 10 x 30 m. The basin was cut with a hydraulic power saw. Ice blocks of approx. 1 m^3 were removed by a power shovel. The freeboard of the ice in the basin was approx. 10 cm. To minimize melting of the ice edges during burns, logs were placed along the inside of the basin and ice-blocks were placed around the basin (Figure 2).

To study the effect of waves on ignition and burning a hydraulically powered wave machine was mounted in the ice along the short side of the basin. The wave flap was 7 meters long and 30 cm high. The frequency of the waves was controlled by valves on the hydraulic controller (see Figure 2).

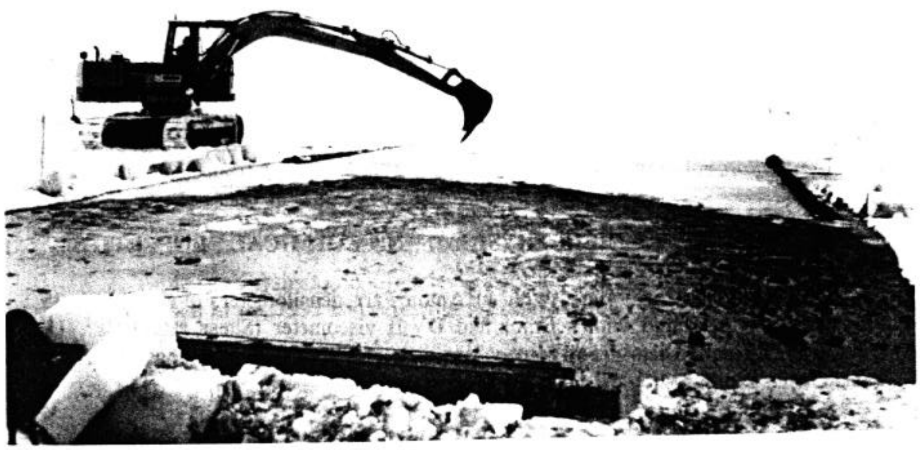

Figure 2. Basin used in the meso-scale burn experiments

For each meso scale burn experiment 4000 litres of oil or emulsions were burned. In total six burn experiments were conducted (see Table 2).

The effect of emulsions; water content in the amount and type of ice in the basins; waves; wind; and, ignition source were studied. The emulsion water content varied between 0 and 25%. The effect of waves both on ignition and burn processes was studied.

Table 2 - Summary of the Meso-Scale Experimental Burn Test Parameters

Exp. #	Oil Type	Water content [%]	Ice condition	Waves Before Ign.	Waves During Burn	Wind velocity [m/s]	Ignition Source
1	250+	25	slush			4-6	250+
2	250+	25	slush	x		11-13	crude
3	"250+"	25	none		x	11-13	250+
4	250+	0	slush	x	x		Gel. crude
5	"250+"	12.5	small floes	x		10-13	250+, crude
6	"250+"	12.5	none		x	8	250+, crude

THE TEST OILS AND THEIR PHYSICAL AND CHEMICAL PROPERTIES

Oil density was determined with an Anton Parr densitometer, model DMA 35. Viscosity was measured with a Brookfield DV-II viscometer (Shear rate 10 s^{-1}, UL adapter). Distillation data and oil composition were obtained from the Mongstad refinery (small scale experiments) and Shell refinery (meso scale experiments).

1991 Experiments

The properties of the oil used in the 1991 experiments are given in Table 3. The different oil types were fresh Statfjord/Gullfaks crude oil, and the 150+, 200+, 250+ and 300+ fractions which simulated evaporated oil; 18, 28, 37.5 and 45.5% by volume respectively.

Table 3 - Physical and Chemical Properties of the Test Oils used in the 1991 Experiments and for Mixing the Emulsions

Oil type	Density [g/ml] @ 13 °C	Visc [cp] @ 13 °C	Initial Boiling Point [°]	Vol % Dist.
Fresh crude	0.846	10.9	n/d*	-
150+	0.881	102	134	18
200+	0.883	87.7	193	28
250+	0.902	429	241	37.5
300+	0.921	n/d*	256	45

* n/d = not determined

1992 Experiments

The oil types used in the 1992 small and meso scale experiments are described in Table 2 as 250+ and "250+". The properties of these oil products are given in Table 4. As can be seen, the properties of this oil differs slightly from the properties of the 250+ oil fraction used in the 1991 experiments.

Table 4 - Physical and Chemical Properties and of the Test Oils used in the 1992 Experiments and for Mixing the Emulsions

Oil type	Density @ 13°C	Viscosity @ 13°C	Initial boiling point	Mixture of
250+	0.935	529	n/d	Marine gasoil, 20% FSD*, 10% Fuel Oil No. 6LS, 70%
"250+"	n/d	n/d	n/d	250+, 80% Statfjord/Gullfaks, 7% Marine gasoil, 13%

* FSD = heavy diesel

MIXING OF EMULSIONS

Small Scale Experiments

The emulsions were made by mixing sea water and oil in the desired proportions. The maximum batch size produced each time was 70 litres. Oil and water were circulated through a gear pump (1450 rpm) until stable emulsions were obtained. Emulsion mixing time ranged from one to six hours depending on oil type and amount of water.

Meso Scale Experiments

In these experiments 4000 litres were burned each time. The oil types used in these experiment were the 250+ and the "250+". The 250+, marine gas oil crude oil and sea water added into a 5000 L tank. A 450 L/min gear pump circulated the oil and water in the tank. Stable emulsions were obtained after approximately 2 hours.

This tank was mounted on a sled and was drawn to the side of the basin and pumped out onto the water in the basin.

Figure 3 illustrates pumping the oil into the basin.

Figure 3. Discharge of crude oil into ice floe filled basin

RESULTS

SMALL SCALE EXPERIMENT - 1991 AND 1992

The effects of evaporation and varying water content on the ignition and burning of emulsions in the small scale 1991 experiments are presented in Bech et al. (1992). The main conclusions were:

- the burn efficiency decreased both with increasing degree of evaporation and increased water content in the emulsions.

- For oils evaporated more than 18% and with a water content of more than 20%, gelled gasoline was insufficient as igniter and a more powerful igniter had to be used. Liquid and gelled crude oil proved to be a better igniter for the emulsions because these burned with a higher temperature.

- the burn rate decreased both with increasing degree of evaporation and water content. For the water free oil the burn rate decreased from 3 mm/min for fresh crude to 1.4 mm/min for the 45% evaporated oil.

The effect of water content on burn efficiency for the 250+ fraction in 1991 and 1992 is illustrated in Figure 4. As can be seen, up to about 20% water content the burn efficiency was relatively high, then the efficiency decreased to zero for the 40% emulsion. This tendency was similar for both the oils used in 1991 and 1992.

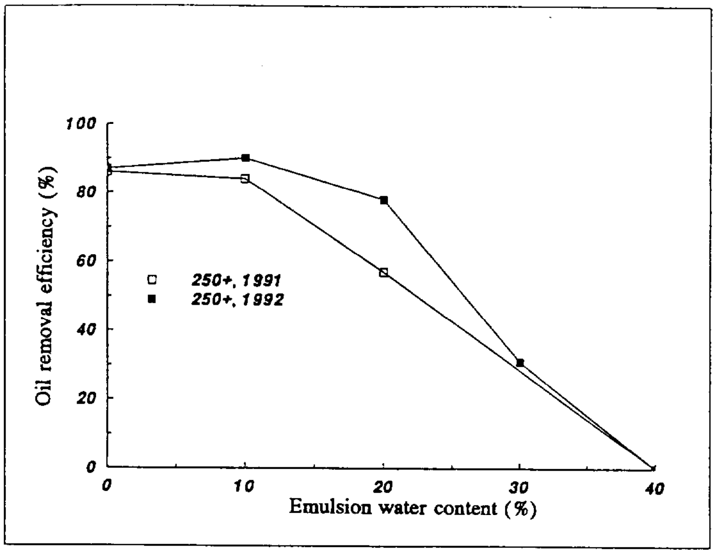

Figure 4. The effect of increasing water content in the 250+ emulsions on burn efficiency. Small scale experiment data from 1991 and 1992

As can be seen from Table 2 the wind velocity when carrying out the small scale experiments (1991) varied between 2 and 11 m/sec and this did not seem to influence the burns. Above 12 m/sec it was not possible to ignite the oil. When conducting the 1992 small scale experiments the wind was calmer and varied between 5 and 7 m/sec.

MESO-SCALE BURNS IN 1992

In total, six experiments were conducted in the large basin. In each experiment 4000 L of oil or water-in-oil emulsion was used. The results from the experiments are given in Table 5. Both water free oil and emulsions with 12% and 25% water were included in the experiments. Experiments were done with and without waves both during ignition and during the burn phase. The amount of oil that was added for ignition varied based on the observations that were made during earlier ignition experiments. Figure 5 shows one of the burns in waves.

Figure 5. Burn of 25% water emulsion in long waves

Table 5

Summary of some of the main experimental conditions and results from the meso-scale experiments
The volume of oil or emulsion used for each test was 4000 L

Experiment	Water Content %	Wind Speed (m/sec)	Waves During Ignition	Waves During Burn	Initial Film Thickness (mm)	Oil Used For Ignition (litres)	Burn Time (min)	Removal Efficiency (%)
11	25	4-6	no	no	50	65	---	0
12	25	4-6	no	no	50	50	---	0
13	25	4-6	no	no	50	90	---	0
14	25	4-6	no	no	50	1000	50	80
II	25	6-7	yes	---	40	400	---	0
III	25	11-13	no	yes	40	200	27	50
IV	0	6-7	yes	yes	30	gelled crude oil	25	90
V	12.5	10-13	yes	---	40	700	---	0
VI	12.5	8	no	yes	40	700	17	50

When there were no waves in the basin, the problem was to ignite the emulsion. Once ignited they burned with high efficiency. In the experiments with waves, conditions were different. None of the attempts to ignite the emulsions with waves present was successful. The wave generator could be turned on and off and regulated during the burn, and it was easy to observe that an emulsion fire extinguished when wave movement in the water was induced. It was also observed that there was a pronounced difference between water-free oil and emulsions. The waves had no influence on the burning of water-free oils. This difference between emulsified and non-emulsified oil can most probably be explained by the difference in burn mechanism, earlier described by Bech et al. 1991. The controlling process in the emulsion burning process is the removal of water from the emulsions and the generation of a water-free oil to burn. There are basically two ways to generate the oil for burning:

1. By boiling the water out.
2. By breaking the emulsions.

Emulsions can be broken by chemical means by the addition of surfactant and breaking is also possible by heat. In the experiments conducted to date, we have not seen any indications of thermal emulsion breaking at the temperatures reached during in-situ burning. Thus, the process of evaporation of water from the emulsions may be the controlling process that contributes water-free oil to the in-situ burn process. At the same time the vaporization of the emulsion water consumes energy. If the in-situ burning of emulsions is to be maintained, the rate of generation of free oil has to be equal to or larger than the rate of combustion of the free oil.

As previously demonstrated, waves had a negative effect on the burning of emulsions while there was no negative effect on the burning of water-free oils. Based on the theories about how emulsions burn, it is reasonable to assume that the problems with the burning of emulsions are due to the fact that the additions of water free oil at the surface of the emulsions layer is lower than the minimum amount required to sustain a burn. The waves can either affect and restrict the evaporation of water or the spatial distribution of released water free oil and create a situation that is different from the situation with water free oil with no waves and optimal thermal conditions. Optimal conditions in this context will be a film thickness of the water-free oil on the emulsion that gives a heat loss to the underlying emulsion that is small enough that the temperature in the oil film is equal to or higher than the flash point of the oil. In the situation with wave movement in a dynamic laminar multi phase system; in this case water free oil, emulsion, and water, we can assume that the thickness of the three of the individual layers will vary as a result of the wave motion. The thickness of the oil film will decrease periodically for a given volume of oil when the waves are swelling depending on wave length and amplitude. The reduction in film thickness will decrease with an increase of the wave length.

In-situ burning of emulsions seems to be a dynamic steady-state process where optimal removal of oil is achieved when the supply of water free oil is greater or equal to the oil volatilization rate. This process will be sensitive to slight reductions in the thickness of the water free oil. If the amount of heat added is high enough to generate water-free oil in excess of what is necessary for a high enough temperature to be maintained in the oil film with the maximum swell, then the emulsions will theoretically be burned.

It is also possible that wave action increases heat transfer through an emulsion slick. This could both help the burn process by mixing more heat down into the emulsion and promote thermal breaking or hinder the process by cooling the upper surface of the emulsion and reducing the water evaporation rate, thus reducing the rate of water-free oil generation.

Wind herding of oil against an edge is known to be a positive factor in the in-situ burning of oil spills (Energetex Engineering 1981). With the in-situ burning of emulsions there are two separate phases: released water free oil and emulsion that may behave differently under the influence of wind. This is because wind herding will be determined in part by the oil viscosity. Oil and emulsions with high viscosity will be more difficult to herd towards a barrier than an oil of low viscosity. It is therefore possible that wind can cause an increased thickness of the free oil layer without herding of the underlying emulsion layer.

CONCLUSIONS

For the oil and emulsions types studied and the experimental situations it can be concluded:

- Evaporated water-free oil is easily ignited and burns with high efficiency. The burn efficiency is not affected by waves.
- Highly evaporated oil with 25% water is hard to ignite with the gelled gasoline. In the presence of waves (swell), it was not possible to ignite a 12.5% stable water in oil emulsion.
- The presence of waves reduced the burn efficiency for emulsions with a low water content.
- The main problem with in-situ burning of emulsions is flame spreading; emulsions require a large initial burn area for the burn to be self-sustaining.
- Small ice-floes and slush did not influence burn efficiency in a negative way.
- In-situ burning could not be accomplished in wind speeds above 10 m/sec.

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