Environmental
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053

Oil Motion During Lead Closure

Canada

January 1987

Environmental Studies Revolving Funds
Report No. 053

OIL MOTION DURING LEAD CLOSURE

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The correct citation for this report is:

MacNeill, M.R. and R.H. Goodman. 1987. Oil Motion During Lead Closure. Environmental Studies Revolving Funds, Report No. 053. Ottawa, 13 pp.

Published under the auspices of the
Environmental Studies Revolving Funds
ISBN 0-920783-52-X

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ACKNOWLEDGEMENTS

The authors wish to acknowledge the generous funding received from the Environmental Studies Revolving Funds. We are grateful for the technical support supplied by Esso Resources Canada Limited personnel: Rob Scott supervised the day-to-day operation of the ice basin; Ken Fairley and Vic Hawtin designed the overhead camera system; Jack Morrison provided advice on electronic matters, and last, but not least, Buffy da Silva typed the manuscript with her usual speed and efficiency.

SUMMARY

In the unlikely event of an oil spill occurring in Arctic waters during the spring break-up season, oil may appear in the leads between ice floes. To develop suitable mitigation tools for this situation, it is essential to know where the oil will move, that is, its fate. This paper reports data on the motion and fate of oil as leads close. The oil used was typical Arctic oil, Adgo, a relatively heavy crude.

This paper describes the experimental apparatus and the data collected during four tests. The closure rate of the leads was varied over a range of 0 to 12 cm/s and the amount of oil that remained on the surface within the closed lead and under the water was measured as a function of closure rate. Results of these tests give a clearer understanding of how oil will react when natural leads close and improve our capability of handling oil in such situations.

RESUME

Dans le cas peu probable d'un deversement d'hydrocarbures dans les eaux de l'Arctique au printemps, au moment ou la glace craque, on en trouvera dans les lignes entre les bancs de glace. Afin de trouver des instruments moderateures adaptes a ce genre de situation, il est essentiel de connaiytre la direction du petrole, a savoir son evolution. Ce document presentera les donnees experimentales sur le mouvement et la destination finale du petrole, au fur et a mesure que l'ensemble des lignes se referment. Le taux de fermeture des lignes variait d'une echelle de 0 a 15 cm/s. et la quantite de petrole, repandu sur l'eau, au sein des lignes et sousmarin etait mesuree en tant que fonction du taux de fermeture. Ce programme s'est servi d'une huile typique de l'Arctique, Adgo, un petrole brut, relativement lourd.

Ce rapport decrit l'equipement experimental et les donnees recueillies au cours de l'experience. Les conclusions de ce programme permettent une meilleure comprehension de la facon dont le petrole reagira lorsque les lignes se referment et amelioreront notre aptitude a traiter le petrole dans ce type de situation.

INTRODUCTION

OBJECTIVE

Progress in the development of cleanup methods for Arctic oil spills has improved over the past few years, in support of the advancements in exploration and production technology. Although exploratory drilling from artificial islands and drillships continues in the Canadian Beaufort, coping with a major oil spill would pose a difficult problem. One of the most challenging aspects of an oil spill in the Arctic would be dealing with oil in leads or in broken ice where conventional mechanical methods for cleanup are not successful. Although dispersants may eventually prove valuable in treating oil spills in cold waters, their use is still controversial. Dispersants are expected to be less efficient in the Arctic not only because of the cold, but also because the presence of ice reduces turbulence and hence chemical dispersion. However, brash ice actually increases chemical dispersion (Brown et al, 1985). Research into clean-up techniques could be facilitated if more were known about the behaviour and fate of oil spilled in leads between large ice floes. An understanding of the behaviour of oil spilled in leads is important in estimating the threat posed by oil to the environment because birds, fish, marine mammals and plankton frequent leads, especially in the spring.

To focus on the "fate of oil," we decided to study the motion of oil in leads on a near field-sized scale. Assuming little natural dispersion because of low turbulence levels, eventually the oil will interact with the ice as the lead either refreezes or closes up. (There is less likelihood of refreezing in the spring than in fall or winter because of warmer weather.) In this experiment, we set out to observe oil motion only during lead closure, and have not looked at refreezing.

PREVIOUS WORK

In previous experiments on interaction between oil and ice, the emphasis has been on oil spilled under the ice. Several researchers have done scaled-down studies of oil in ice in the laboratory. Metge (1978) studied the behaviour and fate of oil spilled in moving pack ice in a cold room test with a 1/30 scale model. His study showed that the impact of floes against each other caused oiled slush to be deposited on the floes. Because the oil was initially released from beneath the floes, he could not determine if oil from the surface reached the underside of ice floes as they struck one another. In another lab experiment, Martin et al, (1978) studied the behaviour of oil released under pancakes floating in a wave field over a grease-ice layer. They found that the oil came to the surface of the ice layer between the pancakes, and that the oscillating motion pumped 25-50% of the spilled oil onto the surface of the pancakes.

The problem with laboratory experiments lies in extrapolating the results to the field situation. Because not all parameters of the complex process of oil-ice interaction can be correctly modelled simultaneously, it is impossible to create an accurate scaled model of the phenomenon. Hence, there is a distinct advantage to be gained in going to a large facility where ice thickness is comparable to that observed at times in the Beaufort Sea, and where scaling problems are eliminated.

Considerable insight is to be gained into the behaviour of oil in ice by examining descriptions of actual accidental spills in pack ice. Two examples that have been reported are the Kurdistan spill of bunker-C off Cape Breton Island in March, 1979 (Reimer 1980) and the Ethel H spill of No. 6 fuel oil in the Hudson River, N.Y., in early February, 1977 (Deslaurier 1979). The oil from the Kurdistan spill, which entrained into pack ice, was observed over a two-week period using aerial reconnaissance. Inspection of floes showed contaminated brash ice deposited on the rims of the floes and spatters of oil extending up to 10 m inward from the floe edge. In the Ethel H spill, ice covered up to 80% of the Hudson River and averaged 15-25 cm thick. Ice floes averaged 7 m in diameter with some as large as 90 m. Subsequent to the spill, it was observed that black, tarry oil adhered to many of the ice floes and, in some instances, as much as 60% of the ice floe surface was covered with oil. It was found that the more porous the ice, the greater the probability that the oil would adhere to its surface, and that heavier oil tended to adhere whereas lighter ends were released to the water in a thin sheen. Although these situations are not completely analogous to the Beaufort scenario, they provide information on a more realistic scale of the behaviour of oil in ice than do scale models.

EXPERIMENTAL METHOD

EXPERIMENTAL FACILITY

The experiment was carried out in an outdoor test basin especially designed for this project and located on the site of the Esso Resources Canada Limited laboratory in Calgary, Alberta (Figure 1), close to a much larger ice test basin. The dimensions of the basin are 15 m x 19 m, with a maximum depth of 2 m. A 0.8-m deep excavation is surrounded by 1.2-m walls, using steel barriers for end walls (see Figure 1B) and steel truss retainers lined with 18.5-mm plywood for

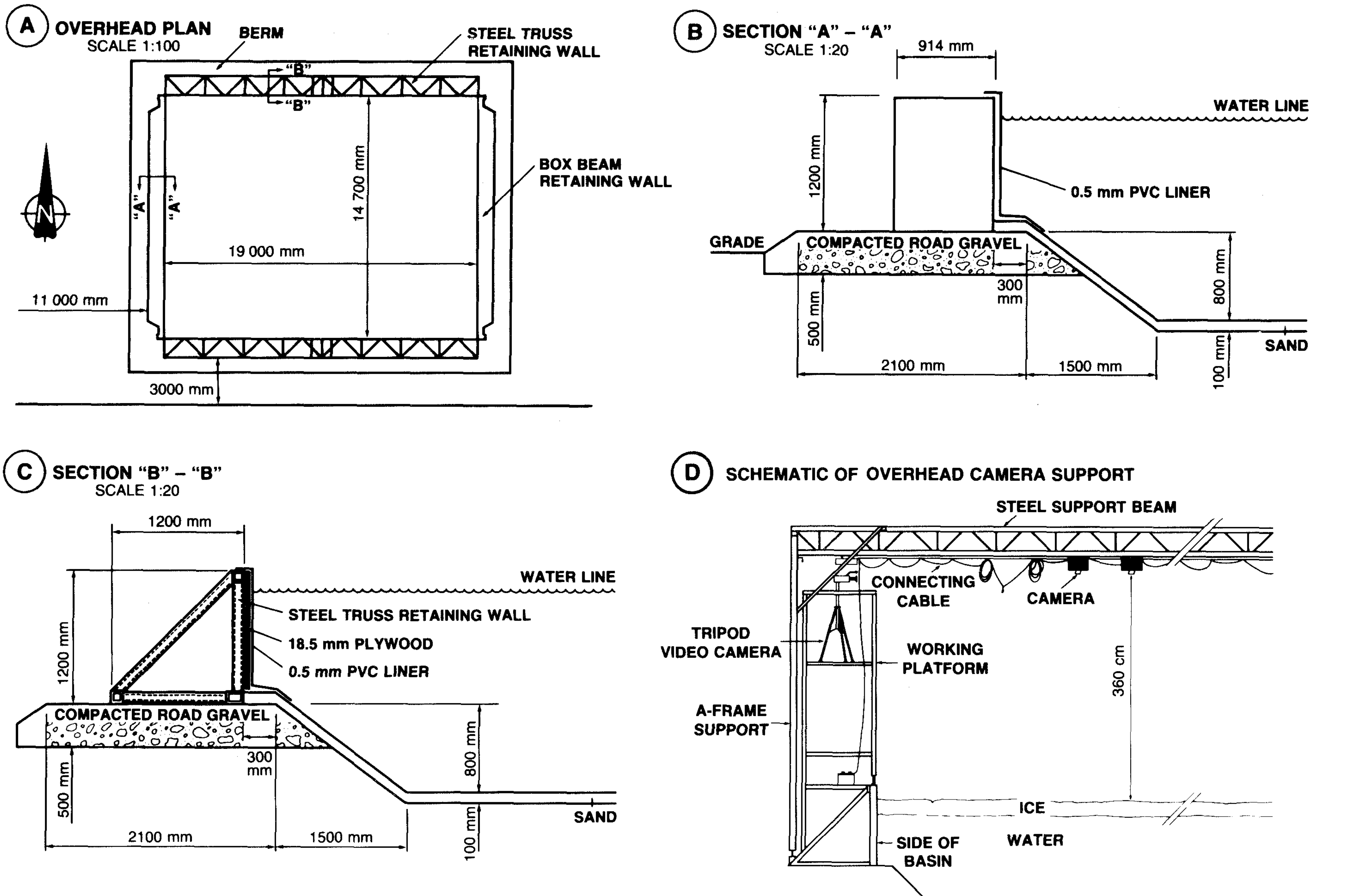

FIGURE 1. SCHEMATIC PLANS OF ICE TEST BASIN

side walls (see Figure 1C). From the side walls, the sand excavation slopes at 30° down toward a flat, sand bottom. The whole basin is lined with a sealed, 0.5-mm PVC liner, which is insulated from the steel and plywood walls by a 25-mm thick styrofoam to prevent icing on the plastic. Plywood (60 cm wide), attached to the upper sides of the basin, secures the liner and protects it from being ripped by ice. Ordinary salt was added to the water to bring the salinity up to about 28 o/oo, corresponding to the surface salinity that would typically be measured in the southern Beaufort Sea in winter.

For the purpose of recording the tests photographically, a light steel beam was erected between two steel A-frames at 3.6 m above the basin (Figure 2). Four, Hulcher 35-mm, motor-driven cameras (5 to 10 frames per second) were suspended from the beam using a pulley system, so that the position of the cameras over the basin could be adjusted easily. The cameras were activated remotely just prior to each test. Because the A-frames were mounted on wheels that ran in tracks on either side of the basin, the entire structure could be moved to any cross-section of the basin.

DEVELOPMENT OF TESTING PROCEDURES

In December 1983, an extended period of cold weather established a 30-cm thick ice sheet in the basin. A single pre-test was performed to test equipment, to establish experimental procedures, and to confirm the suitability of chosen parameters. The experimental procedure was:

a) Chain saws were used to cut a straight lead in the ice sheet 1 m wide across the width of the basin. The ice sheet on one side of the lead was stationary and on the other side was moveable.

b) Thirty litres (L) of oil was applied to the surface of the lead over a pour plate and the oil was allowed to spread to an equilibrium thickness.

c) The lead was closed by pulling the "free" ice sheet straight into the stationary one using two hand winches (one at either end of the moving sheet).

d) Video and overhead 35-m photography were used to record the lead closure.

e) After the lead was closed, underwater photographs were taken of the underside of the lead.

f) A rough estimate was made of the fate of the oil.

The oil used in this and all subsequent tests was unweathered Adgo, a heavy Arctic crude, chosen for its availability and low pour point. Figure 2 shows the gas chromatograph of Adgo oil, and Table 1 presents the properties of this oil.

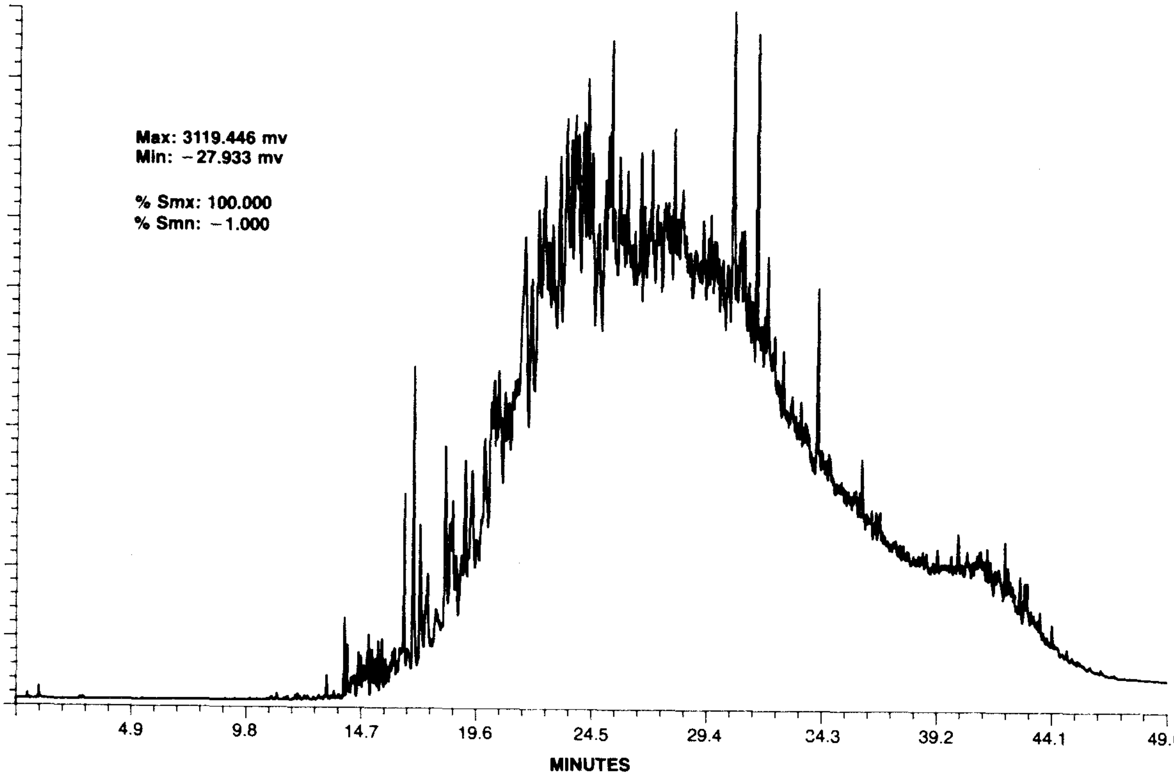

FIGURE 2. GAS CHROMATOGRAPH OF ADGO P25

TABLE 1

Properties of Unweathered Adgo Oil

Viscosities (mm^2/s)			Flash Point °C	Fire Point °C	Pour Point °C	Density @ 20°C	Emulsion
-10°C	0°C	15°C					
661.3	233.9	73.01	95	116	-26	.9520	Fairly Quick Separation

During the initial experiment, 30 L of Adgo oil was applied in an air temperature of -15°C on water with a temperature of -2°C. Based on this run, the following changes were made to the method:

a) The amount of oil used for each test was reduced to 5-10 L.

b) Wire was used in the hand winches, instead of 6 mm polypropylene rope.

c) The lead would be created using a single cut across the basin, then pulling the two ice sheets apart, so that the sides of the lead match.

d) Although slush is found floating naturally on some leads in the field which will affect results, it was decided to eliminate slush for the initial tests to avoid a further complication to interpreting the experiment.

e) Estimating the amount of oil reaching the surface of the ice was accomplished by multiplying the area of the oil by the thickness. The thickness of the oil was measured directly in numerous locations. Overhead 35-mm photographs, taken immediately after lead closure, were used to measure the areal extent of patches of oil of varying thickness. The resulting volumes were estimates.

f) Using manual lead closure meant that the rate of closure could not be controlled with precision, and high rates (greater than 15 cm/s) could not be attained easily. Two rough classifications of lead closure rate were achieved. These rates were about 5-10 cm/s and about 15 cm/s.

g) The underwater photographs showed that some oil may have reached the underside of the ice, hence, more sophisticated underwater photography was warranted. During the subsequent tests in January, underwater photography consisted of real-time underwater video, along with 35-mm motor-drive photography (18-mm and 35-mm lenses) during lead closure and post-test 35-mm shots.

Following the December test, the oiled ice was cut out and manually removed. A crane was then used to break up and remove the remaining ice sheet. A new ice sheet was grown for the next tests.

TEST PARAMETERS

By late January 1984, a new 30-cm ice sheet had grown over the basin. Using the method described, four tests were carried out on four different leads over a two-day period. Table 2 presents the parameters of each test.

TABLE 2
TEST PARAMETERS

Test No.	Volume of Oil (L)	Air Temp (°C)	Water Temp (°C)	Ice Thickness (cm)	Freeboard (cm)	Oil Temp (°C)	Salinity (o/oo)	Rate of Closure (cm/s)
1	10	-3	-0.5	30	0-3	4	24	<5
2	5	-2	-0.5	30	f 3	7	24	6
3	5	+9	-0.5	30	f 3	7	24	6
4	5	+2	-0.5	30	f 3	7	24	12

Following Test 1, it was determined that 5 L of oil would be a sufficient volume for each test, and subsequent cleanup of the oil would be easier. The salinity, as shown in Table 2 (24 o/oo), was slightly lower than in December because of leakage from the basin, but still was within the range of surface salinity observed in the Beaufort Sea in winter.

The main parameter to be varied was the rate of closure. As mentioned previously, the rate could not be changed with precision but could be measured accurately using the change of the lead width in the pictures from the motor-driven cameras. Three rates were attained: less than 5 cm/s, 6 cm/s and 12 cm/s. Although freeboard may also change the fate of the oil, except for Test 1, it was kept constant in this set of experiments. In Test 3, dispersant (Corexit 9550) was sprayed on the oil to investigate any effect on its behaviour. Unfortunately, this test was inconclusive because the large amount of slush remaining in the lead prevented complete closure of the lead.

Mild weather following the January 1984 tests prevented growing a new ice sheet in the small ice basin. However, in late March, it was possible to conduct two tests in the large ice basin on a 45-cm ice sheet that had been previously used for ice stress testing. By this time, however, following prolonged mild weather, the ice conditions had deteriorated to the point that they were unsuitable for the experiment and, as a result, little information could be obtained. One of the major problems with an outdoor ice test is the complete dependence on local weather conditions. Growing a 30 cm thick ice sheet requires two to four weeks of very cold weather, depending on the air temperatures. Slow ice growth was the major obstacle to conducting further tests as part of this experiment. Another factor that caused serious delays in the program was the nature of the small ice test basin. The plastic liner was not rugged enough to withstand impact by ice or hard objects (such as divers' equipment) and leakage was a persistent problem.

OBSERVATIONS

TEST 1

Ten litres of oil were applied to a lead with some slush in it. The oil spread very little on the surface of the lead, creating a slick 0.5 to 1 cm thick. The freeboard on the west (moving) side of the lead was about 2.5 to 3 cm but the other ice sheet was still frozen to the basin walls, and freeboard along the eastern edge of the lead was negative in places, with water flowing over the ice. When the lead closed, there was no observable flow of oil along the lead, but an estimated 3 L of oil flowed over the ice sheet on the east side of the lead (in regions of negative freeboard) as the sides of the lead pressed together. No oil was squeezed out onto the west side of the lead, or under the ice. Figure 3A shows an aerial view of the oil on the ice.

TEST 2

The amount of oil poured onto the lead was reduced to 5 L. Probably as a result of less slush in the lead, the oil spread more evenly and thinly than in Test 1, to about 0.2 cm thick. On both sides of the lead, the freeboard was 2-3 cm. As the lead closed at about 6 cm/s, oil was squeezed over the ice on both sides of the lead (Figure 3B), to a maximum of 20 cm from the edge of the lead. An estimated 0.5 to 1 L of oil covered the ice. Underwater video and photography showed that some oil was squeezed downward between the ice sheets upon impact, then rose again. No oil reached the underside of the sheets. Four to 4.5 L remained between the ice sheets. Again, the oil did not move along the lead.

TEST 3

Extensive slush in the lead prevented complete lead closure.

TEST 4

The oil spread over the lead to a similar thickness as in Test 2. However, the lead closed at twice the rate (12 cm/s), causing the oil to splash over both sides of the ice to a distance of 30-40 cm from the ice edges all along the lead. An estimated 4 L was spread on top of the ice (see Figure 3C). Underwater photography showed that the impact of the ice sheets coming together forced some oil onto the underside of the ice, although the actual amount was negligible, probably less than 0.1 L. This oil appeared as globules scattered as far as 75 cm from the closed lead.

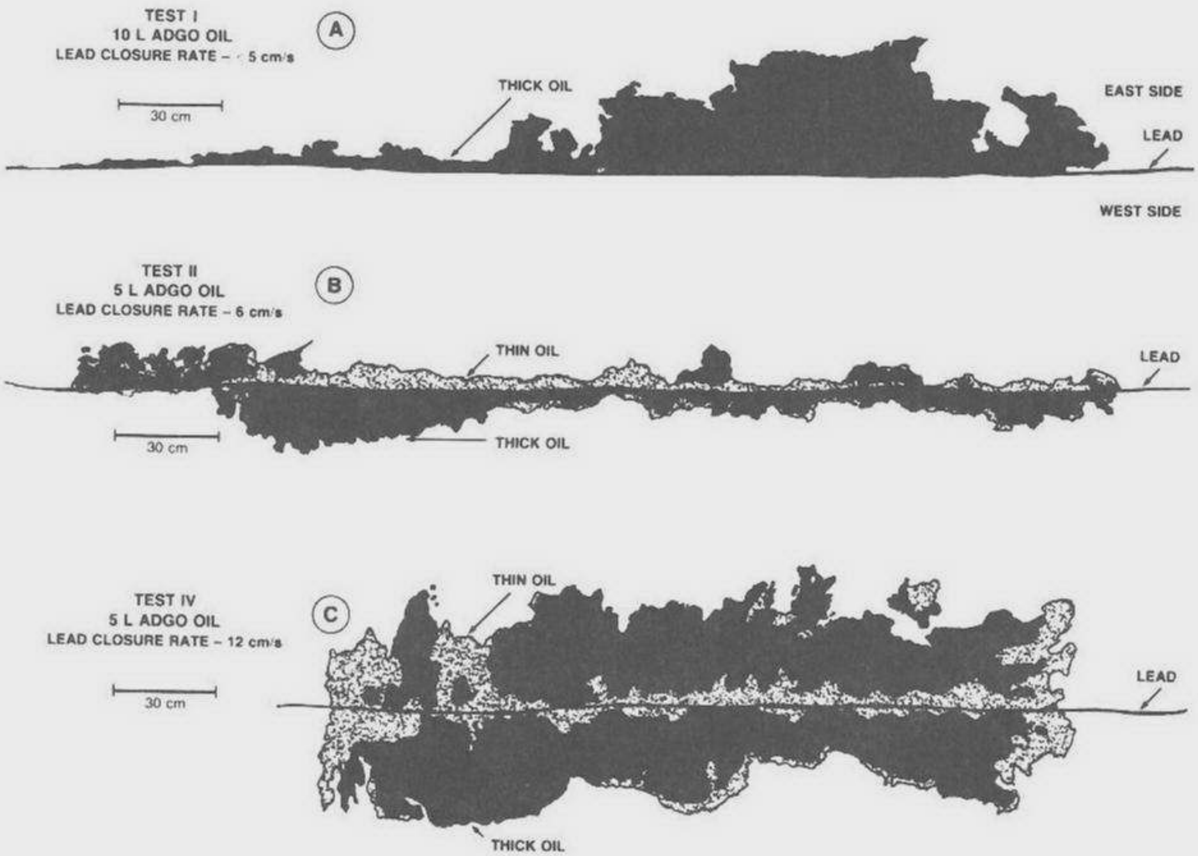

FIGURE 3. OIL SPILLED ON ICE AFTER LEAD CLOSURE

DISCUSSION AND CONCLUSIONS

The few tests that were performed indicate that the fate of oil in a lead when two ice sheets come together is a function of the rate of closure of the lead: the higher the rate of closure, the more oil will spill onto the surface of the ice and the less will be found between the two sheets. When the lead formed between two 30-cm ice sheets closed at rates up to 12 cm/s, little oil found its way under the ice, although the amount appeared to increase with closure rate. The closing motion of the ice did not pump oil laterally along the straight lead. Negative freeboard caused greater quantities of oil to be deposited on the ice.

Because of adverse weather conditions, further tests could not be conducted in 1984. Higher rates of closure need to be investigated as well as several other parameters that could possibly affect the behavior of the oil. For example, the type of oil and initial thickness of the oil in the lead might make a significant difference. In the field, slush in leads is a common occurrence, and the ice thickness is greater in late winter and spring. Both factors affect the fate of the oil and should be studied in the future. The effect of applying dispersant on oil in leads warrants further study.

A major concern, when considering the results of the experiment, is whether the rates of closures used correspond to field values. Unfortunately, a literature review revealed no research that had addressed this question for either the Canadian Arctic or the east coast of Canada. This gap will, we hope, be filled by a project sponsored by the Environmental Protection Service of Environment Canada.[1] Satellite photos taken of the Beaufort Sea and Canadian east coast are now being studied to document lead closure rates and to correlate them to time of year and wind speed. Ice thickness, ice profiles, and ice density are also being documented. This information should provide the link from the basin data to actual field conditions, and could be used as a guide for planning future tests.

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