BURNING OF OIL IN SNOW

Experiments and implementation in a Norsk Hydro drilling contingency plan.

by

Per Sveum and Cathe Bech
SINTEF, Applied Chemistry,
Environmental Technology Group
N-7034 Trondheim
Norway

Magne Thommasen,
Norsk Hydro,
Drilling Department,
N-5001 Bergen,
Norway

Abstract.

A series of experiments with burning of oil/snow mixtures have been carried out. The objective was to develop practical methods for **in situ** burning of spilled oil to be implemented in the Reindalen 1 drilling contingency plan. This paper describes the results from the 8 field experiments (1000 litres each) with naturally spread oil, and two series of burns in small experimental vessels. The oil types studied were Oseberg crude oil and diesel. Efficiencies between approx. 90 % and 99 % were obtained in all the burns. It was demonstrated that oil/snow mixtures with oil concentrations with above 75% could be ignited with a rag soaked in petrol, and that concentrations as low as 3–4% (w/w) could be ignited after supply of additional petrol. Burning of oil in snow is recognized to be similar to burning of oil on water, with separation of oil and snow by melting, and formation of an oil layer on a meltwater pool as the step that determines success. Wind herding is found to be an important regulating factor. Implementation of burning of oil/snow mixtures as an oil spill mitigation tool into the Reindalen 1 contingency plan is outlined at the end of the paper.

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INTRODUCTION.

Most industrial activities involve the risk of accidental pollution. In arctic areas the overall risk might increase due to severe environmental constraints, and an assumed slow recovery of vulnerable areas, if severely disturbed. In the Norwegian Arctic, industrial activity has been limited until now. However, as part of increasing interest for exploring resources in the Norwegian Arctic, Norsk Hydro in cooperation with Petro Arctic and Store Norske Spitsbergen Kullkompani; started exploratory drilling for hydrocarbons on shore on Spitsbergen in January 1991. The drilling is called Reindalen 1. Drilling activities are limited to the winter period. Both Norwegian oil companies and the pollution control authorities have limited experience with oil spill contingency in arctic winter situations. Earlier exploratory drilling for hydrocarbons on Spitsbergen have been carried out in summer, close to the shoreline. The present venture thus presents a considerable challenge to the operating company, Norsk Hydro, in finding means of reducing the potential risk to the arctic environment. Considerable efforts were put into most areas related to the environmental aspects of the drilling activities. This paper presents the main results of experiments with the **in-situ** burning of oil in snow, which is a major technique for oil spill mitigation in the oil spill contingency plan. The paper also gives a short overview of the contingency plan.

Snow will be the major substrate for the reception of oil coming from spills in arctic winter situations. Snow is a porous medium with a retention potential that depends on the snow and oil properties. Besides manual clean-up of oil contaminated snow, and subsequent removal of oil after separation by melting, few options exist to deal with this type of spilled oil. Clean-up like this would be very labour intensive, and thus not feasible for larger spills. An incentive thus existed to develop more labour saving, and efficient methods to be applied in the arctic winter situation.

In-situ burning of oil is already considered a very promising technique to be used in open water situations, and among floes in ice-infested water (e.g. Brown and Goodman,1986;Evans,1988), although restrictions in terms of weathering and emulsion formations on efficiency are known exist (Buist, 1981; Brzustowski and Twardus, 1982; Smith and Diaz, 1987; Twardus, 1980; Twardawa and Couture, 1980).

A series of **in-situ** burning experiments with oil in snow were done. The experiments were performed in connection with the oil in snow spread experiments reported by Bech and Sveum (1991), in which the spreading of both Marine diesel oil and Oseberg crude oil were studied. In addition to experiments with the burning of naturally spread oil, some experiments were done with oil artificially mixed into the snow in smaller vessels.

The main objective of these experiments was to develop practical documentation of **in-situ** burning of oil in snow,so that **in-situ** burning could be incorporated into the contingency plan for the drilling.

MATERIAL AND METHODS.

The experiments were conducted in Spitsbergen during April and May 1990. The experimental conditions were typical of those to be found during arctic winters in Spitsbergen.

Two types of oil were selected for the experiments; Marine diesel oil which is transported in connection with all types of operations in the Arctic, and Oseberg crude oil which was selected as an example of a crude oil. The characteristics of the tested oil are given in Table 1.

TABLE 1 Physical and chemical properties of the two oil types used in the burning experiments with oil in snow; i.e. Marine diesel and Oseberg crude oil.

Properties	Diesel	Oseberg crude
Density (g/ml)	0.847	0.849
Surface tension (Mn/m)		
air/oil	29	29
oil/seawater	20	21
Pour point (°C)	- 27	- 24
Flash point (°C)	55	46.1

The oil that had been released in the experiments with the burning of oil was ignited in different ways. In some experiments the oil-contaminated snow was partly collected into heaps. The oil and snow mixture was ignited with the addition of petrol. The amount necessary for successful ignition depended on the oil concentration, and the degree of evaporation.

In some of the experiments the oil was left more or less undisturbed under the snow after the spreading experiment, and only a small trench was excavated towards the centre of the spill before ignition with petrol.

In addition to the experiments with the burning of diesel and Oseberg crude oil with the distribution obtained after the spreading experiments, a series of experiments was done in small vessels with mixtures of snow and oil with known concentrations. These experiments were designed to allow an evaluation of the accurate determination of burning efficiency, as well as evaluating the effect of decreasing oil concentration on the burning efficiency. Table 2 gives a summary of all the experiments.

TABLE 2. Summary of the burning experiments. (D1, D2 etc. refers to oil spread experiments reported by Bech and Sveum 1991, this issue.)

BURNING	OIL TYPE	VOLUME OIL (litre)	VOLUME SNOW (litre)	NUMBER OF BURNS
B1	Oil from D1	1000	N.D	1
B2	Oil from D2	1000	N.D	1
B3	Oil from D4	1000	N.D	1
B4	Oil from D5	1000	N.D	1
B5	Diesel	0.25–8.0	8	6
B6	Oil from C1	100	N.D	1
B7	Oil from C2	1000	N.D	1
B8	Oil from C4	1000	N.D	1
B9	Oil from C5	1000	N.D	1
B10	Oseberg	0.25–8.0	8	6

It is difficult to evaluate the burning efficiency accurately after field burning. In our experiments the burning efficiency was evaluated from the amount of residue left on the after burn "meltwater pool", and by comparing the size of this pool with the spreading area obtained and mapped after the spreading experiments.

In the small-scale vessel experiments, all the oil was collected and measured volumetrically after the settling of the collected water phase. The exact burning efficiency could thus be evaluated.

RESULTS AND DISCUSSION

The field experiments with the in-situ burning of diesel and crude oil.

Four field trials with in-situ burning with each of the two oil types were conducted. The "response time", i.e. the time between release of the oil and the time of ignition varied from 4 to 13 days. This was intended to simulate real conditions, where countermeasures against oil spills are often limited by environmental or logistic constraints. The variability in response time, implies that the ignited oil varied to some degree in composition, i.e. the degree of natural weathering.

As expected, the results from the burning trials on water, and from experiments with snow/oil mixtures, the success of burning was very much dependent on the success of ignition. The success was established, once the oil had caught fire.

We assumed that it would be necessary to create some kind of artificial containment to achieve successful burning. However, this was not necessary with the spatial distribution the oil had in our field experiments.

TABLE 3. Estimated burning efficiency, with information on the response time, i.e the number of days from the release of oil to the time of ignition for each experiment. (D1, D2 etc. refers to oil spread experiments reported by Bech and Sveum 1991, this issue.)

Burning	Exp. type	Days after release	Estim. burn eff.
B1	Oil from D1	4	> 90%
B2	Oil from D2	12	> 90%
B3	Oil from D4	7	> 90%
B4	Oil from D5	8	> 90%
B6	Oil from C1	13	> 90%
B7	Oil from C2	13	> 90%
B8	Oil from C4	7	> 90%
B9	Oil from C5	8	> 90%

Small scale burning experiments.

As noted above these experiments were carried out in order to establish limitations in terms of oil content in snow on the burning efficiency and the method of ignition. Six individual vessels were used in these experiments. The oil concentration varied from approximately 100 %, in weight, down to approximately 3 %. The initial oil concentration together with the burning efficiencies are given in Table 4.

TABLE 4. Oil concentration and burning efficiency in the small scale experiments.

Vessel #	Oil conc. (%)	Burning efficiency %	
		Diesel	Crude
1	100	99.9	98.3
2	50 (75)	99.9	96.3
3	25	99.0	95.5
4	12.5	99.0	92.5
5	6.25	99.6	89.0
6	3.1	92.0	90.0

In the vessel with the highest concentration of oil, ignition could be accomplished with a small amount of petrol on a small rag. With the same amount of petrol on a rag, the ignition of the oil in an oil/snow mixture of 50 %, ignition was unsuccessful. Oil was then added to give approximately a 75 % concentration of oil. The burning success after increasing the oil concentration was similar to that found with the 100% concentration.

In the vessels with the lower concentrations of oil in snow, the success of ignition could be achieved by increasing the amount of petrol on the rag.

No differences in the overall burning pattern between the two oil types were found, although the crude oil gives a slightly lower burning efficiency than the diesel oil. In both cases, the maximum efficiency is close to 100 %. These small scale experiments were varied with a prevailing wind speed of approximately 10 m/sec. The walls of the vessel worked as a containment, and a pronounced wind herding effect could be observed. There were no attempts to quantify this effect by multiplying the experiment with different wind speeds. The observed lower burning efficiency of the crude can be explained from the content of asphaltens in the crude, in contrast with the diesel, however, the uncertainty of the wind herding effect make make it difficult to draw firm conclusions on this issue.

Comments on burning dynamics of oil mixed with snow.

Based on the results, and the observations of the burning, we have some comments on the in-situ burning process for oil in snow.

As for burning of oil on water, the burning success is mainly dependent on ignition success, though the mechanisms are different. Burning of oil in snow differs from oil burning on water, because oil mixed in snow does not form emulsion, this being one of the characteristics for oil on water. The evaporation rate is also slower with snow. These two features make burning of oil in snow more feasible than oil on water. When oil in snow is ignited, there are no principle differences between burning of oil in snow and oil in water. In the following discussion we refer to Figure 1, which gives a graphical overview of a conceptual model for burning of oil in snow.

The ignition has two functions. The first is to ignite the oil. Then enough heat must be formed during ignition to melt snow and form a meltwater pool. When the snow melts oil is released, which forms a layer on top of the meltwater pool. The ignition success depends on this layer, and thus on the concentration of oil in the snow. If the initial concentration of oil is low, formation of a sufficient oil layer on top of the meltwater pool depends on supply of more oil/petrol, or the use of a more efficient ignitor, which melts snow more efficiently. The properties of the snow also determine the ignition efficiency. With repeated melting and freezing, or when other factors induce ice formation, the need for heat for melting the oil/snow (ice) increases, and the heat loss rises. A greater effort is then required to ignite the oil.

The thickness of the oil layer depends on the area of the meltwater pool, which in turn depends on the way the melting process proceeds, and on the concentration of oil in the melting snow. The melting process is greatly influenced by the wind; i.e. on how the wind deflects the flames, and distributes the radiated heat. The melting will thus proceed downstream of the wind direction.

The burning process starts when enough snow has melted to give a sufficiently thick oil layer to maintain the temperature required to start the gasification process. It is not the oil that burns, but the gas formed from the oil.

Once ignited, the burning process will commence in the same manner as if we were igniting an oil slick on water. Film thickness, and thus burning efficiency is controlled by the supply of oil from melting snow, the increase in meltwater pool area, and the wind control of the spatial distribution of the oil on the pool. The burning process itself leads to a continuous reduction of oil layer thickness. If the melting process supplies the same amount of oil, as that removed by combustion, a steady state situation prevails.

Wind exposure seems to be an important factor for the burning of oil from oil/ snow mixtures. The wind works by:

- controlling the melting area, due to deflection of flames
- controlling the temperature in the oil layer, also as a result of flame deflection
- wind herding.

The first two mechanisms are well known from oil on water burns. Our experiments were done with partly significant wind speeds, without a reducing effect on burning efficiency. Wind herding is easily observed to be a positive factor, from the repeated ignition of an extinguished layer at the edge of the pool, once herding by wind reaches a certain level.

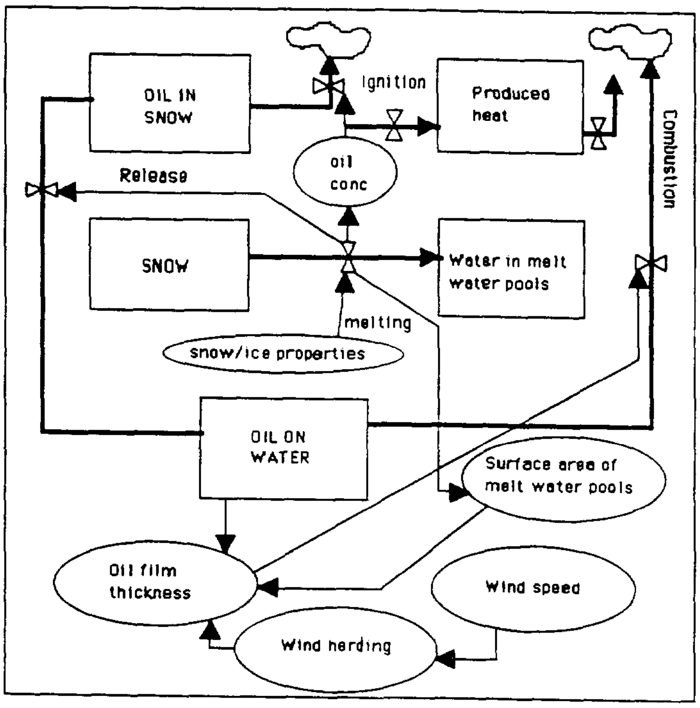

Figure 1. Overview of a conceptual model for burning of oil in snow mixtures.

BURNING OF OIL IN THE REINDALEN 1 CONTINGENCY PLAN

As emphasized in the introduction, the main objective of the experiments presented above was to give practical input for the design of the Reindalen 1 drilling contingency plan. Burning of oil is the main mitigation technique in this plan, which is reviewed below:

The Reindalen 1 drilling site and the transportation route.

The drilling site is located on a slightly sloping fluvial plain on the upper part of a wide valley, called Reindalen which has given the drilling site its name. The vegetation is sparsely developed, and the higher animal life scarce. Both the drilling site and the run-off area are described in detail in an environmental atlas (Sveum and Hoddø 1990).

Transportation to and from the site is restricted to one route, i.e. from Sveagruva to Reindalen. The route which is approximately 40 km long runs mainly on frozen rivers, with moderate slopes.

Overview of the Reindalen 1 contingency plan.

The contingency plan is developed to deal both with accidental pollution both during transport of diesel to the drilling camp, storage of diesel at the camp and if a blow-out should occur during the drilling.

The main feature of the contingency plan is the distinction between frontline contingency and secondary contingency, to make up the total contingency package.

> The frontline contingency implies that one attempts to collect and/or treat entire oil spills before they are transported by natural spread more than approximately 300 metres downstream of the drilling site. A frontline contingency was established to handle a maximum blow-out rate of 2000 m^3/day for 5 days. The main feature of this frontline contingency is given in figure 2.

A large containment wall was established downstream of the drilling site. The wall was constructed from gravel, reinforced with spray ice. The construction was selected to ensure that the wall would neither be permeable to oil, nor should it melt. In the calculation of melting resistance we assumed that oil temperature was 60°C when escaping from the well out of control. It was also required that the well should resist melting during in-situ burning of collected spilled oil, although the main burning, if spills should occur, was to take place in special burning containers. The oil was to be pumped from the collection wall into these tanks.

Ignition of the oil in the tanks or in the collection walls can be done without problem, as this oil will be relatively unweathered, and with a small content of snow.

The secondary contingency was defined as that designed to deal with any spill escaping the frontline contingency. The relation between frontline and secondary contingency is shown in Figure 2.

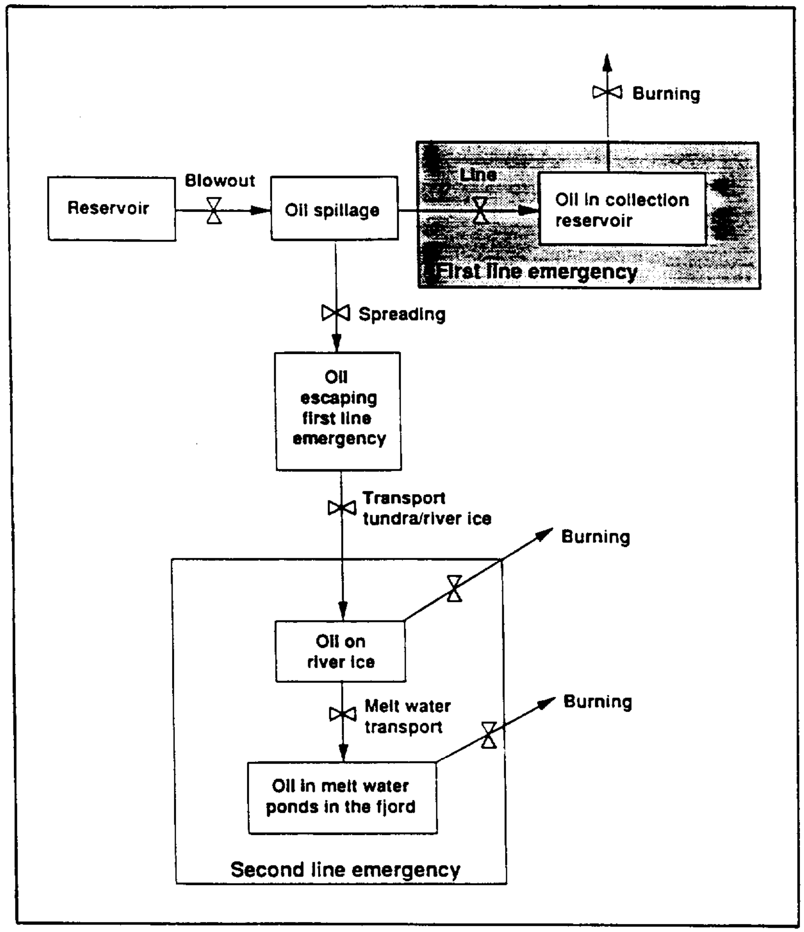

Figure 2. Outline of the total oil spill contingency at the Reindalen 1 drilling as designed for a blow–out situation. The outline shows the relation between the frontline and the secondary contingeny, and emphazisis the position of burning, either in containments or in situ.

If the oil escapes the collection wall in winter, it will spread along the frozen river. In–situ burning is the major mitigation technique, if it is not possible to clean–up the oil and bring it inside the frontline contingency area. If oil escapes the frontline, ad hoc walls should be constructed downstream of the frontline to restrict spreading, and if necessary work as containments for **in-situ** burning. The main problem with the secondary contingency is assumed to be during the spring thaw, when water in the river will enhance spreading along the river, and into overflown areas. The river has its outlet in the Van Mijenfjorden. The fjord ice drifts out of the fjord in late June or early July. The presence of ice will contain the oil between the fjord ice layer and the ice foot. If oil from a blow-out has escaped the frontline contingency, and has not been dealt with before melting, there will be some weeks available for burning. A Helitorch is kept near the drilling site to ignite this oil.

All the fuel storage tanks were located collection walls made of ice with the capacity to keep the total volume of the oil if a spill should occur. The spill oil would be transported to the burning tanks described above, and ignited.

Equipment for the ignition of the oil was kept in a special container together with sorbents etc. which were also an important integrated part of the total contingency measures. All vehicles taking part in the transport to and from the drill site also carried specially designated equipment for the ignition of any accidental spill, as well as sorbents if ignition proved to be unsuccessful.

From experimental results to practical methods.

Implementation of experimental results into a contingency plan can be problematic. This issue was given significant attention by Norsk Hydro during the Reindalen 1 drilling. To assure that the recommended methods would be of practical use if accidental pollution should occur, several efforts were initiated:

> The drilling and transport crew were all trained theoretically and practically in oil spill contingency, and especially in the ignition of oil/snow mixtures.
>
> The contingency plan was published both in Norwegian and English to avoid any language problems, since both Norwegian and foreign crews took part in the operation.
>
> A short version of the oil spill contingency plan was published, and handed the crew and the authorities involved in oil spill contingency.

This pocket sized manual also contained practical hints in ignition techniques, as well as some background on the spreading of oil in snow, which is essential for the evaluation of the spill situation. Possible oil spill scenarios are described in flow sheets together with appropriate responses. Figure 3 presents an example of the flow sheet for the ignition of oil/snow mixtures, as it is presented in the manual (SINTEF 1991).

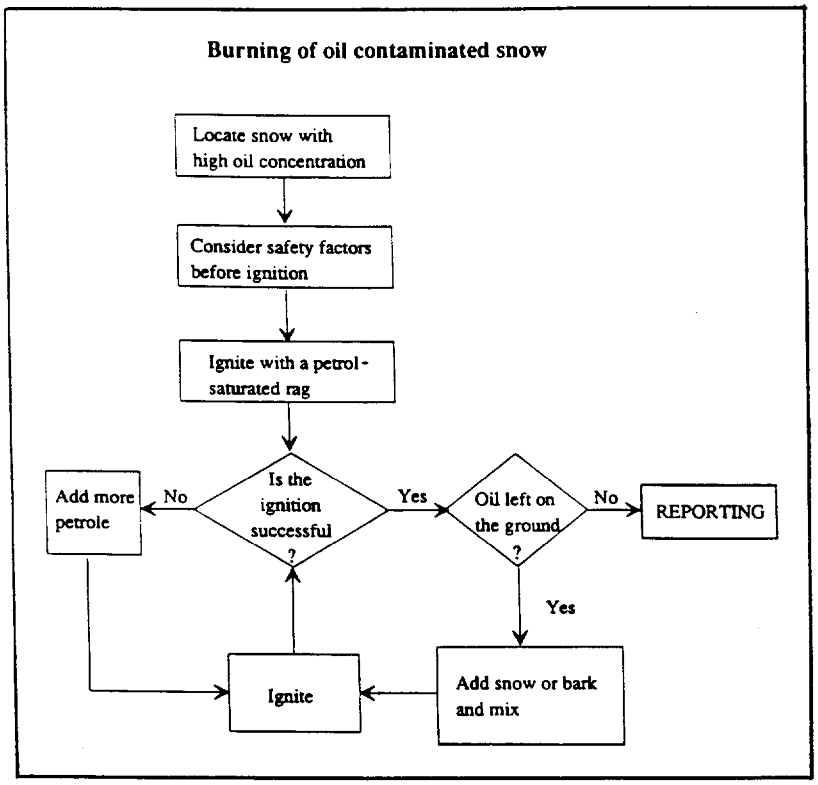

Figure 3. **MANUAL FOR TREATMENT AND CLEAN-UP OF OIL SPILLS. Reindalen 1.** Flow sheet presentation of the procedures to be followed when oil/snow mixtures are to be ignited.

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