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OIL SPILLS IN LEADS:
TANK TESTS AND MODELLING

EE-95

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by

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EE-95 **December 1987**

ABSTRACT

The results of a literature survey and indoor and outdoor experiments have been combined to develop a preliminary computer model of oil spill fate and behaviour in pack ice leads. The model is based largely on theoretical considerations and small-scale experimental results and requires full-scale verification. The areas of major uncertainty are in heat transfer from a large, oiled lead and in the effects of waves and wave damping by slush ice in large-scale leads.

The output of the model concentrates on the amount of oil available for countermeasures as a function of time. Both the experiments and the model indicate that very little oil is incorporated into growing ice in a lead; most remains on the surface of the new ice exposed to the atmosphere. Snowfall and lead closure resulting in ridging are considered to be the major processes that encapsulate oil and render it unavailable for countermeasures.

RÉSUMÉ

Les résultats d'une étude bibliographique ainsi que d'expériences sur le terrain et en laboratoire ont concouru à la construction d'un modèle informatisé du devenir et du comportement des nappes d'hydrocarbures dans les chenaux libres de glace. Le modèle donne, en fonction du temps, la quantité résiduelle d'hydrocarbures qui peut faire l'objet de mesures d'intervention. La théorie (modèle) et l'expérience montrent que très peu d'hydrocarbures sont piégés dans la glace en croissance dans un chenal libre; la plus grande partie reste à la surface de la nouvelle glace, exposée à l'atmosphère. On considère que les chutes de neige et fermeture des chenaux qui aboutit à la formation de crêtes constituent les principaux processus de piégeage des hydrocarbures qui, ainsi, échappent aux mesures d'intervention.

ACKNOWLEDGEMENTS

The authors of this report were Ian Buist and Stephen Joyce, both of S. L. Ross Environmental Research Limited and David Dickins of DF Dickins Associates Limited. The Scientific Authority for this study was Merv Fingas of Environment Canada, EETD. Funding for the study was provided by the Northern Oil and Gas Action Program of Indian and Northern Affairs Canada.

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1.0 INTRODUCTION

Several research programs have been devoted to the modelling of oil spills in Arctic waters. These have resulted in a number of oil spill fate models that tend to fall into certain categories as defined by Mackay (1986): (i) open-water trajectory models that may include interaction with shorelines; (ii) open-water behaviour models that describe the changing properties and configuration of oil spills with time; (iii) descriptions of oil behaviour on shore; (iv) descriptions of oil behaviour in rising blowout plumes beneath open water or an ice-covered surface; and (v) descriptions of oil movement under ice. There is, however, a lack of model capability treating the situation in which a spill on water is subjected to freezing conditions or a developing ice field (Bobra and Fingas 1986).

Spilled oil would be exposed to such a developing ice field if it found its way into pack ice leads in below-freezing temperatures. Leads are long linear regions of open water formed when sheets of pack ice diverge. These leads will often open and close depending on wind stresses, water currents, and ship traffic. Birds, seals, polar bears, and walrus often gather in these open water areas making leads one of the most biologically sensitive areas in ice-covered waters.

1.1 THE STATE-OF-THE-ART

Various experimental studies have investigated the fate of oil spilled on water or in ice during freezing conditions. Perhaps the earliest of these was conducted near Ottawa in 1972 (Scott and Chatterjee 1973). These tests involved pouring 100 litres of Norman Wells crude onto a 13 m^2 area of open fresh water on an ice covered pond. Weather conditions were monitored continuously, as were the physical and chemical properties of the oil as time progressed. For the first 12 days following the release, the air temperature was generally in the $0^{\circ}C$ range and no freezing occurred. On day 13, colder temperatures and snowfall led to incorporation of the weathered oil into slush and the eventual encapsulation of the oil in frozen slush.

Similar results were obtained on a larger scale as part of the Balaena Bay experiments (NORCOR 1975). In this experiment 400 litres of Norman Wells crude was spilled in a 36 m^2 open water area. The oil was mixed with blowing snow in -10 to -40°C temperatures to form oiled slush and was eventually encapsulated. In this and the 1972 experiment, the oil remained on the surface and was affected primarily by evaporation until snowfall caused an oil-snow mulch to develop and encapsulate the oil by freezing. These experimental results were verified at an actual spill in Buzzards Bay (Deslauriers 1978) where the effect of snow greatly hindered cleanup and restricted aerial observation.

Cold room wave tank tests were performed by Martin (1980) to investigate the interaction of Prudhoe Bay crude oil with grease ice. It was observed that oil released in front of the grease ice was rapidly transported into the ice and pumped onto the ice beyond the "dead" zone where wave action was damped out. Some oil droplets remained circulating in the grease ice ahead of the dead zone. This pumping action was also noted by Metge and Telford (1979) and during the Kurdistan spill (C-CORE 1980).

The fate of oil in a closing lead was investigated by MacNeill and Goodman (1985). In this experiment, leads 1 m wide were created in an outdoor test basin containing 30 cm thick ice. Oil was poured into the leads and they were manually closed at varying rates. It was concluded that very little oil ends up beneath the ice surface and that the amount pumped onto the surface of the adjoining edges increases with increasing closure rate from 20% at 6 cm/s to 80% at 12 cm/s. It was noted that lead closure did not cause oil to flow along the lead using a viscous crude for a test oil.

Small scale tests were performed by Wilson and Mackay (1986) in a hoop tank apparatus to investigate the incorporation of various oils in developing grease ice under agitated conditions. They concluded that the amount of oil entrained in ice was increased as a function of the density and viscosity of the oil, the presence of sufficient turbulence, the formation of water-in-oil emulsions and the fineness of the ice particle size (the optimum size was 5 mm). They also indicated that under quiescent conditions, the presence of an oil slick may delay the onset of freezing, though under agitated conditions it may not.

1.2 OBJECTIVE OF STUDY

The objective of the study was to develop a computer model to predict the amount of oil available for countermeasures as a function of time, initial oil properties and environmental conditions, in the event of a significant oil spill in a pack ice lead. A review of the above and other past work indicated that more experimental data would be required to construct the model. Information was still missing on 1) the spreading rate and wind herding of oil on frazil and grease ice over a range of development stages; 2) weathering rates of oil in freezing situations; and 3) data on the fraction of oil remaining as a surface slick as a function of freezing. Before modelling could proceed it was necessary to develop experimental information in these missing areas. This was accomplished by conducting work in a wind/wave tank and at the National Research Council outdoor manoeuvering basin in Ottawa.

2.0 EXPERIMENTAL METHODS

The methodology for the wind/wave tank tests (performed to study oil behaviour in freezing conditions with high winds and waves) is presented first; the methodology for the outdoor tests (performed to study oil behaviour in low wind conditions and with snowfall) follows.

2.1 WIND/WAVE TANK TESTS

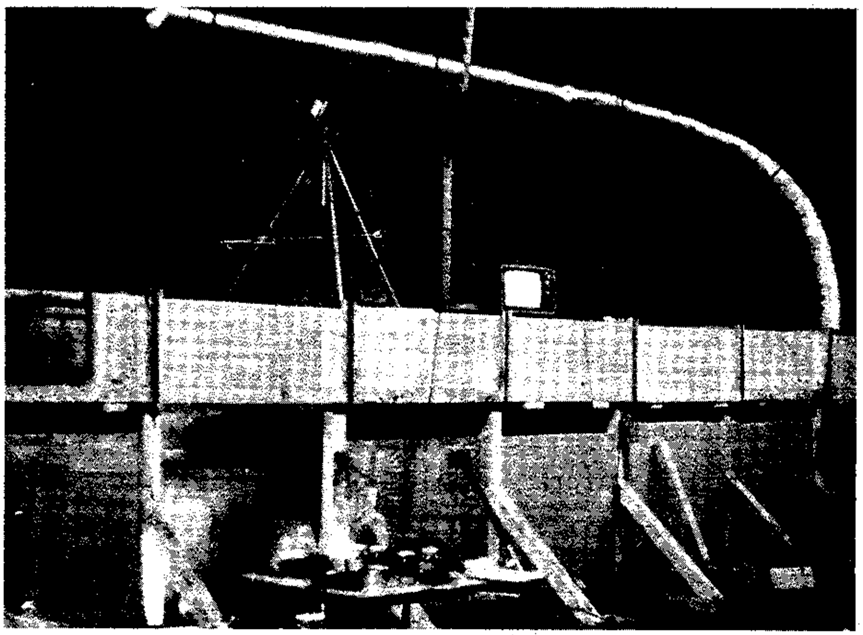
2.1.1 Wind/Wave Tank as a Simulator

Figure 1 shows the wind/wave tank at the S.L. Ross laboratory. The tank is 11 m long by 1.2 m wide by 1.2 m deep. A large fan and ductwork allow the passage of outside air over the water surface at varying wind speeds. A wave paddle is used to mechanically generate waves of varying amplitude and period. The tank was fitted with a 40 cm wooden barrier 7.2 m from the upwind edge. This section of the tank simulated a small 1.2 m wide section of a pack ice lead at the downwind edge.

Ice formation in the freshwater tank was found to be very similar to ice formation in actual pack ice leads as described by Dickins et al. (1986). Ice crystals formed in the open water area and drifted down the length of the tank to pile up against the fixed barrier to form grease ice. Without mechanically generated waves the grease ice eventually formed a dense dead zone where it behaved as a solid. Allowed to continue, the entire tank became covered with slush ice which formed a hard impermeable layer on the surface.

In the presence of mechanically generated waves the same grease ice formation was observed but eventually became so thick that circulation within the ice was suppressed and the surface froze into chunks of "pancake" ice floating over a grease ice layer. The pancakes formed in the tank were generally circular with a diameter of about 30 cm and slightly

FIGURE 1 -Wind/Wave Tank Photo



turned up edges. This phenomenon of pancake ice formation was well documented by Martin (1980) and Metge and Telford (1979).

The wind/wave tank set-up can be considered to be an approximate full-scale representation of a spill situation in which a lead has opened up and oil has found its way into the open water or forming ice field. Since the oil in this situation will quickly spread and drift to the downwind edge of the lead, the tests in the wind/wave tank can be used to predict the fate and behaviour of the oil at the downwind edge as the ice growth progresses under the influence of a variety of different environmental conditions.

2.1.2 Test Matrix

The ability of an ice field to retain quantities of oil within its structure is presumably a function of the oil's density, viscosity, and interfacial tension as well as the thickness of the oil layer, the porosity of the ice field and the level of turbulence present.

The four easily adjusted variables of: windspeed, oil type and volume, wave height, and initial ice maturity were chosen to form the test matrix (Figure 2) since they incorporate all of the parameters thought to affect the interaction of oil and developing ice. Since each run took up to 24 hours under the right conditions, it was not possible nor was it thought necessary to do all of the tests in the matrix.

One crude oil, Mixed Sweet Western (MSW) and two mixtures of Bunker C and automotive diesel were used as test oils. Table 1 shows the properties of these oils.

Three distinct ice maturities were identified. I_1 represents no initial ice present. I_2 is a covering of grease ice at the barrier up to about 15 cm thick and to 50 cm upwind from the barrier. The I_3 condition

		S_1			S_2		
		I_1	I_2	I_3	I_1	I_2	I_3
W_1	O_1		Run 9		Run 1 Run 2	Run 3	Run 4
	O_2					Run 13	
	O_3					Run 8	Run 12
W_2	O_1				Run 7	Run 6	Run 5
	O_2				Run 14		
	O_3					Run 10	Run 11

Figure 2 : Test Matrix

O_1, O_2, O_3 - Oil Type
I_1, I_2, I_3 - Initial Ice Maturity
W_1, W_2 - Wave Condition
S_1, S_2 - Wind Speed

TABLE 1: TEST OIL PROPERTIES

Oil Type	**Test Temp.**	**Density (g/cm^3)**	**Dynamic Viscosity (mPas)**	**Kinematic Viscosity (mm^2/s)**
Bunker C[1]	1°C	1.025	2,310,000	2,253,658
Diesel[2]	0°C	0.838	3.9	4.65
MSW[2]	0°C	0.847	47.3	55.9
Bunker C/19% Diesel[1]	7.5°C	0.981	1480	1509
Bunker C/55% Diesel[3]	2°C	0.917	71.8	78.3

Source

1. S.L. Ross 1987;
2. Bobra and Chung 1986;
3. Measured

occurred after the transition from slush-like grease ice to a semi-solid but malleable mass of dense grease ice. When waves were present, the I_3 condition contained pancake ice.

Two wave conditions, W_1 = no waves generated by the wave paddle and W_2 = mechanically generated waves, were also used as test variables. The windspeeds S_1 and S_2 were 3.5 m/s and 7 m/s respectively, measured with a hot-filament anemometer at 30 cm above the ice surface.

2.1.3 Experimental Method

The tank was filled with approximately 10,000 L of tap water to a depth of 0.85 m. The proper initial ice conditions were allowed to develop for each run with the artificial barrier in place and the blower turned on. If no initial ice was called for then the water was allowed to cool until ice crystals just started to appear. The inlet air temperature, the air temperature at the barrier and the water temperature were all recorded just prior to adding oil and at regular intervals thereafter. One litre of the test oil was added at room temperature with the fan momentarily shut off using a spill plate. The oil was spilled at least 1 m from the barrier so it could spread and cool before the wind herded it into the developing ice. The first five minutes of each run were recorded on video tape in order to observe wind herding behaviour.

When the wave paddle was not used, the experiment was allowed to continue until the surface of the tank was completely frozen over (including the area underneath the slick). When waves were artificially generated, the experiment was allowed to continue until the amount of oil remaining as a surface slick was thought to have reached equilibrium. The wave generator was then shut off and the surface of the tank allowed to freeze solid for analysis.

At the completion of each run, the area and thickness of the surface slick was measured or estimated. The slick was then removed with sorbent material from the surface of the ice. The remaining oil frozen in the ice was then separated and measured when possible or its percentage of the total was estimated. A short video tape was taken for each run before and after the surface slick was removed.

2.2 OUTDOOR TANK TESTS

The outdoor tank tests were conducted in late January and early February in the manoeuvring basin located on the Montreal Road campus of the National Research Council of Canada in Ottawa. The basin is 120 m long by 60 m wide and contains fresh water to a depth of 3 m. At the time of the tests the basin was covered with approximately 29 cm of ice and 50 cm of snow. This snow was removed from the test area prior to the tests. Figure 3 shows the layout of the experimental plots in the test area. Two 10 m x 1 m open water areas were cut in the ice sheet at right angles to each other. The first, Lead 1, was used to study the behaviour and fate of oil in a freezing lead under light wind conditions. The second, Lead 2, was used to investigate the behaviour and fate of oil in a freezing lead in higher wind conditions (along the length of the lead) with snowfall. Four 1 m x 1 m test squares were cut out and used to examine the effect of oil slick thickness on oil behaviour and fate processes.

Figure 3: Outdoor test tank layout

2.2.1 Test Procedures

Prior to putting oil in each lead, the accumulated frazil and slush ice was skimmed from the water surface. The oil used for these tests was the Mixed Sweet Western crude used in the wind/wave tank tests (see Table 1). Ten litres of this oil was poured, via a spill plate, onto the surface of both Leads 1 and 2 for a nominal initial thickness of 1 mm. One, two, five and ten litres of oil were poured onto the surface of the four test squares to give nominal initial thicknesses of 1, 2, 5 and 10 mm respectively.

Oil thickness samples were taken periodically using pre-weighed squares of sorbent pad which were subsequently reweighed to determine thickness (corrected for density). Grab samples of surface oil from each test area were also taken periodically to document oil weathering. The evaporative loss of these samples was determined by comparing their density at 0°C (as determined by a Parr densitometer) with density vs evaporative data for the same oil from both field and laboratory tests (S.L. Ross and D.F. Dickins 1987).At the same time that the oil samples were taken, snow, ice and meltwater data were also collected. This involved drilling a hole through the new ice in the test areas and measuring the depth of snow and/or slush on the oil, the depth of meltwater beneath the oil and the thickness of new ice beneath the water.

Air temperatures, wind speed and wind direction were continuously monitored by a computerized weather station mounted 10 m above the ice level on an observation tower adjacent to the test tank. Surface temperatures (water, oil and air 1 cm above the lead) were measured periodically with a thermistor. Ice level winds were measured with a hand-held thermal anemometer.

The behaviour of the oil in Leads 1 and 2 was recorded by both a video system mounted on the observation tower and time-lapse 8 mm movies from a tripod-mounted camera on the ice.

3.0 RESULTS AND DISCUSSION

3.1 LITERATURE SURVEY

An on-line search of eleven different scientific databases was carried out with the objective of revealing any new and/or foreign references applicable to the study of oil spills in pack ice leads (see Appendix 1). The search covered papers prepared in Japan, North America, Scandinavia, Europe and the Soviet Union. Results demonstrated a paucity of information on the subject. The search uncovered no significant sources that were not already known to the study team. Many of these sources had already been reviewed, and the results used to develop formulations for lead freezing rates in a previous Environment Canada study (Dickins et al. 1986). Several of what can be considered as basic references in the field are described briefly below.

Andreas et al.(1979). The Turbulent Heat Flux for Arctic Leads.

The analysis and measurements described in this paper are appropriate for small leads in the order of 5 to 10 m wide with relatively mild wind chill of less than 200 ^{o}Cm/s (i.e., conditions representative of this study). Unfortunately, the mathematics describing turbulent heat flux in this paper are somewhat impractical in a working field situation. The results of Andreas were used in conjunction with the work of Bauer and Martin (1983) to present ice production rates in practical terms of wind speed and temperature differences, air to water (Dickins et al 1986).

Bauer and Martin (1983). A Model of Grease Ice Growth in Small Leads

This paper provides the most comprehensive analytical treatment of grease ice production in open water under winter Arctic conditions (wind chill in excess of 200 ^{o}Cm/s) and provides the basis for some of the mathematical modelling found in Section 4.0. The authors consider that the results of this paper are applicable to small leads with widths in the order of tens of metres (Martin 1987).

Martin and Kauffman (1981). Field and Laboratory Study of Wave Damping by Grease Ice

As inferred by the title, the primary objective of this study was to look at the mechanism of wave damping where the open ocean swell penetrates grease ice and pancake ice at the peak ice edge (so called marginal ice zone). Martin describes naturally occurring emergence zones where grease ice has been observed to collect in rows within large leads. This phenomenon could result in an effective oil herding or concentrating mechanism in large leads.

The existing literature relates directly to the problem of oil freezing in new ice forming on leads in the presence of wind herding. Previous work can be used as a basis for modelling the results obtained in this study from the wind/wave tank (Joyce 1987). In considering how accurately model predictions might relate to a field situation, the existing literature identifies a number of other environmental factors that could play an important role in controlling the time taken to establish a solid ice cover across a lead. One factor, unproved but plausible, is the presence of fog layers over large open leads which will tend to decrease the heat flux to the atmosphere (Lo 1980). A second potentially more important factor concerns the process of saline convection caused by the exclusion of salt during the freezing process. Modelling of this process by Kozo (1983) showed significant circulation in quiet conditions but the model broke down in the presence of currents >5 cm/s.

Any overturning of the water column will slow icing by introducing warmer deeper water. The density pycnocline common in the Beaufort Sea effectively insulates the upper layer from deeper heat sources and promotes rapid refreezing of leads.

3.2 WIND/WAVE TANK TESTS

A short description of each test run in the wind/wave tank follows.

Run 1

This initial run was primarily to evaluate and make changes to the test procedure. 500 ml of Mixed Sweet Western (MSW) was initially spilled. The water temperature in the tank was 2.5°C and the air temperature at the tank inlet and above the test area were -2.5 and 0.5°C respectively. There was no ice initially present and the wave generator was off. Another 500 ml of MSW was added 20 minutes later to bring the slick volume and area to a more representative level. The slick quickly spread and drifted to the barrier and the edges of the slick were swirling back into the centre in a cyclic motion. This unnatural behaviour was corrected for subsequent runs by moving the barrier farther down the tank. New ice crystals were forming 30 minutes after the start of the test and the tank was completely frozen over in 6 hours when the air temperature over the slick had dropped to -6°C. There was no oil incorporated into the developing ice in this run.

Run 2

Run 2 was a repeat of Run 1 with the barrier moved farther down and using one litre of test oil. The temperatures during the run were -8 and -3.5°C for the inlet and test area temperatures and 1.5°C for the water temperature. Ice started forming 2 hours and 10 minutes after the fan was started. After 3 hours and 20 minutes, the slick was on top of a fairly solid mass of grease ice. After 7 hours and 30 minutes the tank was completely covered with solid ice about 8 mm thick. Below this, there was a layer of fine crystals approximately 3 cm thick. A thickness sample of the surface slick showed it to be about 1 mm, although there seemed to be thicker patches present. All of the oil with the exception of a few scattered drops remained on the surface of the ice. The area of the surface slick was about 3120 cm^2 and it was located up against the barrier in the same position and shape as the wind originally herded it to before the ice growth.

Run 3

This run was similar to Run 2 except that an initial covering of slush ice was allowed to build up to 40 cm from the barrier prior to spilling the 1 L of MSW. The air temperature above the water was -3^{o}C. The oil quickly herded to the edge of the grease ice and then slowly migrated across the surface of the grease ice to the barrier. It took about 3 minutes for the oil to completely spread on top of the slush ice. After 8 hours and 30 minutes the tank was frozen over and the surface slick was found to have an area of 3960 cm^2 next to the barrier where the wind had originally herded it. After cleaning the surface slick with sorbent pads, it was found that some of the oil had become trapped in the slush ice that was initially present. This remaining oil was removed and had a mass of approximately 54 g or slightly more than 6% of the original volume.

Run 4

Again 1 L of MSW was spilled under conditions of no waves and a windspeed of 7 m/s. This time there was about 80 cm of consolidated grease ice initially present. The air temperature was -3^{0}C over the slick. The slick was quickly herded to the ice edge as in the previous run but then spread more slowly on top of it. Once the entire slick was on top of the ice, the spreading stopped completely. There was very little sideways spreading and the slick did not expand the full width of the tank. The run was stopped after about 1 1/2 hours since the surface slick was completely on top of the ice and was no longer exposed to developing ice. It was found that a small amount of oil was frozen into the ice at the water/ice edge. This made up less than 1% of the slick volume. The final area of the surface slick was about 3456 cm^2 and it was easily removed from the surface with sorbent pads.

Run 5

This began the series of experiments on the MSW oil type with waves being generated. Run 5 had a wave generator setting of 50 which corresponded to an amplitude of about 50 mm at the barrier and a wave period of 1.58 seconds. In this run there was a 1 m wide covering of slush ice in the tank just starting to form pancakes. The air temperature was -2°C. The slush ice thickness was about 20 cm. The oil quickly herded to the ice edge and then made its way to the barrier through the slush-filled spaces between pancakes within about 6 minutes. As the oil moved through the pancake ice field most of it was pumped onto the top of pancakes by the opening and closing motion of the spaces. The wave generator was stopped after 2 hours and the tank was allowed to freeze over. It was found that about 80% of the oil was deposited on top of the pancakes. Most of the remainder was stuck to the sides of the tank and the barrier. About 14 g was determined to be frozen in the ice (mostly at the edges of the pancakes) or less than 2% of the total volume. The area covered by the slick was about 14400 cm^2. It seemed to be evenly distributed throughout the initial ice cover.

Run 6

1 L of MSW was spilled with an initial grease ice cover to 50 cm from the barrier. The wave generator setting was again 50 and the waves at the barrier were 60 mm in height. The slick was herded quickly right across the top of the slush ice to the barrier. After 40 minutes, pancakes started to form and the crust around the edges was largely saturated with oil. There was evidence of weak (black) emulsion formation at the barrier and at the edges of the tank. The surface slick took up an area of 6100 cm^2. It was estimated that about 10% of the oil was frozen in the ice; mostly in the form of small droplets 1-2 mm in diameter. These were evenly distributed beneath the slick.

Run 7

The wave generator was set at 60 for a wave period of 1.36 seconds and a wave of 65 mm at the barrier. One litre of MSW was spilled with no ice initially present. The inlet temperature was extremely cold at -16°C giving an air temperature over the water of -9°C. In less than 2 hours, there was a covering of slush ice about 20 cm thick starting to form pancakes. The action of the waves on the oil against the barrier caused a significant amount of dispersion throughout the depth of the tank. This caused some of the oil to go under the barrier (which extended about 20 cm under water) and resurface or get trapped on the other side. Again there was weak emulsion formation noted at the edges of the tank. It was estimated that about 20% of the original oil volume became trapped in the ice.

Run 8

Run 8 was a repeat of the conditions of Run 3 (i.e. initial slush ice and a windspeed of 7 m/s) except a heavy Bunker C/diesel blend oil was used. The air temperature was -3 through most of the run. The heavy oil was quickly herded into one ribbon about 50 to 80 mm wide and 10 mm thick located at the edge of the ice. After 5 minutes, this slick slowly rolled up inside the grease ice border, The surface of the tank froze after 2 1/2 hours and the slick was removed easily from the ice surface with a spatula. As in the other experiments without waves, the oil slick remained in the same location as the wind originally herded it to.

Run 9

1 L of MSW was spilled with an initial grease ice cover and a slow windspeed of 3.5 m/s. The inlet temperature was 0°C and the temperature over the slick was +3 so the experiment was run overnight to get cold enough temperatures. It was noted that the slow windspeed did not herd the slick toward the barrier very much and natural spreading determined its

area. After 14 hours the surface slick area was 8592 cm^2 and there was no oil in the ice underneath.

Run 10

1 L of Heavy Bunker C/diesel mix (0_3) was spilled with an initial slush ice cover about 40 cm wide and a wave generator setting of 50. The air temperature was +1.5 at the beginning of the run and dropped to -6 after 4 hours. The heavy viscous oil formed a ribbon at the grease ice edge as in Run 8 that slowly made its way to the barrier. From here the oil spread along both edges of the tank, sticking to the walls along the way. There was very little emulsification as there was with the crude oil, 0_1. At the completion of the run, there was only about 30% of the oil remaining as a surface slick with approximately 5% frozen in the ice and 65% stuck to the sides of the tank and the barrier underwater.

Run 11

1 L of 0_3 was added to the open water ahead of a 72 cm wide area of 11 cm thick pancake ice. The waves generator was set at 50 and the waves were 50 mm high at the barrier. The air temperature was -0.5°C. After 30 minutes the pancake ice had consolidated into 2 large chunks and most of the oil was in the space between them and on the adjacent edges. There was some migration down the space to the tank edges but the oil never did spread all the way to the barrier. After about 4 hours, the surface slick was removed with a spatula and sorbents. It was found that about 1% of the oil was trapped in the ice in scattered globs.

Run 12

An extremely heavy oil was mixed with 86% Bunker C and 14% Diesel for this run giving it a density of 0.995 g/cm^3 and a viscosity of 2570 mPas at 10°C. This oil was spilled in front of a consolidated grease ice area in order to see if the wind would push it underneath the ice edge. The wave generator was turned off. The oil formed a large blob about 3 cm thick at the edge of the ice and it floated low in the water but would not roll under or over the ice edge. After 15 hours, the ice around the blobs was at least 3.5 cm thick but there was no ice underneath the oil. None of the oil was completely encapsulated in the ice although it was sunk in about 1.5 cm.

Run 13

The 45% Bunker C diesel mix, 0_2 was added to the open water ahead of a small area of grease ice. The wave generator was off. The air temperature was +2 at the time of the release but there were colder temperatures overnight. The slick was herded quickly over the grease ice to the barrier and remained there as the ice developed. After 12 hours, it was found that about 8% of the oil was frozen in the ice in fairly large blobs and distributed throughout the area where the original slush ice was.

Run 14

0_2 was used in this experiment with the wave generator setting at 50 and no initial ice present. The air temperature was +1 at the beginning and dropped to 0 later. Figure 4 shows the results of this run after 11 hours. Most of the oil was on the surface either as a slick on top of the pancakes or in the form of a weak emulsion at the edges of the tank. An estimated 30% was frozen in the ice in small drops about 3-5 mm diameter. However as can be seen from Figure 4, this was largely due to the crystals scraping away at oil on the sides of the tank. Finer droplets were distributed throughout the ice cover.

Run 15

The purpose of Run 15 was to investigate the behaviour of a highly viscous oil. Hibernia B-27 was chosen since it is a waxy crude with a high viscosity but a density comparable to that of the MSW (S.L. Ross 1984). It was added to the open water ahead of a grease ice area extending to 65 cm from the barrier. The oil migrated very slowly onto the slush ice surface. Figure 5 shows the slick shortly after release. About 1/2 of the slick was pushed on top of the ice and the rest stayed in open water. Slush ice eventually formed underneath the slick and stopped it spreading altogether. Twelve hours later the slick had moved forward but its area had not changed. The slick was easily removed from the surface of the ice and it was noted that it left a fairly deep impression in the ice surface.

Figure 6 summarizes the results obtained from these tests.

Figure 4a: Oiled pancake ice; top view

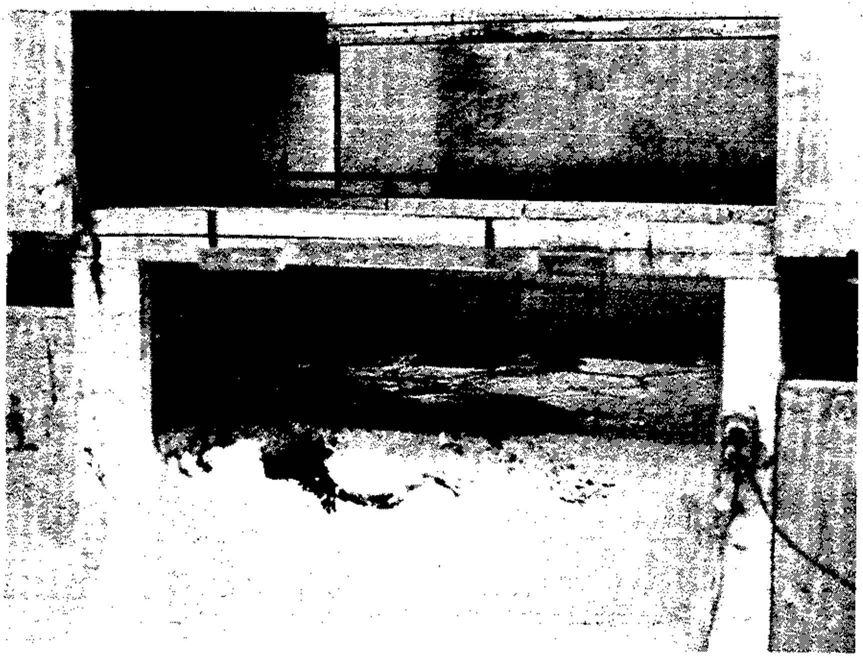


Figure 4b: Oiled pancake ice; side view

Figure 5: Wind herding of the slick into grease ice

		S_1			S_2		
		I_1	I_2	I_3	I_1	I_2	I_3
W_1	O_1		0 (+3)		-7 (2)	-2 (0)	-7 (-3)
	O_2					-2 (+2)	
	O_3					-8 (-3)	-2 (1.5)
W_2	O_1				-16 (-9)	-6 (-2)	-5 (-1.5)
	O_2				-1 (1)		
	O_3					-4.5 (-1)	-3.5 (0)

T_{inlet}
(T_{air})

Average temperatures during run

		S_1			S_2		
		I_1	I_2	I_3	I_1	I_2	I_3
W_1	O_1		8592		3120	3960	3456
	O_2					7200	
	O_3					960	255
W_2	O_1				3600	5100	14400
	O_2				5400		
	O_3					1700	4800

Final surface area of slick (cm^2)

		S_1			S_2		
		I_1	I_2	I_3	I_1	I_2	I_3
W_1	O_1		0%		0%	6%	1%
	O_2					8%	
	O_3					0%	0%
W_2	O_1				20%	10%	2%
	O_2				30%		
	O_3					5%	1%

Percentage of original volume frozen into ice

Figure 6: Summary of test results

3.3 DISCUSSION OF RESULTS

3.3.1 Effect of Wind Speed

Wind speed affects a number of processes that are important to oil fate and behaviour. Information already exists on: 1) the rate of evaporation (Mackay 1980), ii) the grease ice thickness and coverage time for a lead (Dickins et al. 1986), iii) the wave heights for a given lead, which were treated as a separate variable in these experiments, iv) the drift rate and final location of the slick, and v) the slick thickness and area due to wind herding (Energetex 1981). What remained to be determined from these experiments was the effect of wind on the distribution of oil in developing ice situations.

In order to accomplish this, it was originally thought that three different windspeeds would be required in the tank tests. After the first few experiments, however, it was decided that only two windspeeds would be required. In fact, only one test was performed with a windspeed of 3.5 m/s and all of the others were done at 7 m/s. The reasons for this were:

1. It was discovered that with the I_3 initial ice condition and no waves, the oil slick would quickly migrate across the open water and any fresh grease ice until it reached the dense dead zone. This effectively stopped spreading and drift. Similar behaviour was noted by Wilson and Mackay (1986). Therefore, for modelling purposes, the dead zone can be treated as impermeable and wind herded slick thicknesses can be calculated from data on wind herding against a fixed barrier from experiments by Energetex (1981).
2. Difficulties were encountered in freezing the tank using windspeeds lower than 7 m/s, which was the maximum speed attainable with the blower used.
3. Other tests for this project conducted at a larger, outdoor tank in Ottawa (see Section 3.4) provided good data on the behaviour of oil in freezing situations under quiescent and low wind speed conditions.

4. The one experiment with a 3.5 m/s windspeed showed a larger surface slick area, as expected, and no oil frozen into the ice. Lower windspeeds were not expected to give more useful results.

3.3.2 Effect of Oil Type

An oil's density and viscosity seem to be important for determining the amount of oil frozen in ice: density because it determines the buoyancy of the oil in the water or the water/grease ice mixture, and viscosity because it determines the oil's ability to break up into particles that are small enough to migrate through the porous grease ice and also because it affects the thickness of the slick. A higher oil density will increase the amount of oil frozen in the ice as shown consistently in the experiments for oils 0_1 and 0_2. These oils have similar viscosities but 0_2 is more dense. This relationship was also found by Wilson and Mackay (1986). The effect of viscosity is not as clear. There appears to be two different processes by which oil can become incorporated into the ice. The first is by infiltration from above as in Runs 3 and 13 where there were no waves and an initial grease ice cover. In this case the low viscosity oil tends to be encapsulated in large globs; a low viscosity seems to permit the oil to move through the ice crystals more freely. The highly viscous 0_3 oil was not encapsulated at all in run 8.

The second process was noted only when waves were generated. This involves dispersion of the slick into the water column and a resurfacing of the oil droplets to become trapped in the grease ice. In this case, a high viscosity would inhibit resurfacing through the grease ice, thus encapsulating the oil. The result is an even distribution of 1-2 mm diameter oil droplets in the final ice cover. This was the explanation used by Wilson and Mackay (1986) in their bench scale mixing experiments. However, the high viscosity may also somewhat inhibit dispersion of the slick to begin with. These experiments showed that there was more encapsulation with a non-viscous oil for the same wave and ice conditions.

It therefore must be concluded that the amount of oil frozen in the ice decreases with increasing viscosity by virtue of both processes.

3.3.3 Effect of Wave Condition

Waves are a significant factor in the interaction of oil and ice not only because they provide mixing energy but because they affect the process of ice formation and also induce dispersion of the slick into the water column. As previously mentioned, pancake ice forms in the presence of waves while a dense dead zone forms without them.

It was found that the fraction of oil incorporated into ice is increased considerably by wave action. Waves also have a large effect on the spreading of the slick. The oil seems to be able to spread readily in the slush around pancake ice as shown in Runs 5 and 11.

The experiments without waves showed that the slick rarely exceeds its wind herded slick area in all ice conditions. The pancake ice generated by waves caused two dimensional spreading that was not stopped until the oil was pumped on top of the pancakes or expanded to fill the test area of the tank.

3.3.4 Effect of Initial Ice Maturity

In the presence of mechanically generated waves, it was found that the amount of oil in the ice decreased with increasing ice maturity. The major factor in determining the amount in the ice under wave conditions was dispersion of the slick and subsequent resurfacing of the droplets. This dispersion only happened when there was no ice present and to a lesser extent when there was slush ice present. The slush ice may dampen the wave action and also limit the downwelling currents necessary for dispersion. It is reasonable to assume that the final amount in the ice was related to the amount of time that the slick was exposed to open water dispersion or dampened slush ice dispersion. The presence of an initial ice cover only reduces or eliminates this exposure time. In addition, most of the dispersion occurred at the artificial barrier (which may not adequately represent a real lead situation) and when the slick was released in front of pancake ice, most of the slick was immobilized on the surface by the time the leading edge reached the barrier.

Without waves present, the effect of an initial ice cover was not the same. Significant amounts of oil in ice were found only when there was an initial grease ice covering. The oil moved into the grease ice layer from above probably because the density of the oil was very close to that of the grease ice. Thus, the oil has very little buoyancy in the grease ice and globs may sink and become encapsulated as the ice growth progresses.

3.4 OUTDOOR TANK TESTS

The outdoor lead experiments conducted in the NRC Ship Model Manoeuvring Basin encompassed a variety of combinations of oil ice and snow under wind conditions ranging from calm to 10 m/s. The coincidence of a heavy snowfall at the time of maximum wind converted the second lead experiment to a static condition in terms of subsequent oil spreading after release.

A variety of oil film thicknesses ranging from 1 to 10 mm were provided by a series of separated 1 m^2 test patches.

Air temperatures were variable, ranging from -10°C at time of discharge (1210) to -2°C within ten hours post spill and warming to -3°C within the following two days. Table 1 in Appendix 2 summarizes the surface environmental conditions along with the weather station records.

The following observations describe the results of the field experiment in terms of oil/ice interaction, using a series of photographs to illustrate the progressive changes in surface appearance with time.

3.4.1 Lead 1

The oil quickly spread to cover the entire lead until the oil reached an area of ice crystals extending approximately 1 m out from the west end of the lead. The remainder of the lead was cleared of ice crystals before oil release by manually straining the water prior to discharge. The oil spreading slowed significantly when it encountered the first loose ice crystals floating on the water surface and stopped completely when it reached the concentrated edge of ice crystals stretching across the lead. This action left three distinct zones: new clean ice (small crystals, rapid growth) at the extreme west end, a thin oil sheen covering new ice crystals (slower freezing, larger crystals) and thicker oil with no immediate ice formation. This thicker oil was quickly heated by solar absorption, reaching +2°C at 1330 one hour after discharge. Air temperatures at the time were -4.8°C (1 cm above the oil) and -8°C at 10 m. Similar degrees of self heating have been observed in previous oil/ice experiments. For example oil temperatures on ice melt pools at Balaena Bay were over 5°C higher than in the immediately adjacent air mass and over 8°C higher than the 5 m air temperature (NORCOR 1975). Figure 7 taken 10 minutes after the first oil release shows the clean ice at the west end of Lead 1 moving into thicker oil from left to right.

By 1230 (20 minutes post-spill) there was a clear visual transition between new ice growth in the lightly oiled area and the clean ice at the extreme west end (Figure 8).

Without the contrast of the adjoining clean ice, the only means of confirming the presence of oil on the surface was to physically rub the surface with a tissue to detect the oil. Eventually the lightly oiled ice took on a buff coloured surface appearance which enabled easy differentiation between the oiled and clean areas.

Figure 7:View towards the west end of Lead 1, 10 minutes after oil release 27/01/87

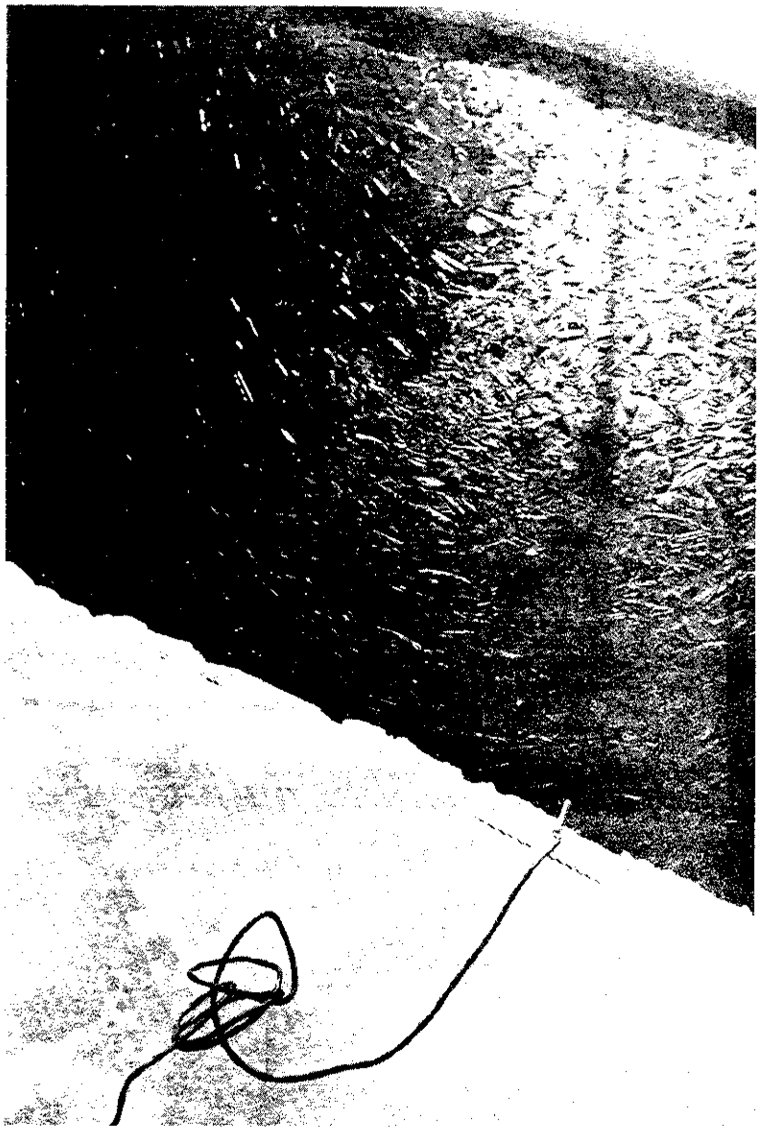


Figure 8: Close-up view showing the difference in surface appearance between the ice growing under a thin oil sheen (left) and clean ice (right) Note the outlines of individual crystals.

Figure 9 shows the transition between the thicker oil with no visible ice formation 50 minutes after oil release and the lightly oiled new ice. Eventually, extremely large ice crystals formed under the thicker oil and floated high enough to expose their outlines (Figure 10). Figure 11 shows a close-up view of the new ice crystals in Zone 3.

Edge effects played a minor role in creating localized patches of new ice growth within the thicker oil prior to first crystal occurrence over the general area. Figure 12 shows a patch of clean new ice growing out as lobes from the edge into a thick oil film. The processes are not clear, but it appears that any area along the edge where the oil is not butted tightly to the vertical lead edge acts as a nucleation site for new crystal growth. These crystals then expand laterally and actually push the oil ahead of them to create clear spaces for further growth.

Ice growth in Zone 1 was rapid, reaching 1 mm in 30 minutes, 3 mm in 90 minutes, and 45 mm in 22 hours. In contrast, the heavily oiled areas took 70 hours to reach an equivalent thickness. First ice formation in the oiled area required a surface disturbance to initiate crystal nucleation. Analysis of 8 mm time lapse footage showed that freezing of the thick oiled area covering most of Lead 1 was precipitated by a slight breeze which rippled the surface for a few minutes at 1600 hours on January 27. Subsequent crystal growth out from the lead edges took approximately 10 minutes to cover the lead and produce the surface appearance shown in Figure 4. Following first crystal formation, the oiled ice in Lead 1 followed a distinct cyclic pattern of diurnal growth and melt as the oil layer warmed during the day (melting the upper surface of ice formed) and cooled at night (refer to Figure 15).

3.4.2 Test Squares - Effect of Slick Thickness

The individual 1 m^2 test patches displayed similar behaviour with a spread in ice thickness apparently related to the oil thickness.

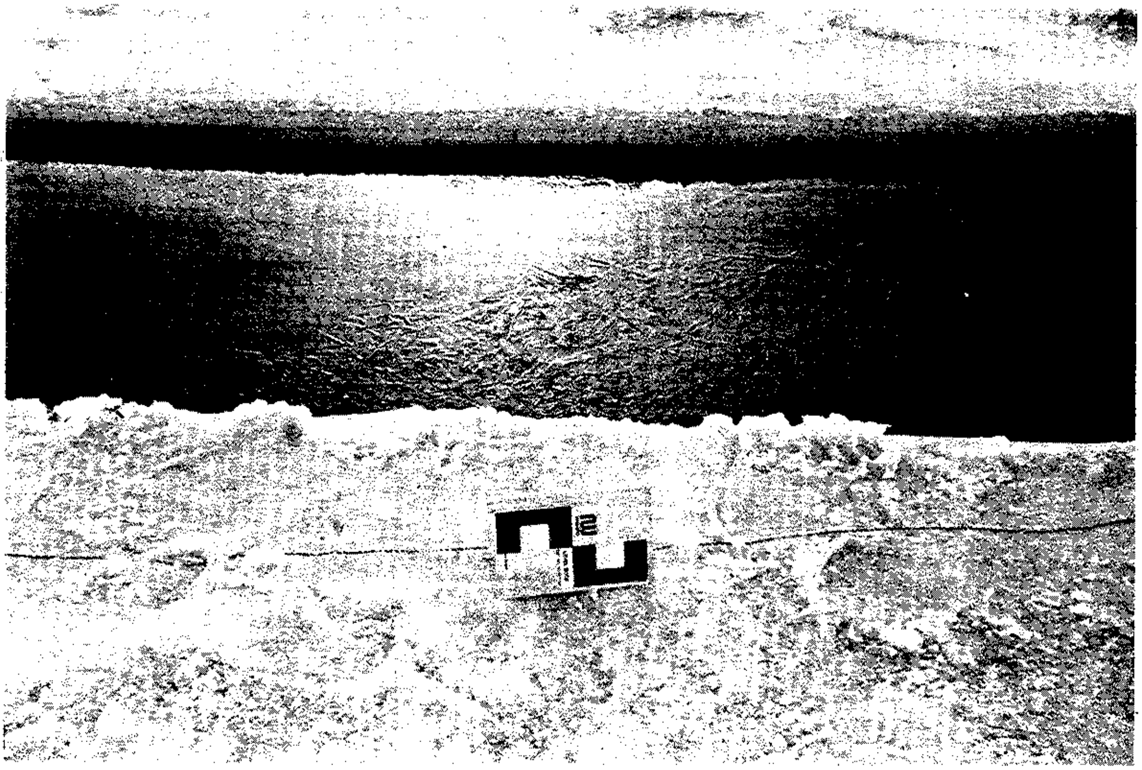


Figure 9: Transition between thicker oil and lightly oiled new ice.

Figure 10: View along Lead 1 to the west showing three zones: 1. clean solid ice at the extreme west end; 2. lightly oiled solid ice; 3. new ice crystals in thicker oil over most of the lead. Picture taken at 1630 - Spill + 4.3 hours.

Figure 11: Close-up view of new ice crystals in Lead 1 - see Figure 4 for photo orientation.

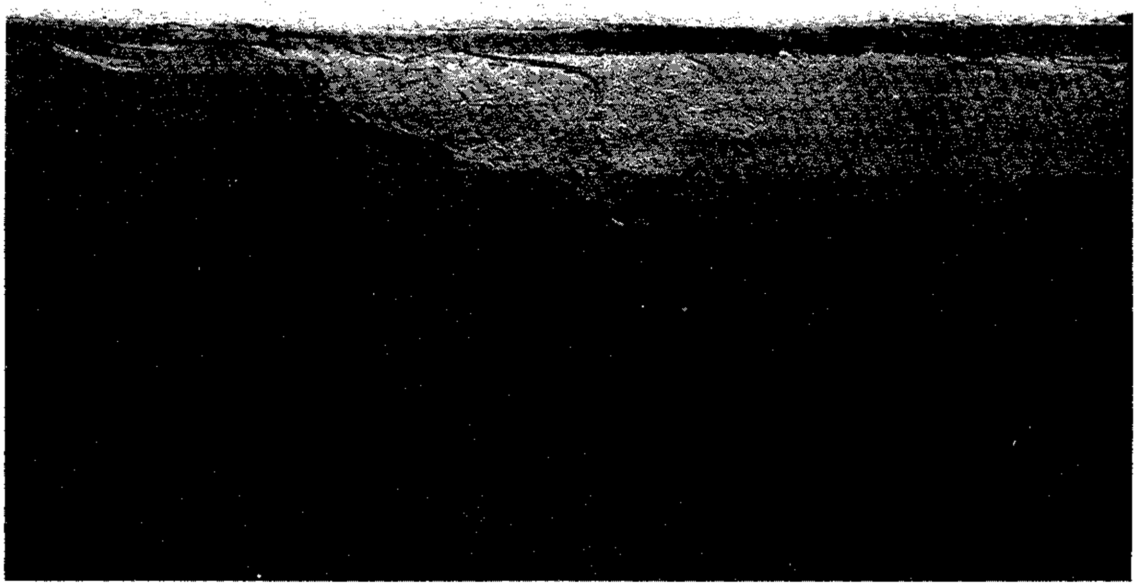


Figure 12:Localized patch of new clean ice growing into an oiled area (Spill + 2 hours).

Figures 13 and 14 show the test plot containing 2 mm of oil on January 28 the day following oil release. In Figure 13, taken at 0945, the outlines of the first large crystals that formed the previous day are clearly visible. By the afternoon on January 28 the new ice surface has been partly melted by the warm oil and the new crystals are no longer visible (Figure 14).

The differences between the sites gradually increased with time, until after 116 hours there was a 60% reduction in ice thickness beneath oil of 10 mm as opposed to that beneath oil of 1 mm (27 vs 45 mm). Figure 15 is a graph showing the ice growth history of all oiled sites, together with the clean ice at the west end of Lead 1 for comparison. It can be seen that the combined effects of 1) reduced heat flux due to the presence of an oil layer, and 2) the daily melt caused by radiation absorption by the oil, both act to reduce net ice growth rates after several days by approximately 50% (oiled ice/clean ice).

3.4.3 Effect of Snowfall

The snowfall accumulation which began at the time of the second oil release on January 29, immediately changed the surface appearance and subsequent physical oil fate in all sites. Figures 16 and 17 show the change in a section of Lead 1 before and after a snowfall starting at 1000 January 30. Later in the day, the snow was eventually absorbed and partly melted by the warming oil producing a mixture of oily slush and water overlying the solid ice grown beneath the oil. By February 1, the combination of successive snowfalls and a number of diurnal freeze/thaw cycles led to a situation where new clean snow had accumulated on top of a frozen slush/oil crust overlying several cm of water on top of 3 to 4.5 cm of solid clean ice. Failing a significant rise in air temperatures, the oil was essentially sealed off at this point and isolated from further solar heating. Snow is quite opaque to solar radiation. Any radiation not reflected by the snow will be absorbed in a thin layer and will not affect the oil.

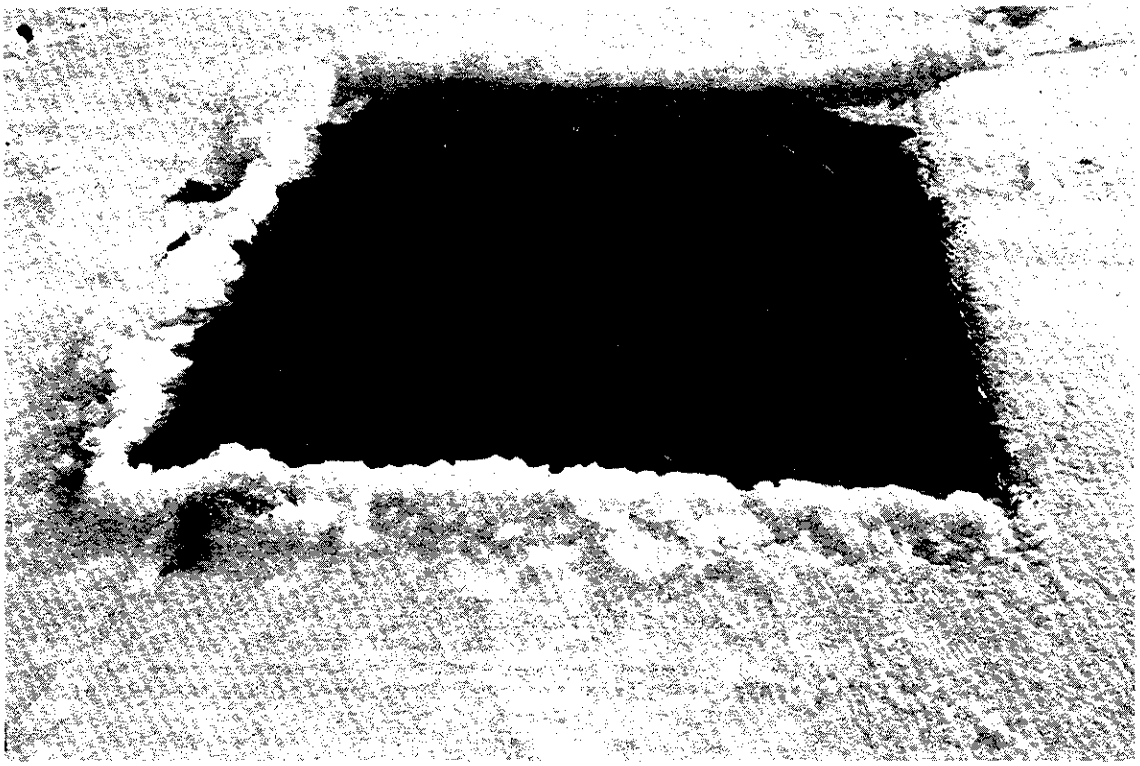


Figure 13:2 mm test plot at 0945 January 28

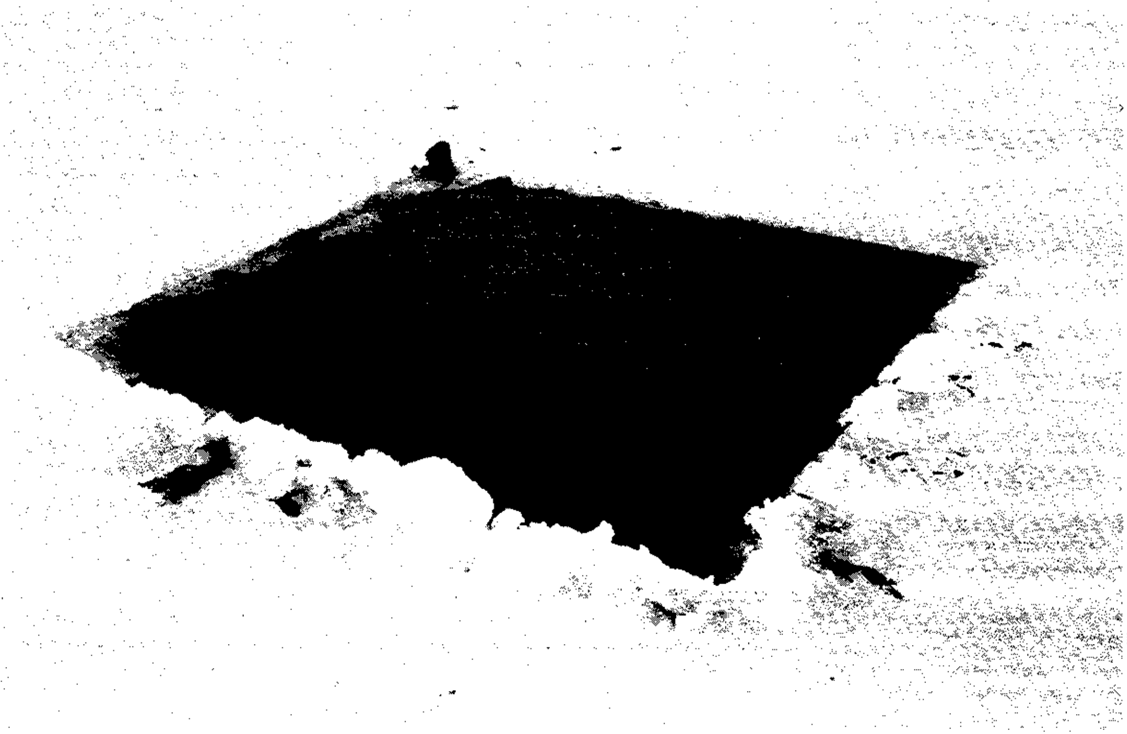


Figure 14:2 mm test plot at 1600 January 28.

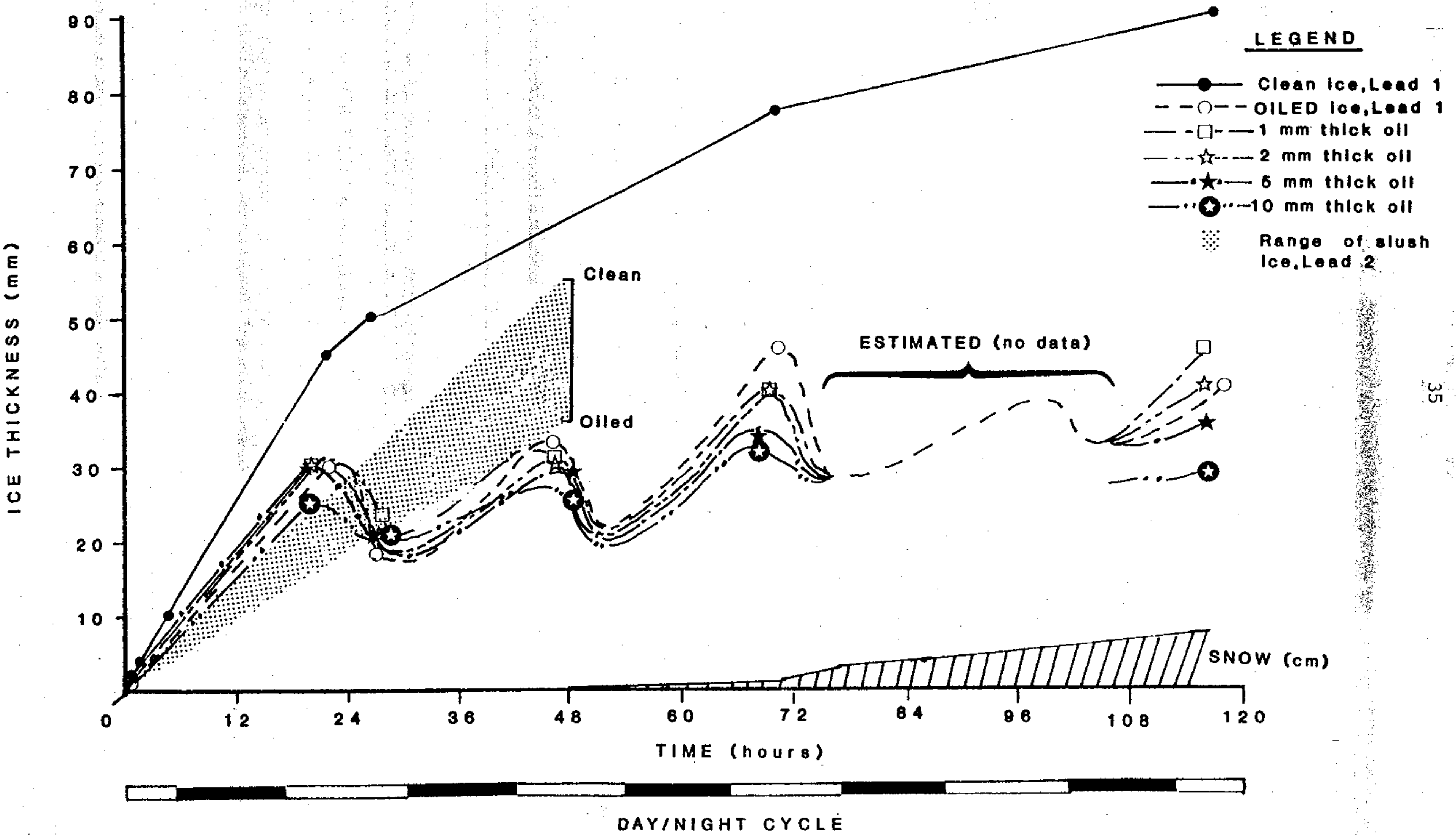


FIGURE 15: CONSOLIDATED ICE GROWTH DATA

Figure 16:Close-up of Lead 1, 1000, Jan. 30 showing oiled snow/slush lying on top of the ice.

Figure 17:Close-up view of same area shown in Figure 16, 30 minutes later. Note snow on top of oiled snow/slush from previous day

3.4.4 Lead 2

The second lead experiment carried out on January 29 presented an entirely different situation from either Lead 1 or the test plots. Snow flurries started 27 minutes before the oil was released. At the same time the surface wind increased from a faint breeze to 3 m/s gusting to 10 m/s at a slight angle across the length of the lead. The oil film quickly travelled the length of the lead at rates up to 6 cm/s and accumulated within 2 m of the south end in an arc across the lead, oriented perpendicular to the wind (Figure 18).

While the initial distribution and extent of heavy oiling was entirely wind generated, the oil quickly became embedded in a snow/slush "soup" which effectively prevented any further oil spreading or redistribution. By 1030 on February 1, 48 hours after oil release, the oil was incorporated into 3.5 cm of frozen oil slush. Depth of frozen snow/slush at the north end was 5.5 cm indicating, as with the previous oiled/clean ice comparisons in Lead 1 and the test plots, that the presence of oil significantly reduces the rate of initial ice growth by both delaying the onset of freezing and acting as a solar absorber until covered by later snowfalls.

Analysis of 8 mm time lapse footage, covering the period January 29 to February 1, provided the following observations of oil behaviour and changes to surface conditions in Lead 2 with time. On January 30, the boundary between oiled and clean slush became more and more distinct as continued snowfall contributed more and more slush in proportion to the original oil volume. There was no evidence of any infiltration or penetration of the clean area by oil from the heavily oiled section. On January 31, within three hours of sunrise, a narrow band of melt water could be seen forming in a rim around the edge of the heavily oiled frozen oil/slush crust. Once this melted border spread out to several cm from the edge the remaining area appeared to melt at a uniform rate. Within six hours of sunrise the entire oiled area was covered by a thin film of

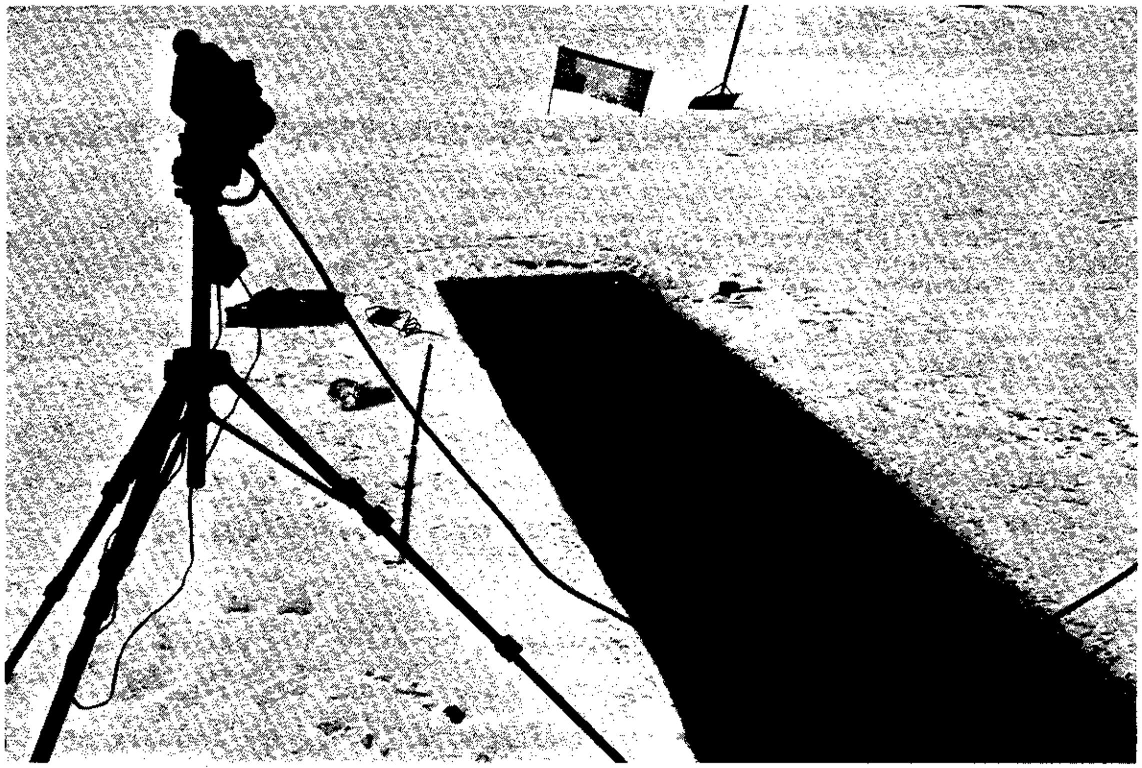


Figure 18:View towards the south end of Lead 2 shows the area of heavily oiled slush

meltwater. Later in the day the initial meltwater strip around the edges of the oiled area refroze as a smooth shiny surface, leaving a rougher surface with oiled crystals projecting out from the rest of the area. This rough surface then acted to catch and hold later snowfalls. On February 1, the oiled/clean boundary was somewhat more diffuse in appearance with patches or smudges of oil extending several feet into the previously "clean" area.

3.4.5 Evaporation Rates

Figure 19 shows the evaporative loss for oil samples taken from the various test plots plotted against evaporative exposure (after Stiver and Mackay 1983). Also shown is the predicted evaporative loss at -10°C (the average experimental temperature - see Appendix 2) using a modified ASTM distillation procedure and equation given by Stiver and Mackay (1983). The prediction fits the data quite well, with the exception of one sample from Lead 1 which may have been improperly stored. It is interesting to note that the evaporation does not seem to be greatly reduced by the presence of snow in or on the surface oil. No samples of under-ice oil were obtained (since none of the oil was encapsulated other than by snow), however the results of other studies (NORCOR 1975; Dome 1981; and Dome 1983) all indicate that oil under a complete ice cover is not subject to evaporation.

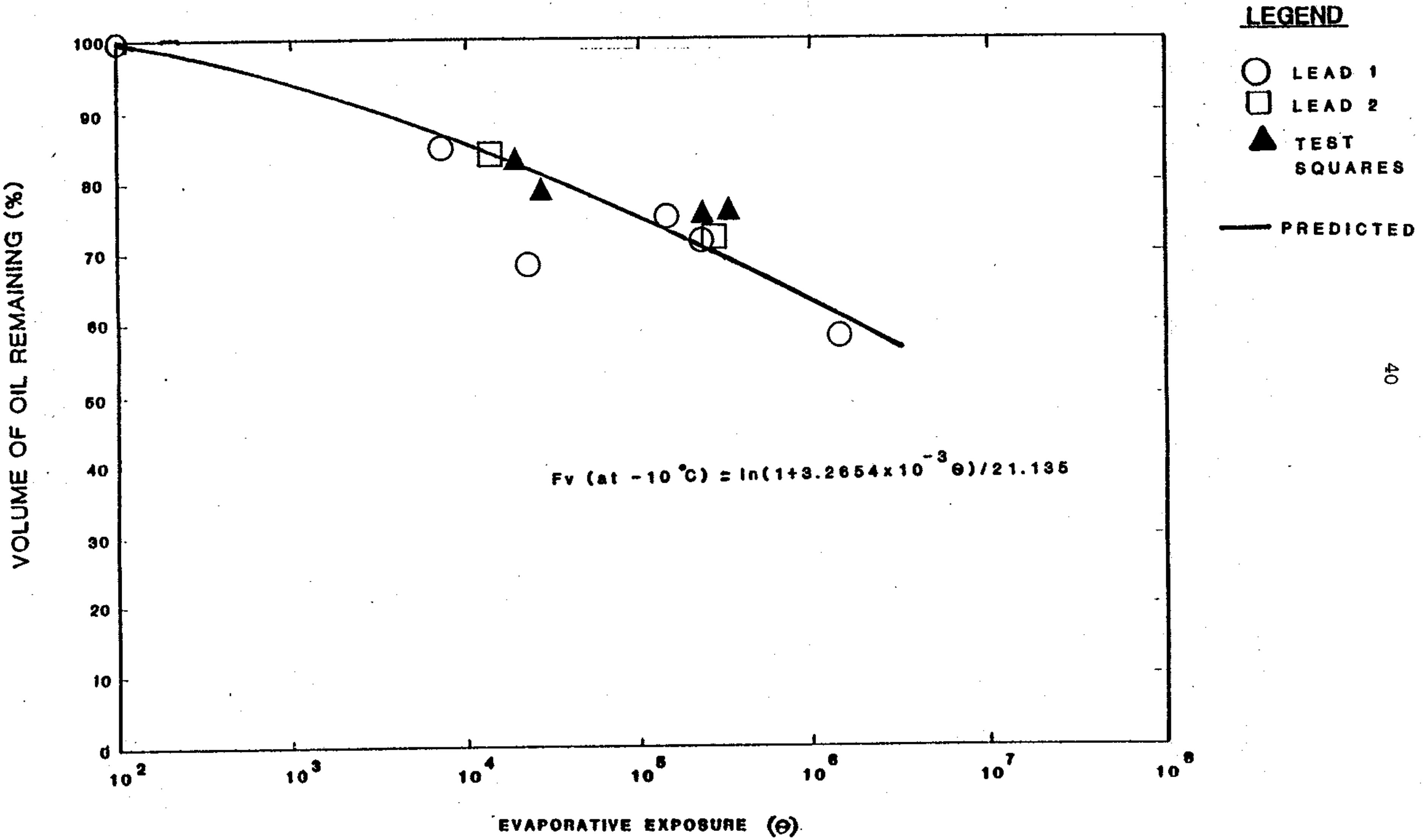


FIGURE 19 - EVAPORATIVE LOSS

4.0 INCORPORATION INTO A COMPUTER MODEL

In this section of the report the process equations describing the fate and behaviour of oil spills in pack ice leads are developed, based on the experimental results. Their incorporation into an existing computer model is also described.

4.1 THE OIL FATE MODEL

The purpose of incorporating the process equations into a computer model was to allow predictions of spill behaviour in pack ice leads as oil slicks weather, spread and emulsify with time so as to be able to estimate the amount of oil available for countermeasures. The approach taken in this study was to modify an existing oil fate and behaviour model. The main features of this model are presented prior to discussing the process equations and the model modifications.

The model is based primarily on work performed at the University of Toronto over the past decade; oil spreading is based on the model of Mackay et al. (1979) which utilizes the thick/thin approach; oil evaporation is based on the evaporative exposure approach of Stiver and Mackay (1983), and subsequent oil property changes are determined using the approach of Tebeau et al. (1983); sea state (i.e., wind speed) and oil properties are used to calculate natural dispersion (after S.L. Ross 1984) and emulsification (after Mackay et al. 1979, modified to include a delay until the particular oil weathers to an emulsifiable state). A routine has also been included to assess chemical dispersion effectiveness (S.L. Ross 1987), though this was not used for this study.

In its present form, the model requires a fairly large number of oil property inputs to be used to its full potential. Much of this information is presently available in oil property catalogues published by Environment Canada (S.L. Ross 1985; Bobra and Chung 1986) for many Canadian oils. Work is also underway at the University of Toronto (S.L. Ross and

DMER 1987) to develop a technique to fully quantify oil property changes with evaporation using only a simple distillation procedure.

4.2 PROCESS EQUATIONS

4.2.1 Ice Growth

4.2.1.1 Open Water

The ice growth routine for unoiled areas in a lead was developed using equations for grease ice formations reported by Dickins et al. (1986). These equations are:

$$P = 1.2 + 0.0312\ U\ (Tw - Ta) \qquad (1)$$

and

$$P = 3.0 + 0.0204\ U\ (Tw - Ta) \qquad (2)$$

where: P = production rate ($kg/m^2/h$)
U = wind speed (m/s)
Tw = water temperature (^oC)
Ta = air temperature (^oC)
$U(Tw - Ta)$ = wind chill factor (^oC m/s)

Equation (1) is used for mild conditions (wind chill less than 200 $^oCm/s$), and equation (2) for severe conditions (wind chill greater than 200 $^oCm/s$), The final coverage thickness is estimated by $H\ (m) = 0.06\ U$ where U is the windspeed in m/s. The rate of ice cover can be calculated using the density of the grease ice (ρ_i) and the final thickness of the cover (H) as:

$$dA_I = \frac{P}{\rho_i H} \qquad (3)$$

where A_I is the ice coverage area in m^2 of ice per m^2 of open water remaining per hour. If the width of the lead (W) is known, the differential linear grease ice cover for one 100 second program pass is calculated by:

$$dL = \frac{P\,A_W}{\rho_i\,H\,W} \times 100 \times \frac{1}{3600} \qquad (4)$$

in linear metres of grease ice, where A_W is the open water area. This length is combined with that generated beneath the slick and subtracted from the length of open water for each iteration.

4.2.1.2 Beneath Oil

One of the problems that this study addressed was that of predicting the initial freezing rate of water beneath an oil slick spilled in a lead under calm conditions. Once a solid sheet of ice has formed beneath the oil the countermeasures approach for the exposed oil becomes one of oil on ice as opposed to oil on water.

The predictive equation developed in this section is concerned primarily with calculating the time required to form a "solid" ice cover in the presence of oil and the absence of snow (see Section 4.2.6 for the treatment of snow in the model). The approach taken is to calculate the amount of ice formed beneath the slick based on heat transfer considerations and convert this to a length of new ice of thickness H (see Section 4.2.1.1 above) that is wind herded against the downwind ice edge. Although the equations are only truly valid for calm, low turbulence conditions the presence of an oil film is assumed to dampout any waves that would normally be present under higher wind conditions.

The equation used is an adaptation of the formulation of Ashton (1986) which treats snowcover and ice as resistances in series. Oil is introduced in the classic heat transfer equation as an additional resistance to yield:

$$\Delta h/\Delta t = (T_m - T_m)/\ (\rho_i \lambda)((h_i/k_i) + (h_o/k_o) + (1/H_a)) \qquad (5)$$

where: h_i = ice thickness (m)

h_o = oil thickness (m)

t = time (s)

T_a = air temperature (^oK)

T_m = water temperature (^oK)

k's = thermal conductivities of ice (i) and oil (o) (W/m^oC)

H_a = surface heat transfer coefficient ($W/m^{2o}C$)

λ = latent heat of fusion of water (J/kg)

ρ_i = density of ice (kg/m^3)

Once the ice has formed an additional resistance due to the presence of snow on the ice could be added; this was not considered to be warranted for this study since snowfall obscures any surface oil which then becomes unavailible for countermeasures (see Section 4.2.6 below).

The only term in equation 5 that cannot be readily obtained from the literature is H_a. As a first approximation, its value was determined using the results of the outdoor tank tests to provide estimates of the initial ice growth rate $\Delta h/\Delta t$. Table 2 summarizes the data used in solving for H_a in equation 5. Table 3 shows the results; the very small change in H_a with oil thickness and the seeming dependence only on the presence of oil indicate that the correct form of equation was chosen. The values shown in Table 3 were used in the computation of ice growth beneath oil in the model.

4.2.2 Slick Advection

The oil slick on the open water is estimated to drift at 3% of the wind speed (only wind parallel to the length of the lead is included) across the water surface. This continues until the leading edge of the thick slick reaches the downwind ice edge.

4.2.3 Oil Spreading

During the time that the oil is on open water, and the calculated area of thick oil does not exceed the area of open water, the thick/thin spreading routine is utilized. If the thin slick area exceeds the open water area it is reset to the difference between the lead area (length x width) and the thick slick area and thin spreading ceases. If the thick slick area equals

TABLE 2

Initial Ice Growth Rates and Ice Property Data

SURFACE CONDITION	TEMPERATURE DIFFERENCE (^{o}C)	ICE GROWTH RATE ($m/s \times 10^7$)
Clean ice	18	6.36
Oiled ice 1 mm oil	18	4.10
2 mm oil	18	3.64
5 mm oil	18	3.18
10 mm oil	18	<2.55

OIL/ICE PROPERTIES

Thermal conductivity:		
	oil	0.149 W/m°C
	ice	2.20 W/m°C
Ice density		
	primary	916.6 kg/m^3
	snow ice	803-900 kg/m^3
Latent heat of fusion		
	pure water	333.4 x 10^3 J/kg
	sea water to sea ice	200 x 10^3 J/kg

TABLE 3

Calculated Heat Transfer Coefficients

Surface Condition	Experimental Heat Transfer Coefficient ($W/m^2{}^\circ C$)
Clean ice	10.8
1 mm oil	7.3
2 mm oil	6.7
5 mm oil	6.6
10 mm oil	6.1
Clean snow slush	10.1
oiled snow slush	6.4

the open water area the thin slick area is set to 1 m^2 and thick slick spreading ceases. Otherwise the slick is allowed to spread until the leading edge of the thick slick reaches the downwind grease ice edge. If the slick diameter is less than the lead width at this point the slick continues to spread, but only laterally until it fills the width of the lead. When the thick slick fills the width of the lead and is touching the downwind ice edge all spreading stops and wind herding commences.

4.2.4 Wind Herding

Eventually the leading edge of the slick will encounter the downwind edge of the lead where drift and spreading will stop. Wind herding will determine the final slick area and thickness at this point. Energetex Engineering (1981) performed a series of experiments on wind herding of fresh and aged Prudhoe Bay crude oil. They found that the wind herded oil thickness is primarily a function of the initial oil thickness and the windspeed. The empirical equation used in this model is:

$$T_H = 1.01\ T_I + 0.72U \qquad (5)$$

where

T_H = herded thickness (mm)

T_I = initial thickness (mm)

U = wind speed (m/s)

This equation shows a good correlation for initial thickness between 1 and 6 mm and windspeeds between 2.78 and 8.3 m/s.

A final thick slick area is calculated based on the wind herded thickness; no further spreading takes place.

4.2.5 Fraction of Oil Frozen into Ice

The wind/wave tank tests showed that a small percentage of the oil slick may become trapped in the developing grease ice. During each program iteration a volume of oil becomes trapped in the differential area of new ice growing beneath the slick. The fraction encapsulated is based on the oil properties, and is increased by a density factor:

$$K_1 + K_2 \rho_o \qquad (6)$$

and decreased by a viscosity factor:

$$K_3 + K_4 \mu_o \qquad (7)$$

The fraction (F) of the oil in that is underlain by new ice growth for that iteration that becomes encapsulated is then given by:

$$F = (K_1 + K_2 \rho_o) - (K_3 + K_4 \mu_o) \qquad (8)$$

or

$$F = K + K_2 \rho_o - K_4 \mu_o \qquad (9)$$

where

ρ_o = density of oil,

μ_o = viscosity

Substituting from the experimental results and solving for the constants yields values of:

$K = -0.19966$

$K_2 = 0.31053$

$K_4 = 0.0000709$

The differential volume encapsulated is then given by:

$$dV = (-0.19966 + 0.31053 \rho_o - 0.0000709 \mu_o)\, dA_I . T_H \qquad (10)$$

where dA_I is the differential ice area for that program pass and T_H is the wind herded slick thickness.

Effect of Waves. In order to include the effect of waves on oil incorporation it was first necessary to calculate the significant wave height that would exist in a lead. The following equation is used to calculate fetch-limited wave conditions (Department of the Army 1984):

$$H = 5.112 \times 10^{-7}\ U\ F^{1/2} \tag{11}$$

where H = significant wave height (m)
U = wind speed (m/s)
F = fetch (m)

The effect of wave properties on increasing the fraction of oil incorporated in the grease ice was not fully investigated in the experimental portion of this study, thus a very simple algorithm was used to estimate their effect. If the calculated wave height in the unfrozen length of the lead exceeds a certain value (that is input by the operator) the fraction of oil incorporated is arbitrarily increased by 0.2, consistent with the results of the wind/wave tank tests.

4.2.6 Snowfall

Based on the results of the outdoor test tank experiments the effect of snowfall is twofold: initially snow is absorbed by the oil until such time as the water content of the oil (or emulsion) reaches a maximum (presumed to be in the range of 75% for the model), after this the snow covers the oil rendering it unavailible for countermeasures.

The water content increase of the oil due to snowfall is calculated by dividing a snowfall rate per iteration by ten (to account for the lower density of snow) and adding the equivalent fraction of water (based on the existing slick thickness) to the oil.

4.2.7 Lead Closure

The model includes the ability to close the lead at a specified rate. This has the effect of decreasing the width of the lead thus reducing the slick width and increasing its thickness if its diameter equals that of the lead. If the thick slick fills the lead, closure thickens the oil. Once the lead edges touch, all of the oil is unavailable for countermeasures being either under the ice edges or incorporated into the resulting ridge.

4.2.8 Natural Dispersion

The equation used to calculate losses to natural dispersion on the open sea was modified to account for the fact that the wind over a lead will generate smaller, less energetic, fetch-limited waves (see Section 4.2.5 above).

4.3 MODEL RESULTS

The model was written in Pascal and is suitable for use on an IBM compatible PC. A complete program listing may be found in Appendix 3. The model simulates the fate and behaviour of a spill of oil in a lead until such time as the oil slick is entirely on top of or encapsulated in new ice; subsequent evaporation is not considered.

Figure 20 shows the model graphic output for the case of a 1000 m^3 spill of Alberta Sweet Mixed Blend crude oil in a new lead measuring 10,000 m in the direction of the wind and 200 m perpendicular to the wind. The oil property, lead information and environmental inputs used are given in Table 4 .The numerical model outputs are given in Table 5.

Figure 20 1000m3 Example

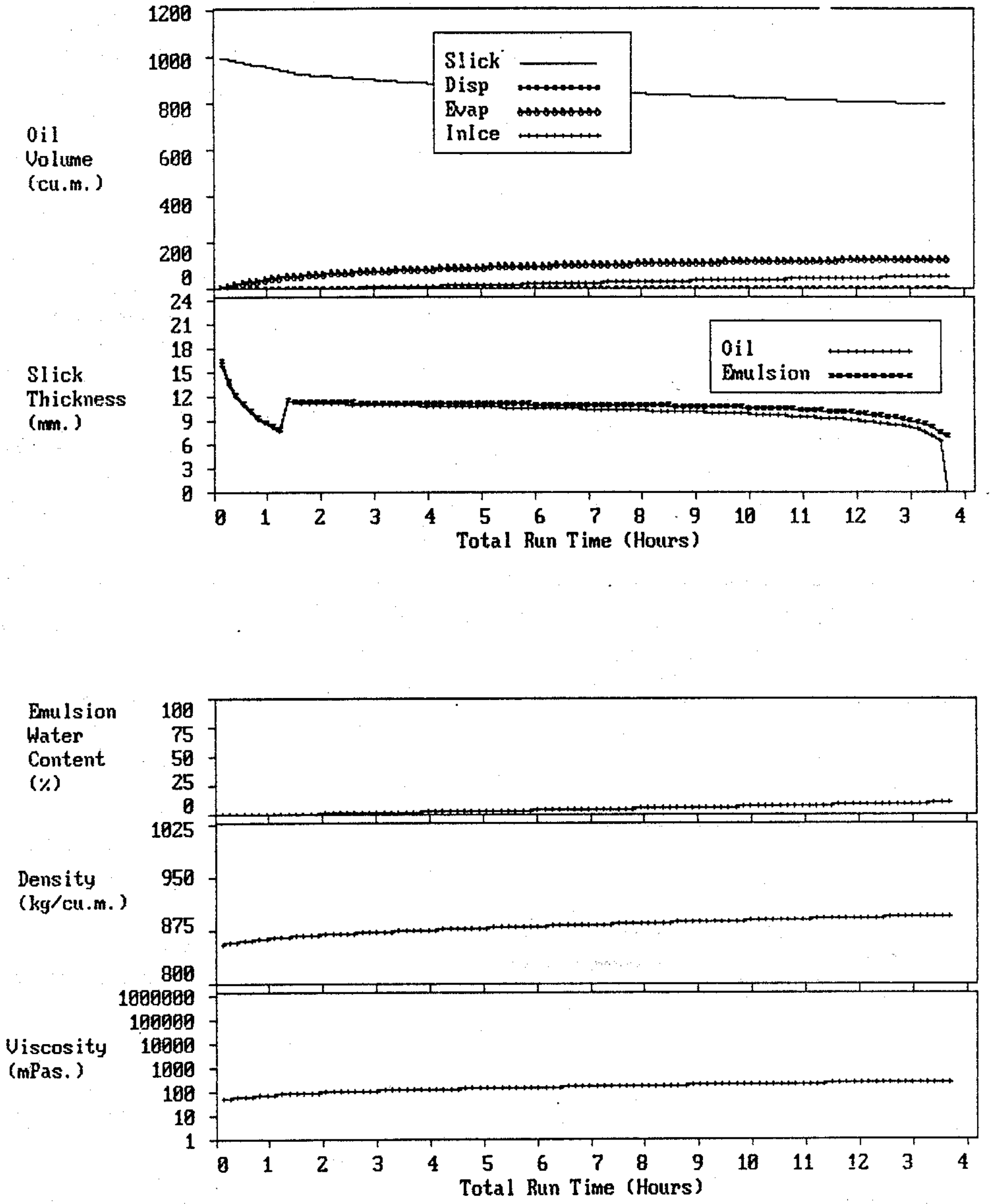


TABLE 4

Model Inputs

Fresh oil properties

Emulsification delay (theta)	50000.0
Density (kg/m3)	855.60
Standard density temperature (K)	273.00
Viscosity (mPas)	43.70
Standard viscosity temperature (K)	273.00
Pour point (K)	265.00
Aqueous solubility (g/m3)	0.00
Flash point (K)	280.00
Oil-water interfacial tension (N/m)	0.02
Oil-air interfacial tension (N/m)	0.026

Leads spill conditions

Length of lead parallel to wind (m)	2000.00
Width of lead perpendicular to wind (m)	200.00
Fraction of lead initially iced	0.00
Snowfall rate (cm/day)	2.000
Lead closure rate (m/s)	0.00
Starting distance: spill to ice (m)	1000.00

Spill conditions

Duration of spill (100sec)	1.00
Windspeed (m/s)	5.00
Air temperature (K)	243.00
Water temperature (K)	272.00
Volume of oil spilled (m3)	1000.00

Constants

Density constant 1	168.0000000
Density constant 2	0.4000000
Viscosity constant 1	8.7200000
Viscosity constant 2	8582.00
Pour point constant	0.3820000
Solubility constant	0.0000000
Flash point constant	0.0000000
Oil-water int. tension constant	0.0000000
Oil-Air int. tension constant	0.5820000
ASTMA constant	540.00
ASTMT constant	385.00

TABLE 5

Numerical Output

```
The slick hit the ice after   4500 seconds
                               Figure 20 1000m3 Example

time  5
        area      thickness    volume     evap       dispersed
thick  56806     0.0105771    600.840    89.625      1.024
thin       1     0.0000010      0.000     0.394      0.085
OnIce  26383                  269.677     5.259
InIce                          18.535
total  83190                              95.158      1.109
available for cleanup         870.517

             density   viscosity  water content   thickness
oil            873        118
emulsion       879        130        0.0379         0.0109954

theta   8807
----------------------------------------------------------------



time 10
        area      thickness    volume     evap       dispersed
thick  22439     0.0096736    217.068   101.956      1.331
thin       1     0.0000010      0.000     0.394      0.085
OnIce  60750                  605.090    17.656
InIce                          41.860
total  83190                             119.886      1.415
available for cleanup         822.158

             density   viscosity  water content   thickness
oil            878        152
emulsion       889        186        0.0765     ..  0.0104810

theta  18117
----------------------------------------------------------------



time 14
        area      thickness    volume     evap       dispersed
thick    206     0.0000000      1.126   103.463      1.376
thin       1     0.0000010      0.000     0.394      0.085
OnIce  82983                  796.045    28.011
InIce                          54.939
total  83190                             131.748      1.461
available for cleanup         797.171

             density   viscosity  water content   thickness
oil            880        173
emulsion       896        230        0.1069         0.0070367

theta  25733
----------------------------------------------------------------
```

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

A computer model has been developed that predicts the amount of an oil spill in a pack ice lead that remains exposed to the atmosphere, and is thus available for countermeasures, as a function of time. The results of indoor wind/wave tank experiments and outdoor test tank experiments show that the fraction of a slick that is incorporated into new, growing ice in a lead is generally very small; most of the oil remains on the surface of the new ice.

The major factors that increase the fraction of oil incorporated into growing ice in a lead are:

- increasing oil density
- decreasing oil viscosity
- the presence of waves
- the presence of grease ice at the time of the spill

The factors that result in encapsulation of the oil, or that render it unavailable for countermeasures are:

- lead closure resulting in ridge formation
- snowfall resulting in water content in the oil greater than about 75%

It must be emphasized that the model is intended as a preliminary formulation.

5.2 RECOMMENDATIONS

Further experiments on the effect of wave height, period and wavelength on the fraction of oil incorporated into growing ice in a lead are recommended. Additional verification under Arctic field conditions will be required before the model can be considered as a reliable operational tool.

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APPENDIX 1

Results of Literature Review

DF Dickins
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3732 W. Broadway, Vancouver, B.C., Canada V6R 2C1 (604) 224-4124

Job 486-7

Phase 1: Computerized Literature Survey

Objective: Access new or foreign data sources applicable to the study of oil spills in pack ice leads.

Methodology:

Key Words Used:

General: PETROLEUM/OIL/ICE/OILSPILL/CLEAN-UP

Specific Subject: LEADS/BROKEN/BREAKING/MELTING/REFREEZING

Specific Area: USSR, SOVIET NORTHERN SEAS (Barents, White, Kara, Laptev, Okhotsk, East Siberian), FINLAND (Baltic), NORWAY, SWEDEN, GREENLAND, ANTARCTIC, JAPAN, U.S.A.

Data Bases Queried: Through CISTI (NRC)

Aquatic Sciences and Fisheries Abstracts
Arctic Institute of North America
Engineering Meetings, 82-86
CODOC (Cooperative Documents Project)
Computerized Engineering Index, 1970-86
Conference Papers Index, 1973-86
Pollution Abstracts, 1970-86
Oceanic Abstracts, 1964-86
Soviet Science and Technology, 1975-86
NTIS, 1964-86
Compendex, 1970-86

RESULTS OF
LIT SEARCH

OIL IN LEADS

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   $9.05  Estimated cost this file
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File  41:POLLUTION ABSTRACTS - 70-86/JULY
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    S15   1405  CS=USSR OR CS=SSR OR CS=SOVIET OR CS=LAPTEV OR
               CS=SIBERIA? OR CS=OKHOT?
    S16   3918  S15 OR S8
    S22   3402  (OIL OR PETROLEUM OR DIESEL)(F)(SPILL? OR POLLUT?)
    S23    115  S16 AND S22
          115  S23
    S24    272  ICE
    S25      1  S23 AND ICE
?


 23/3/1
86-04716
 Sorbent preparations for oil pollution cleanup in northern seas
 Mesyats, S.P.; Nesterova, M.P.; Gornitskiy, A.B.
 Shirshov Inst. Oceanol., USSR Acad. Sci., Moscow, USSR
 OCEANOL. ACAD. SCI. USSR  VOL. 24, NO. 6,  pp. 692-694,   Publ.Yr: 1984
 SUMMARY LANGUAGE -  ENGLISH

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    S22   3503  (OIL OR PETROLEUM OR DIESEL)(F)(SPILL? OR POLLUT?)
    S23    147  S16 AND S22
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78-03478
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 25/3/3
81-08074
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 Nelepo, B. A.
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Coden: IOCTAH   pp. 41-50
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 illus.  refs. (Some in Ger.; Russ.; Scand.)
 Abs.

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 331685  DA
  OIL IN MOVING PACK ICE--LABORATORY STUDY
  Metge, M; Telford, AS
  Norwegian  Institute  of  Technology  University  of  Trondheim  N-7034




 rondheim Norway
 1980 Conf Proc pp 255-264 Ref.
 AVAILABLE  FROM:  Calgary  University,  Canada Interlibrary Loans Office,
Room 218 Library Tower Calgary Alberta T2N 1N4 Canada
 SUBFILE: MRIS
 REPORT NO: Volume 3

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312634  DA
 AIRBORNE OIL SPILL SURVEILLANCE SYSTEMS IN SWEDEN
 Backlund, L
 Swedish Space Corporation Solna Sweden
 Mar 1979 20 p.
 AVAILABLE  FROM:  National  Technical Information Service 5285 Port Royal
Road Springfield Virginia 22161
 SUBFILE: NTIS; MRIS
 REPORT NO: FP1-9  N80-11646/0
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RE - N1004: 1-04931
TI - OIL SPILLS IN A RIVER: A ONE-DIMENSIONAL MODEL.
AU - VOZNESENSKY,G.T. (INST. APPL. GEOPHYS., MOSCOW, USSR)
PU - HYDROL. SCI. BULL., (1979), 24(2), 213-223
LA - (ENG) ENGLISH
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                                 AU - CHEN, E.C.; KEEVIL, B.E.; RAMSEIER, R.O.
                                 OR - (EP37) CANADA.  INLAND WATERS DIRECTORATE
                                 SE - CANADA INLAND WATERS DIRECTORATE SCIENTIFIC SERIES.
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RE - EIM8511-069372
TI - ARCTIC OIL SPILLS IN RELATIONSHIP TO SEA ICE MOTION.
AU - DENNER, WARREN W.; LEWIS, JAMES K.
OR - SCIENCE APPLICATIONS INT CORP, MONTEREY, CA, USA; *ASCE,
     WATERWAY, PORT, COASTAL & OCEAN DIV, NEW YORK, NY, USA;
     ASCE, TECHNICAL COUNCIL ON COLD REGIONS ENGINEERING, NEW
     YORK, NY, USA; ASCE, SAN FRANCISCO SECTION, SAN
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CO - CIVIL ENGINEERING IN THE ARCTIC OFFSHORE, PROCEEDINGS OF
     THE CONFERENCE ARCTIC '85. SAN FRANCISCO, CA, USA. 1985
     MAR 25-27
PU -  PUBL BY ASCE, NEW YORK, NY, USA P 878-887, 1985; 7 REFS.
NU - 06334; ISBN 0-87262-441-2
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TI - BAFFIN ISLAND
AU - SERGY, GARY A.
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     OIL IN THE ARCTIC: BAFFIN ISLAND OIL SPILL STUDIES 1980-
     1983.
AU - BEOHM, PAUL D.; STEINHAUER, WILLIAM; REQUEJO, ADOLFO;
     COBB, DONALD; DUFFY, SUZANNE; BROWN, JOHN
OR - BATTELLE, NEW ENGLAND MARINE RESEARCH LAB, DUXBURY, MA,
     USA; *API, WASHINGTON, DC, USA; EPA, WASHINGTON, DC, USA;
     US COAST GUARD, WASHINGTON, DC, USA
CO - PROCEEDINGS - 1985 OIL SPILL CONFERENCE (PREVENTION,
     BEHAVIOR, CONTROL, CLEANUP). LOS ANGELES, CA, USA. 1985
     FEB 25-28
PU -  PUBL BY API (PUBL N 4385), WASHINGTON, DC, USA P 561-
     569, 1985; 14 REFS.
NU - 07108
LA - (ENG) ENGLISH
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AU - HILLMAN, SHAR
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RE - EIM8511-069164
TI - IN-PLACE BURNING OF PRUDHOE BAY OIL IN BROKEN ICE.
AU - SMITH, NELLINE K.; DIAZ, ANIBAL
OR - MASON & HANGER-SILAS MASON CO, LEONARDO, NJ, USA; *API,
     WASHINGTON, DC, USA; EPA, WASHINGTON, DC, USA; US COAST
     GUARD, WASHINGTON, DC, USA
CO - PROCEEDINGS - 1985 OIL SPILL CONFERENCE (PREVENTION,
     BEHAVIOR, CONTROL, CLEANUP). LOS ANGELES, CA, USA. 1985
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CO - PROCEEDINGS -
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NU - 07108
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RE - EIM8511-069162
TI - UNIQUE DISPOSAL TECHNIQUES FOR ARCTIC OIL SPILL RESPONSE.
AU - SWISS, JAMES J.; SMRKE, DONALD J.; PISTRUZAK, WILLIAM M.
OR - DOME PETROLEUM LTD, CALGARY, ALBERTA, CAN; *API,
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     GUARD, WASHINGTON, DC, USA
CO - PROCEEDINGS - 1985 OIL SPILL CONFERENCE (PREVENTION,
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RE - EIM8511-06912
TI - INNOVATIVE RE
AU - TEAL, ANDREW
OR - ESSO RESOURCE
     ALBERTA, CAN;
     DC, USA; US C
CO - PROCEEDINGS -
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AU - HILLMAN, SHARON O.
OR - SOHIO ALASKA PETROLEUM CO, ANCHORAGE, AL, USA; *API, WASHINGTON, DC, USA;
EPA, WASHINGTON, DC, USA; US COAST GUARD, WASHINGTON, DC, USA
CO - PROCEEDINGS - 1985 OIL SPILL CONFERENCE (PREVENTION, BEHAVIOR, CONTROL,
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PU - PUBL BY API (PUBL N 4385), WASHINGTON, DC, USA P 411-414, 1985; REFS.
NU - 07108
LA - (ENG) ENGLISH

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RE - EIM8511-069099
TI - OHMSETT TESTS OF A ROPE-MOP SKIMMER IN ICE-INFESTED WATERS.
AU - SHUM, J. S.; BORST, M.
OR - MASON & HANGER-SILAS MASON CO, LEONARDO, NJ, USA; *API, WASHINGTON, DC,
USA; EPA, WASHINGTON, DC, USA; US COAST GUARD, WASHINGTON, DC, USA
CO - PROCEEDINGS - 1985 OIL SPILL CONFERENCE (PREVENTION, BEHAVIOR, CONTROL,
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PU - PUBL BY API (PUBL N 4385), WASHINGTON, DC, USA P 31-34, 1985; 5 REFS.
NU - 07108
LA - (ENG) ENGLISH

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RE - EIM8511-069098
TI - SIMULATION TESTS OF PORTABLE OIL BOOMS IN BROKEN ICE. *
AU - SUZUKI, ISAO; TSUKINO, YOSHIHISA; YANAGISAWA, MASAMITSU
OR - JAPAN FOUNDATION FOR SHIPBUILDING ADVANCEMENT, INST OF OCEAN ENVIRONMENTAL
TECHNOLOGY, IBARAKI, JPN; *API, WASHINGTON, DC, USA; EPA, WASHINGTON, DC,
USA; US COAST GUARD, WASHINGTON, DC, USA
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 DOCUMENT NUMBER: 185884
 TITLE: Oilspill response technology for the Arctic
 AUTHOR: Shafer, R.V.
 SERIES: Civil engineering in the arctic offshore : proceedings
    of the Conference Arctic '85 / Edited by F.L. Bennett and
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 TITLE: High pressure waterjet barrier trial in Norman Wells
 AUTHOR: Laperriere, F.
 SERIES: Spill technology newsletter, v. 10, no. 1-3, Jan.-June
    *1985,*p. 5-10, ill., map
 NOTE: References.
 YEAR OF PUBLICATION:*1985*
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 DOCUMENT NUMBER: 177075
 TITLE: Oil-in-ice and oil-stranding observations
 AUTHOR: Vandermeulen, J.H.
 SERIES: The Kurdistan oil spill of March 16-17, 1979
    : activities and observations of the Bedford Institute of
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 TITLE: In-place burning of crude oil in broken ice :*1985*
    testing at OHMSETT
 AUTHOR: Smith, N.K.
    Diaz, A.
 SERIES: Proceedings of the Eighth Annual Arctic Marine Oilspill
    Program Technical Seminar, June 18-20,*1985,*Edmonton,
    Alberta. - [Ottawa : EPS],*1985,*p. 176-191, ill.
 NOTE: References.
 YEAR OF PUBLICATION:*1985*
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DOCUMENT NUMBER: 174734
TITLE: The transport and behaviour of spilled oil under ice
AUTHOR: Cox, J.C.
Schultz, L.A.
SERIES: Proceedings of the Arctic Marine Oil Spill Program
Technical Seminar, June 3-5,*1980,*Edmonton, Alberta.
- Ottawa : Environmental Protection Service,*1980,*p.
45-61, ill.
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TITLE: Oil spreading in broken ice
AUTHOR: Schulze, R.
SERIES: Proceedings of the Eighth Annual Arctic Marine Oilspill
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Alberta. - [Ottawa : EPS],*1985,*p. 1-4, ill.
NOTE: References.
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DOCUMENT NUMBER: 162442
TITLE: Laboratory testing of an oil-skimming bow in broken ice
AUTHOR: Arctec Canada Limited [Sponsor]
Abdelnour, R.
Johnstone, T.
Howard, D.
Nisbett, V.
Environmental Studies Revolving Funds (Canada) [Sponsor]
IMPRINT: Ottawa : ESRF [publisher] ; Calgary, Alta. : Pallister
Resources Mgt. Ltd. [distributor],*1986.*
COLLATION: v, 60 p. : ill. ; 28 cm.
SERIES: Environmental Studies Revolving Funds report, no. 013
ISBN: 0-920783-12-0
NOTE: Appendices.
References.
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DOCUMENT NUMBER: 162000
TITLE: Oil spill countermeasures in landfast sea ice
AUTHOR: Allen, A.A.
Nelson, W.G.
SERIES: Proceedings -*1981*Oil Spill Conference : Prevention,

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TITLE: Laboratory studies of oil spill behavior in broken ice fields
AUTHOR: Free, A.P.
Cox, J.C.
Schultz, L.A.
SERIES: Proceedings of the Arctic Marine Oil Spill Program Technical Seminar. - [Ottawa : EPS. Environmental Emergency Branch],*1982,*p. 3-14, figures
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TITLE: State lifts Beaufort broken-ice restrictions
SERIES: The Arctic policy review,*1984*[03-05] Mar.-May, p. 9-13, ill.
YEAR OF PUBLICATION:*1984*
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DOCUMENT NUMBER: 120650
TITLE: Proceedings of a Brainstorming Workshop on Recovery of Oil in an Ice Environment
AUTHOR: S.L. Ross Environmental Research Ltd.
Canadian Offshore Oil Spill Research Association [Sponsor]
IMPRINT: Ottawa : S.L. Ross Environmental Research Ltd.,*1982.*
COLLATION: 3 microfiches : figures, tables ; 11 x 15 cm.
SERIES: COOSRA project report, no. CS10
NOTE: Appendices.
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TITLE: Tier II Beaufort Sea oil spill recovery tests conducted : can spilled oil be recovered in the Arctic?
SERIES: The Arctic policy review,*1983*[09] Sept., p. 12-14, ill.
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 TITLE: POAC 81 : the Sixth International Conference on Port and
    Ocean Engineering Under Arctic Conditions, Quebec, Canada,
    July 27-31, 1981, proceedings
 LANGUAGE: Multilingual
 AUTHOR: Universite Laval
    Quebec (Province). Ministere de l'Environnement
 IMPRINT: Quebec City, Que. : Universite Laval, 1981.
 COLLATION: 3 v. : ill., figures, tables ; 21 cm.
 NOTE: Text in English and French.
    English abstracts provided for French papers.
    COE, E-I
 YEAR OF PUBLICATION: 1981
END OF DOCUMENT.

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 DOCUMENT NUMBER: 47163
 TITLE: Arctic sea inspection technology
 AUTHOR: Taagholt, J.
 IMPRINT: Lyngby, Denmark : Ionosphere Laboratory, Danish
    Meteorological Institute, 1980.
 COLLATION: 7 leaves : ill. ; 30cm.
 SERIES: Contribution - Danske Meteorologiske Institut.
    Ionosphere Laboratory, R- 59
 NOTE: Presented at: The Arctic Committee meeting: The Arctic
    Ocean : The hydrographic environment and the fate of
    pollutants, at the Royal Geographical Society on 11th and
    12th March, 1980.
 YEAR OF PUBLICATION: 1980
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 DOCUMENT NUMBER: 120669
 TITLE: Fate and behaviour of water-in-oil emulsions in ice
 AUTHOR: Dome Petroleum Limited
    Buist, I.A.
    Dickins (D.F.) Associates Ltd.
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    Canadian Offshore Oil Spill Research Association [Sponsor]
 IMPRINT: Calgary, Alta. : Dome Petroleum Ltd.,*1983.*
 COLLATION: 2 microfiches : ill., figures, tables ; 11 x 15 cm.
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 NOTE: Appendices.
    References.
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DOCUMENT NUMBER: 183881
TITLE: A review of ice information for offshore eastern Canada
AUTHOR: Newfoundland Oceans Research and Development Corporation
Royal Commission on the Ocean Ranger Marine Disaster
(Canada) [Sponsor]
IMPRINT: [Ottawa] : Royal Commission on the Ocean Ranger Marine
Disaster [publisher] ; Calgary : Pallister Resource
Management Ltd. [distributor], 1984.
COLLATION: 3 microfiches : ill., maps ; 11 x 16 cm.
SERIES: Royal Commission on the Ocean Ranger Marine Disaster
(Canada). RCOR, 2
NOTE: Bibliography.
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YEAR OF PUBLICATION: 1984
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TITLE: Ice and its drift into the North Atlantic Ocean
AUTHOR: Dinsmore, R.P.
SERIES: Symposium on Environmental Conditions in the Northwest
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Commission for the Northwest Atlantic Fisheries, no. 8,
1972, p. 89-128, ill., maps
NOTE: References.
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YEAR OF PUBLICATION: 1972
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DOCUMENT NUMBER: 169684
TITLE: Physical weathering of Kurdistan oil : droplet formation
and effect on shore-ice melting
AUTHOR: Vandermeulen, J.H.
Amero, B.
Ahern, T.P.
SERIES: Scientific studies during the "Kurdistan" tanker
incident : proceedings of a workshop, June 26 and 27, 1979,
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TITLE: Sea ice and iceberg conditions on the Grand Banks

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DOCUMENT NUMBER: 165077
TITLE: Motion of oil in leads
AUTHOR:*MacNeill,*M.R.
   Goodman, R.H.
SERIES: Proceedings of the Eighth Annual Arctic Marine Oilspill
   Program Technical Seminar, June 18-20, 1985, Edmonton,
   Alberta. - [Ottawa : EPS], 1985, p. 42-52, ill.
NOTE: References.
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YEAR OF PUBLICATION: 1985
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DOCUMENT NUMBER: 83160
TITLE: Iceberg motion in Lancaster Sound and northwest Baffin
   Bay, summer 1978
AUTHOR: De Lange Boom, B.R.
   *MacNeill,*M.R.
   Buckley, J.R.
SERIES: Eastern Arctic Marine Environmental Studies Program
   / Edited by N. Sutterlin. Arctic, v. 35, no. 1, Mar. 1982,
   p. 219-233, ill. figures, tables
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NOTE: References.
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DOCUMENT NUMBER: 5274
TITLE: Radar tracking of ice in the Griffith Island area of
   Barrow Strait, N.W.T.
AUTHOR:*MacNeill,*M.R.
   de Lange Boom, B.R.
   Ramsden, D.
IMPRINT: Sidney, B.C. : Institute of Ocean Sciences, Patricia
   Bay, 1978.
COLLATION: iv, 105p. : maps, charts, graphs ; 28cm.
SERIES: Contractor report series - Institute of Ocean Sciences,
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TI - THE SNOW COVER OF SEA ICE DURING THE ARCTIC ICE DYNAMICS JOINT EXPERIMENT,
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TI - ORBITAL SENSING OF MACKENZIE BAY ICE DYNAMICS.

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TI - THE TURBULENT HEAT FLUX FROM ARCTIC LEADS.

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TI - TESTS OF OIL RECOVERY DEVICES IN A BROKEN ICE FIELD.

32/17
TI - RECTILINEAR LEADS AND INTERNAL MOTIONS IN THE ICE PACK OF THE WESTERN
ARCTIC OCEAN.
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RE - N1411: 2-10159
TI - INITIAL MODEL RESULTS FOR ARCTIC MIXED LAYER CIRCULATION UNDER A
REFREEZING LEAD.
AU - KOZO, T.L. (VENTURA RES. GROUP, OCCIDENTAL COLL., LOS ANGELES, CA 90041,
USA)
PU - J. GEOPHYS. RES. (C OCEANS ATMOS.)., (1983)., VOL. 88, NO. C5, PP. 2926-
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RE - N1401: 1-01442
TI - ECOLOGICAL INVESTIGATIONS IN THE MARGINAL ICE ZONE IN THE BARENTS SEA THE
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AU - ELLERTSEN, B.; HASSEL, A.; LOENG, H.;REY, F.;TJELMELAND, S.;SLAGSTAD, D. (
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PU - FISKEN HAVET., (1982)., NO. 3, PP. 31-83
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RE - N1111: 2-09613
TI - OBSERVATIONS OF CONDENSATE PROFILES OVER ARCTIC LEADS WITH A HOT-FILM
ANEMOMETER.
AU - ANDREAS,E.L.; WILLIAMS,R.M.; PAULSON,C.A. (US ARMY COLD REGIONS RES. ENG.
LAB., HANOVER, NH 03755, USA)
PU - Q. J. R. METEOROL. SOC., (1981), 107(452), 437-460
LA - (ENG) ENGLISH

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RE - N1005: 2-03270
TI - THE TURBULENT HEAT FLUX FROM ARCTIC LEADS.

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U - T178 R18P2 P-6620 : MAIN SER/ XCAU
I - A 3-D OIL SPILL MODEL WITH AND WITHOUT ICE COVER.
U - =>LIU, SHIAO-KUNG.; LEENDERTSE, J. J.
E - THE RAND PAPER SERIES ;  P-6620  ISSN 0092-2803
U - P6620; RANDP6620
U - SANTA MONICA, CALIF. :  RAND CORPORATION,  1981. 23 P.
O - PRESENTED AT THE INTERNATIONAL SYMPOSIUM ON MECHANICS OF
    OIL SLICKS ON SEPTEMBER 8, 1981, PARIS, FRANCE.
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U - ZCX-APOA-R-100-1 : AERO MFORM/ XQUC
I - =>PROPOSAL TO EVALUATE AN OIL CONTAINMENT BOOM FOR USE IN
    ICE-INFESTED WATERS.
R - ARCTEC CANADA LIMITED.
E - ARCTIC PETROLEUM OPERATORS' ASSOCIATION.  REPORT - ARCTIC
    PETROLEUM OPERATORS' ASSOCIATION ;  APOA 100-1
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O - MICROFICHE.
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SU - GB707 C213 NO.50 : MAIN SER/ XONC
TI - BEHAVIOUR OF OIL UNDER CANADIAN CLIMATIC CONDITIONS :
     PART 1, OIL ON WATER UNDER ICE-FORMING CONDITIONS.
AU - =>SCOTT, BRIAN F.,; CHATTERJEE, ROBI M.
OR - CANADA.  WATER QUALITY BRANCH.
SE - CANADA.  INLAND WATERS DIRECTORATE.  SCIENTIFIC SERIES ;
     50  ISSN 0318-5850
NU - EN36-502/50; UTLAS 55035756
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AD - OIL ON WATER UNDER ICE-FORMING CONDITIONS.
NO - INCLUDES AN ABSTRACT IN FRENCH.; BIBLIOGRAPHY: P. 18.
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SU - GC1 I591 NO. 77-4 : MAIN SER/ XBCC
TI - A SATELLITE-BASED STUDY OF SEA ICE DYNAMICS IN THE
     CENTRAL CANADIAN ARCTIC ARCHIPELAGO.
AU - =>MARKO, J. R.
SE - INSTITUTE OF OCEAN SCIENCES, PATRICIA BAY.  CONTRACTOR
     REPORT SERIES ;  77-4
NU - UTLAS 55027652
PU - 1977. 103P.
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SU - GC1000 M53 NO. 78-12 : MAIN SER/ XNFC
TI - DETECTION AND MONITORING OF OIL POLLUTION IN THE ICE
     ENVIRONMENT THROUGH MICROWAVE TECHNIQUES.
AU - =>PARASHAR, SURENDRA K.; DAWE, BYRON R.; WORSFOLD,
     RICHARD D.
OR - MEMORIAL UNIVERSITY OF NEWFOUNDLAND.  CENTRE FOR COLD
     OCEAN RESOURCES ENGINEERING.
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PU - ST. JOHN'S :  CENTRE FOR COLD OCEAN RESOURCES
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U - TD195.P4 E62 NO. 18 : IMDS SER/ XONC
I - =>TESTING OF AN OIL RECOVERY CONCEPT FOR USE IN BRASH AND
    MULCHED ICE.
R - S.L. ROSS ENVIRONMENTAL RESEARCH LTD. ENVIRONMENTAL
    STUDIES REVOLVING FUNDS (CANADA)
E - ENVIRONMENTAL STUDIES REVOLVING FUNDS REPORT,  NO. 018
    ISSN 0833-2169 ;
U - ISBN 0920783171
U - OTTAWA :  PUBLISHED UNDER THE AUSPICES OF THE
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O - INCLUDES SUMMARY IN FRENCH; BIBLIOGRAPHY: P. 33.
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U - TD195.P4 E62 NO. 19 : IMDS SER/ XONC
I - =>OIL IN ICE COMPUTER MODEL.
U - WOTHERSPOON, P.; LAWRENCE, D.
R - ENVIRONMENTAL STUDIES REVOLVING FUNDS (CANADA) DOME
    PETROLEUM LIMITED.
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O - SUMMARY IN FRENCH.; BIBLIOGRAPHY: P. 29.
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    THE BEAUFORT EXPERIENCE : PROCEEDINGS OF A SYMPOSIUM HELD
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    SEPTEMBER 20 - OCTOBER 1, 1983.
O - =>ALASKA SCIENCE CONFERENCE  (34TH :  1983 :  WHITEHORSE,
    YUKON)
U - MCTIERNAN, TIMOTHY J.; DEMCHUK, BRUCE E.
R - YUKON TERRITORY.  DEPT. OF ECONOMIC DEVELOPMENT.  MAJOR
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RE - EIM8605-031189
TI - RANDOM TRANSPORT OF OIL BY SEA ICE.
AU - COLONY, ROGER
OR - UNIV OF WASHINGTON, SEATTLE, WA, USA; *INTL ASSOC ON
     WATER POLLUTION RESEARCH & CONTROL, LONDON, ENGL
CO - ARCTIC WATER POLLUTION RESEARCH: APPLICATIONS OF SCIENCE
     AND TECHNOLOGY, PROCEEDINGS OF AN IAWPRC CONFERENCE.
     YELLOWKNIFE, CAN. 1985 APRIL 28-MAY 1
PU - WATER SCIENCE AND TECHNOLOGY V 18 N 2 1986 P 25-39, 1986;
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RE - EIM8603-018178
TI - TRANSPORT OF CRUDE OIL UNDER SALINE ICE.
AU - PUSKAS, JAMES K.; MCBEAN, EDWARD A.
OR - UNIV OF WATERLOO, DEP OF CIVIL ENGINEERING, WATERLOO,
     ONT, CAN; *ASCE, TECHNICAL COUNCIL OF COLD REGIONS
     ENGINEERING, NEW YORK, NY, USA; ASCE, ALASKA SECTION, AK,
     USA
CO - COLD REGIONS ENGINEERING, PROCEEDINGS OF THE FOURTH
     INTERNATIONAL CONFERENCE. ANCHORAGE, AK, USA. 1986 FEB
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Dept. Envir., Hull, Can.
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78090202 v6n11
Behavior of Bouchard 65 oil spill in ice-covered waters of Buzzards Bay
Deslauriers, P.C.
Arctec, Inc.
Tenth Annual Offshore Technology Conference 782 1056
Houston, Texas 8-11 May 78
Offshore Technology Conference; Society of Petroleum Engineers (American Institute of Mining, Metallurgical & Petroleum Engineers)
Papers in bound volume (Eng), available from date of conference, $25 members, $35 non-members, prepayment required: Offshore Technology Conf., 6200 North Central Expressway, Dallas, TX 75206.

78089398 v6n11
Oil behavior in ice during 1977 Buzzards Bay spill
Desaurlers, P.C.
Arctec, Inc.
Conference on Assessment of Ecological Impacts of Oil Spills
782 2330 Keystone, Colorado 14-17 Jun 78
American Institute of Biological Sciences
Papers (Eng) in "Proceedings of Conference on Assessment of Ecological Impacts of Oil Spills," Sept/Oct 78, free to registrants, $10 to non-registrants prepaid: AIBS, 1401 Wilson Blvd., Arlington, VA 22209.

75052247 v3n6
Behavior of oil spilled under floating ice
Keevil, B.E.
1975 Conference on Prevention and Control of Oil Pollution
A751091 San Francisco, California 25-27 Mar 75
American Petroleum Institute; Environmental Protection Agency; United States Coast Guard
Proceedings: ~ 1975 Conference on Prevention and Control of Oil Pollution," (Eng); March 1975; $25.00: API, Suite 700, 1629 K St., NW, Washington, D.C. 20006.

APPENDIX 2

Environmental Data for Outdoor Experiments

TABLE A1

Ice Thickness Measurements and Associated Surface Conditions

Date	Time	Site	Ice Thickness (mm)	Water Depth (mm)	Slush Depth (mm)	Snow Depth (mm)	Temperatures	
							Air (^{o}C)	Oil
27	1213	L1,C					-5.9	-1.8
	1244	L1,C	1				-5.0	1.6
	1330	L1,C					-4.8	2.0
	1400	L1,C	3					
	1630	L1,C	8					
28	1000	L1,C	45				-8.0	-3.0
	1017	L1,O	30					
	1020	TA1	30					-1.0
	1021	TA2	30					-1.0
	1022	TA3	30					0.0
	1023	TA4	25					1.0
	1045						-6.5	
	1500	L1,C	50				-5.0	
	1501	L1,O	18	3				
	1530	TA1	23	3				0.5
	1531	TA2	20	5				0.0
	1532	TA3	20	4				0.0
	1533	TA4	20	3				0.5
29	1015	L1,O	33	4			-6.0	-3.2
	1130	TA1	31	4				-3.4
	1131	TA2	30	5				-2.9
	1400	TA3	29	3			-2.0	1.0
	1401	TA4	25	4				1.5

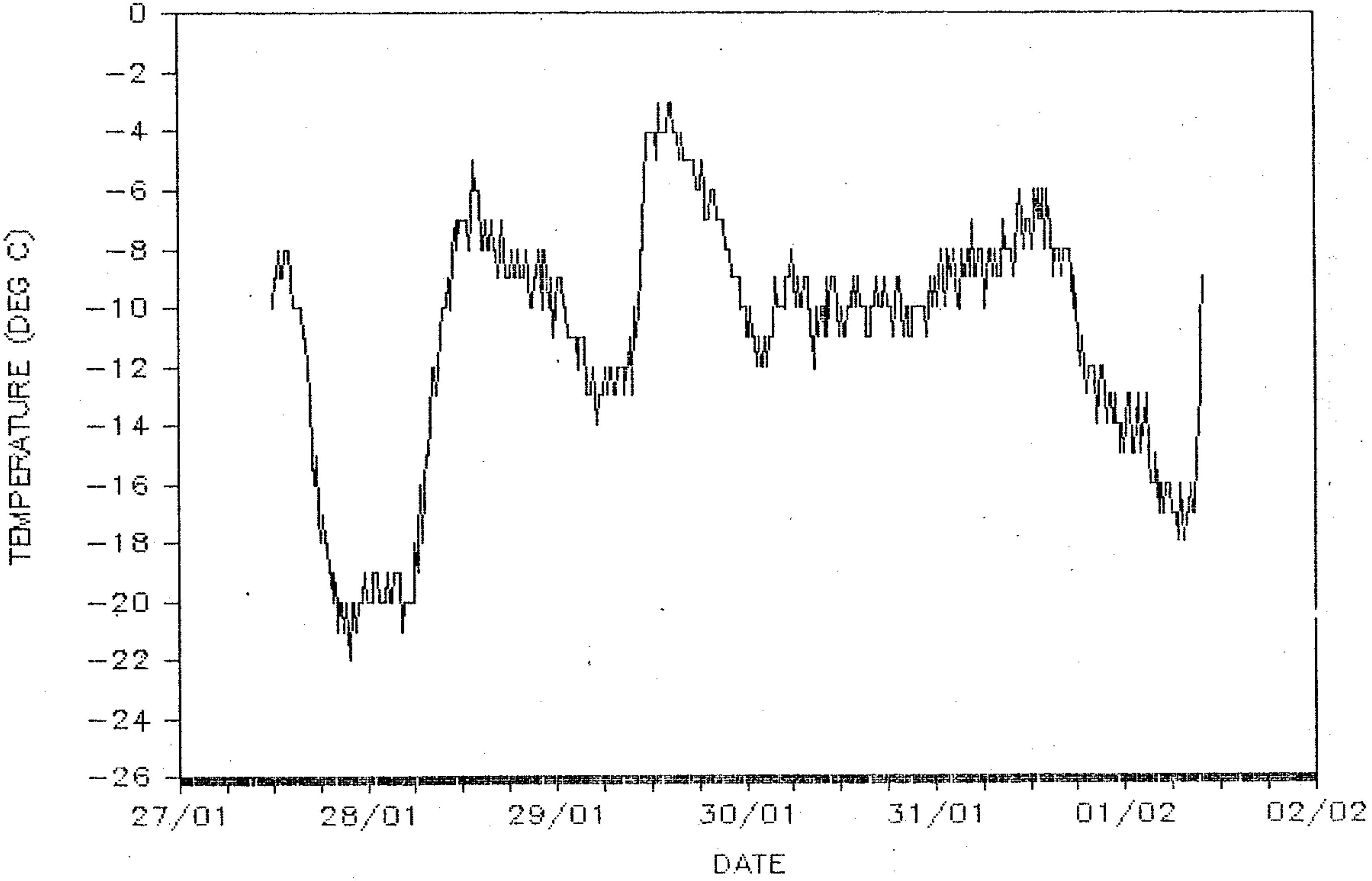
Ice Thickness Measurements and Associated Surface Conditions

Date	Time	Site	Ice Thickness (mm)	Water Depth (mm)	Slush Depth (mm)	Snow Depth (mm)	Temperatures	
							Air (°C)	Oil
30	1030	L1,C	77					
		L1.O	46					
		TA1	39					
		TA2	39	2				
		TA3	33	3				
		TA4	32	4				
	1120	L2			15			
01	1000	L1,C	90		30	60		
	1015	L1,O	40		25	45		
	1030	L2,O			35			
		L2,C			55			
		TA1	45	20	10	95		
		TA2	40	20	10	70		
		TA3	35	20	30	80		
		TA4	28	20	25	90		

L1,L2 = Lead 1&2; O = oiled, C = clean; TA = Test square (1 m^2)

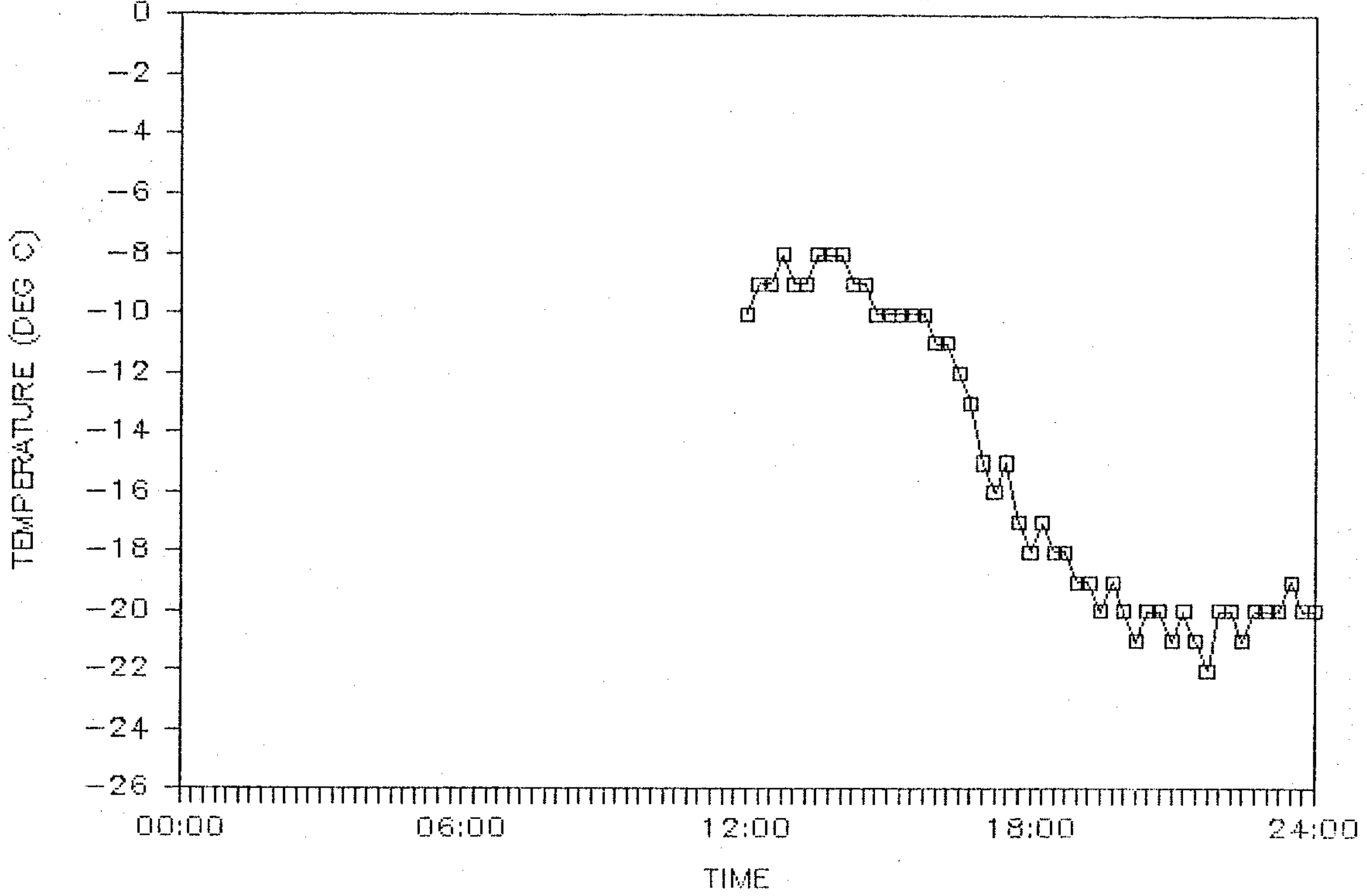
OIL IN LEADS

TEMPERATURE vs. TIME



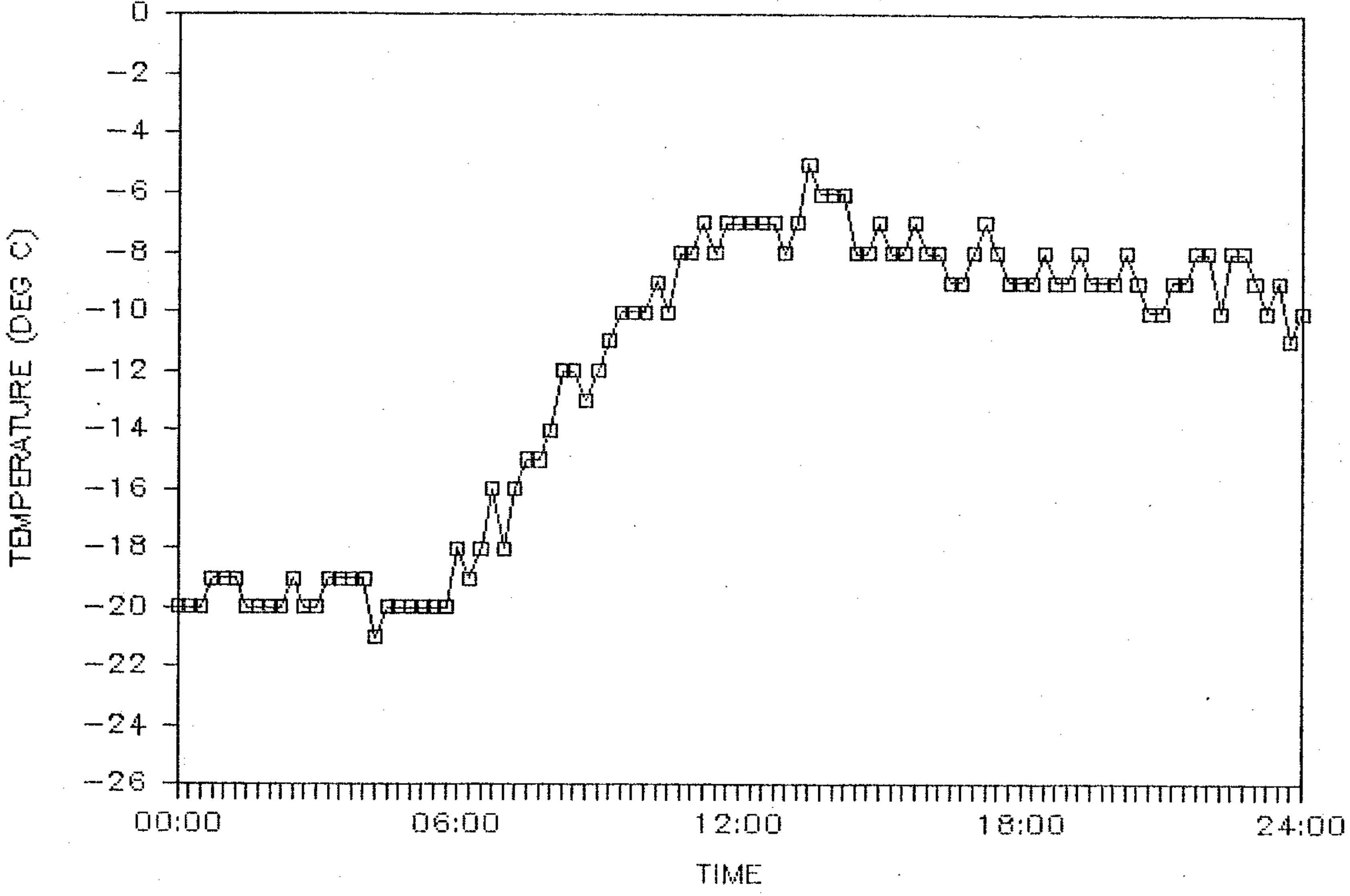
OIL IN LEADS (27/01/87)

TEMPERATURE PROFILE



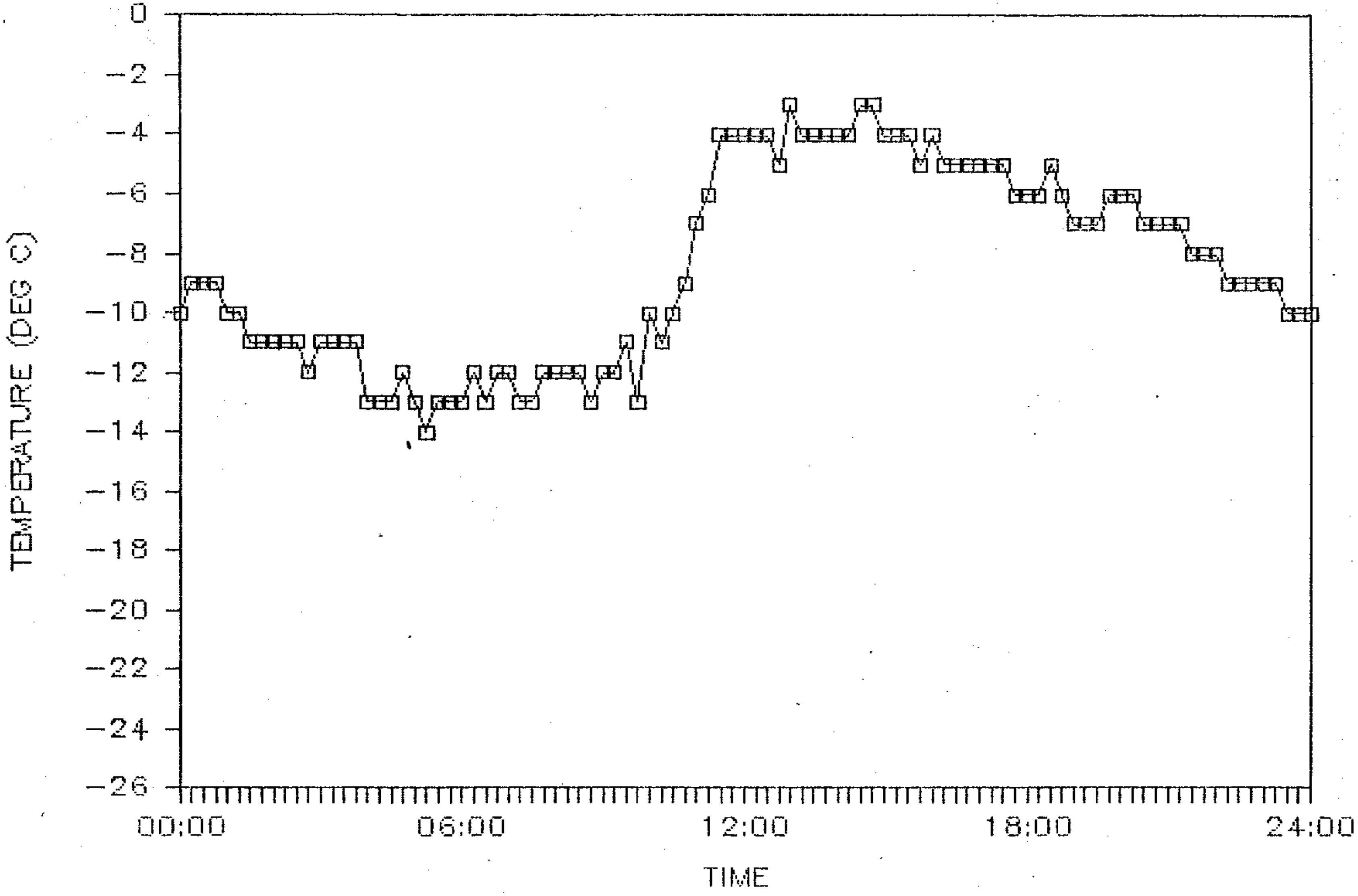
OIL IN LEADS (28/01/87)

TEMPERATURE PROFILE



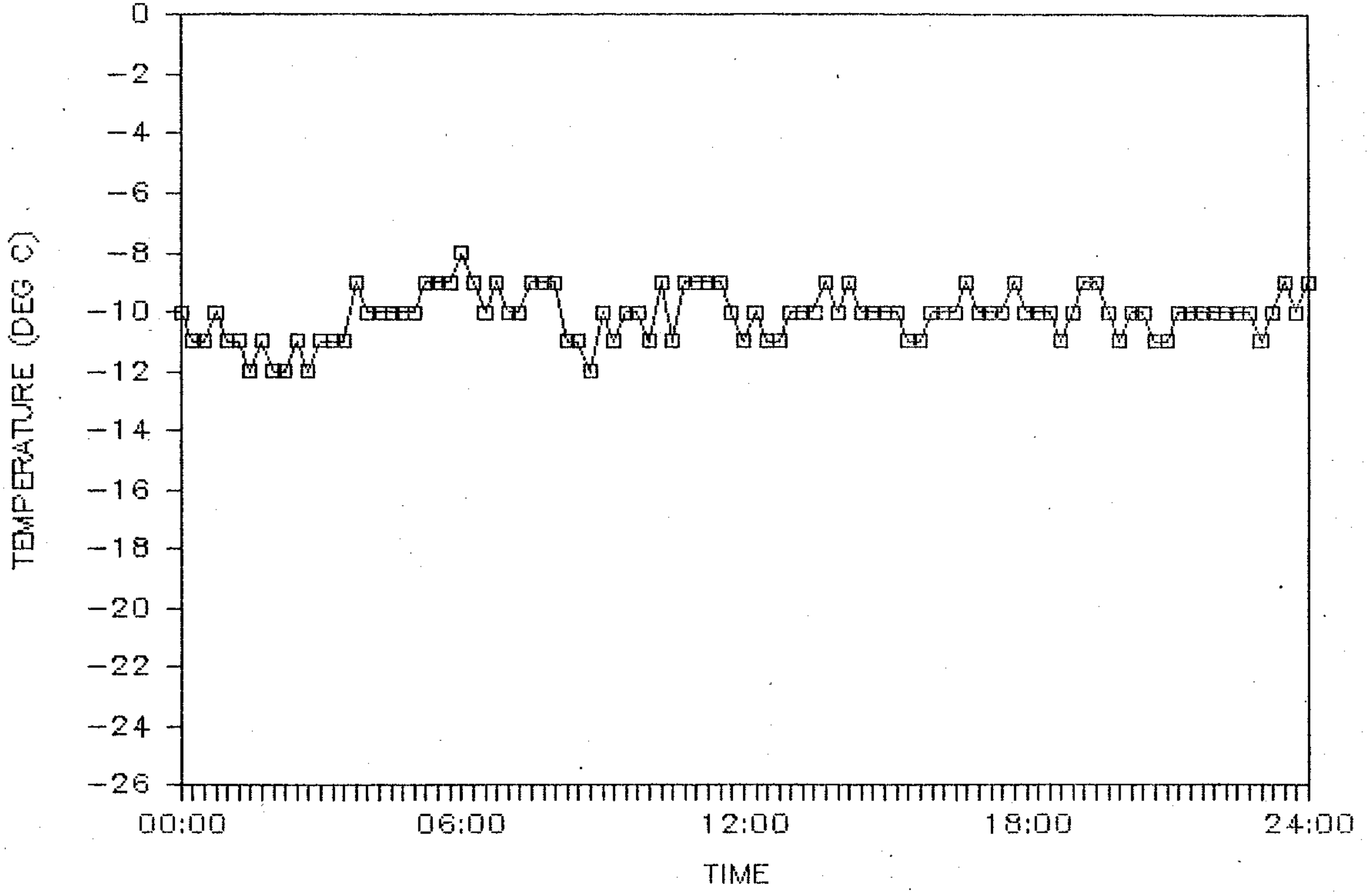
OIL IN LEADS (29/01/87)

TEMPERATURE PROFILE



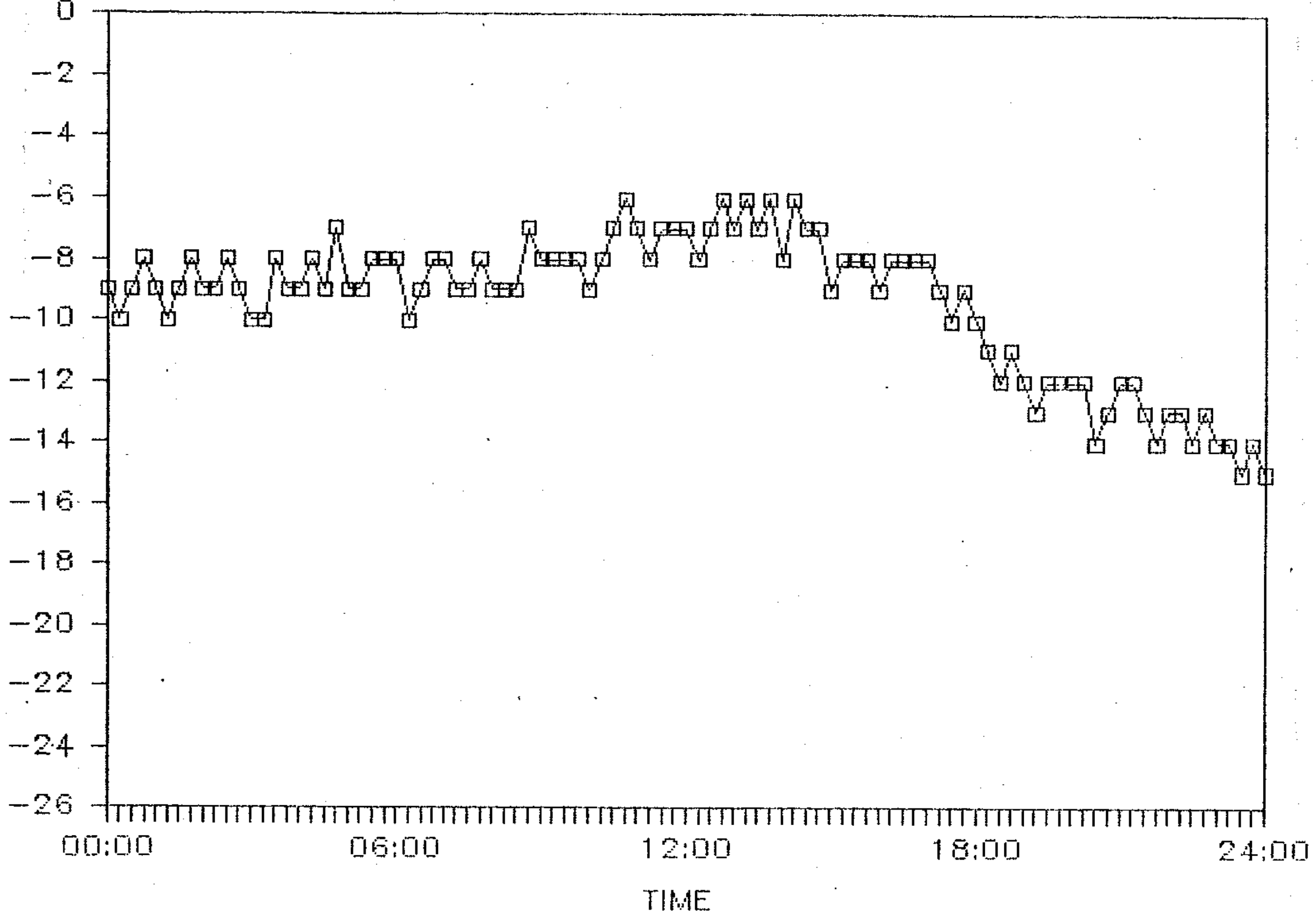
OIL IN LEADS (30/01/87)

TEMPERATURE PROFILE



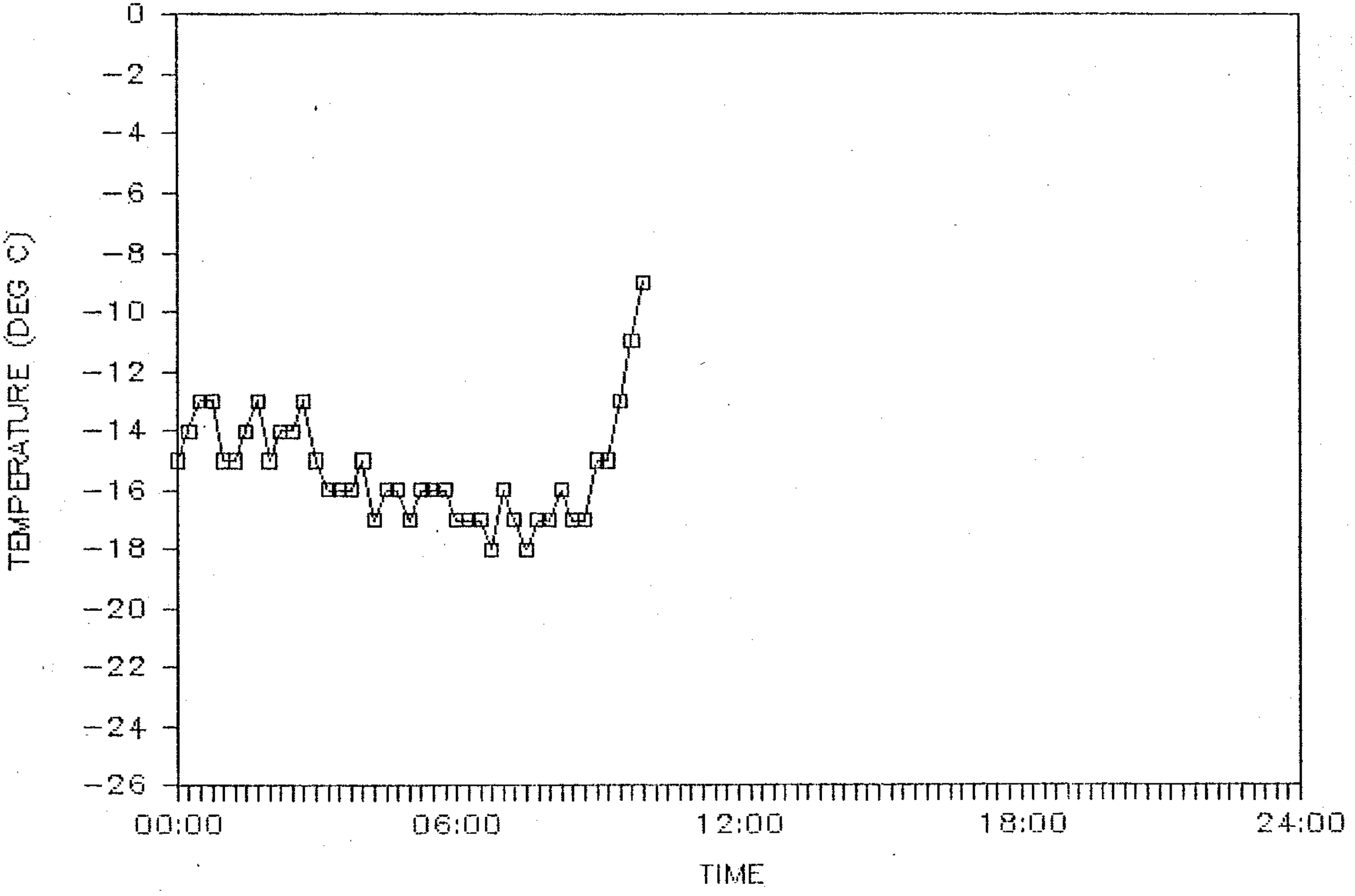
OIL IN LEADS (31/01/87)

TEMPERATURE PROFILE



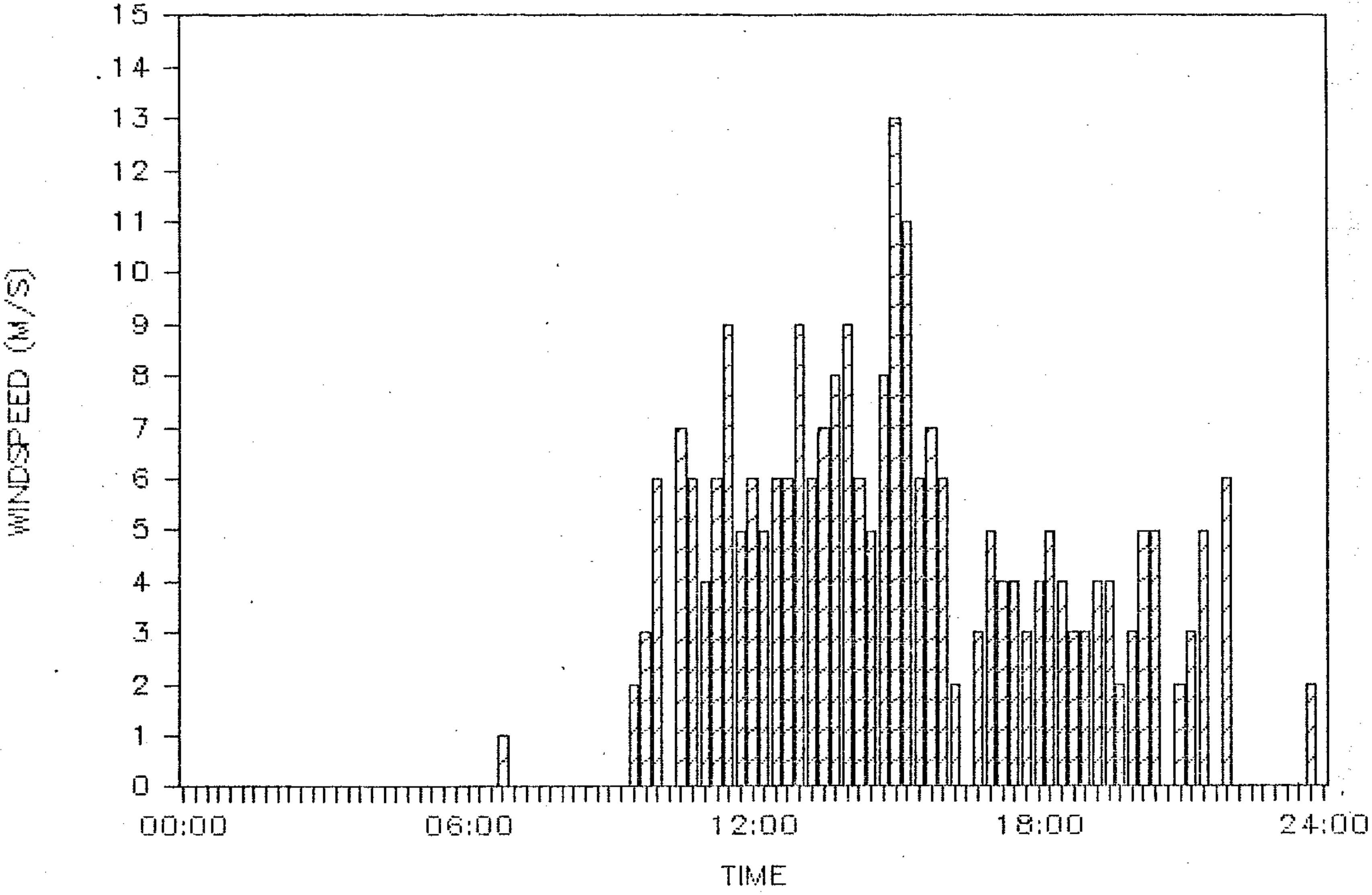
OIL IN LEADS (01/02/87)

TEMPERATURE PROFILE



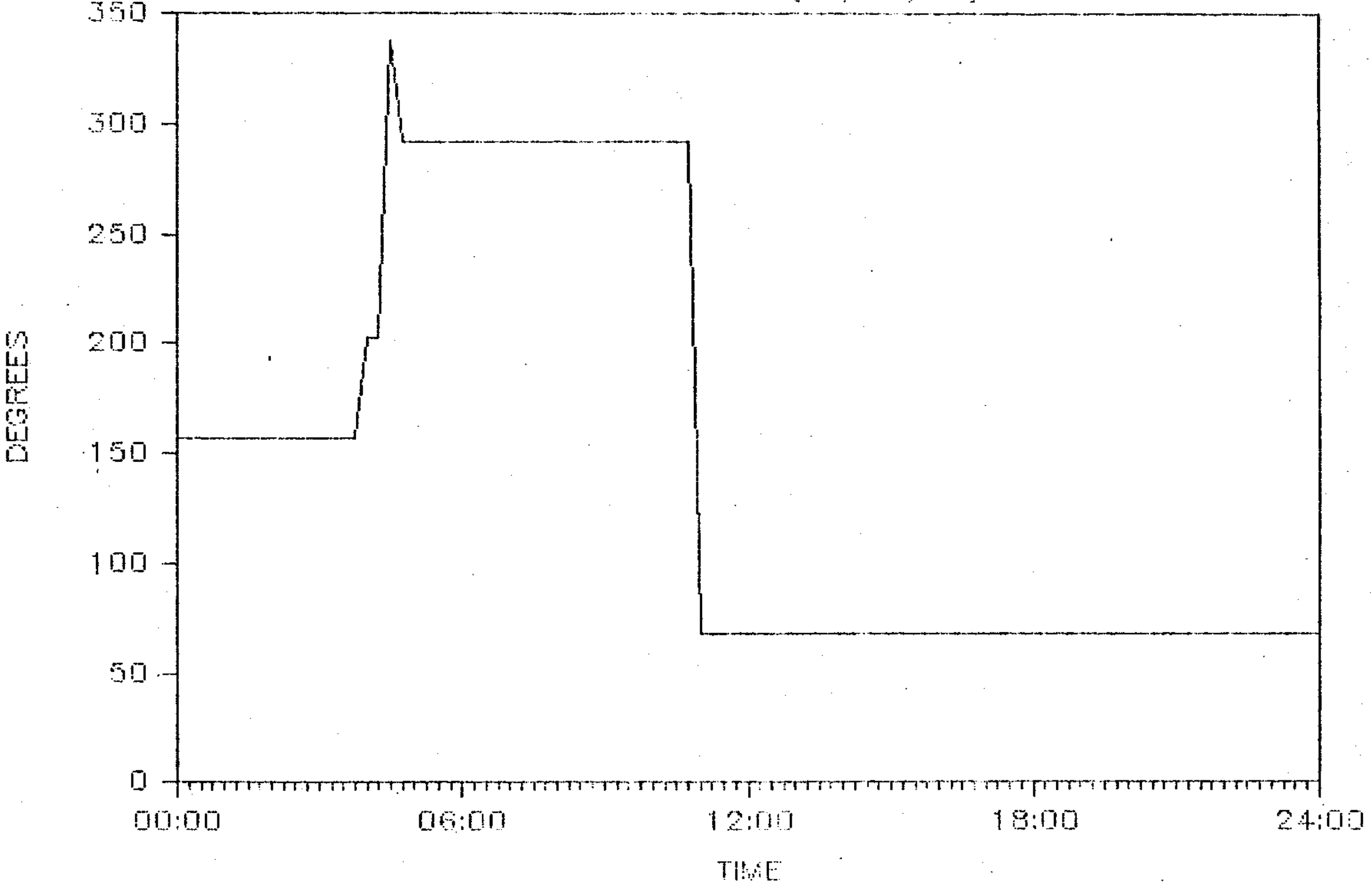
OIL IN LEADS (30/01/87)

NO MEASURABLE WIND ON OTHER DAYS



OIL IN' LEADS

WIND DIRECTION (30/01/87)



APPENDIX 3

Computer Model Code

```
program leadfate;
        {
        ***********************************************************************
        *                                                                     *
        *       This version of OilFate has been modified for oil-in-leads.   *
        *                                                                     *
        ***********************************************************************
        }

   {$I UT-MOD00.INC}    { load global variables }
   {$I UT-MOD01.INC}
   {$I UT-MOD02.INC}
   {$I UT-MOD03.INC}
   {$I UT-MOD04.INC}
 const
    tstep = 100;                  {The basic 'heart-beat' of the model - in
                                                                   seconds}

 const
    Size = 41;                        {this is the current size of the fateinit
                                      file and the array that it gets read into.
                                      If this size needs changing go to InitInit.pa
                                      and change the Size constant and run it. It
                                      will generate a new fateinit.dta,incorporatin
                                      the old data, that can then be filled}
                                      {the assumption there is that its getting
                                      bigger}

  type
    String16 = string[16];
    string20 = string[20];
    string25 = string[25];
    string80 = string[80];
    initfile=record
                cond:array[1..Size] of string25;
             end;
    physprop=record
                sumvevap,
                sumvdis,
                volume,
                area,
                fevap,
                vevap,
                fdis,
                vdis,
                thickness:real;
             end;
    chemprop=record
                density,
                viscosity:real;
             end;
    IceProp=record
                area,
                vevap,
```

```
                  sumvevap,
                  fevap,
                  vol_in,
                  vol_on,
                  sumvol_in,
                  sumvol_on:real;
               end;


const
    OutFileName: string20 = 'fategraf.dta';
    RunStatsFileName: string20 = 'fatestat.dta';

var
   Run_Stats: text;
   Out_file: text;
   init_value : file of initfile;
   initial : initfile;
   initfilename : string20;
   sTitle: string25;
   i,code:integer;
   thickspread,
   thinspread,
   change: boolean;
   r:array[1..Size] of real;
procedure CentrePrint(title:string80);    {assume 80 column printer}

var
   i,
   offset: integer;

begin
   offset:= (80 - length(title)) div 2;
   for i:= 1 to offset do
      write(lst,' ');
   writeln(lst,title);
   writeln(lst);
end;


function exist(filename : str20): boolean;

   var
    fil:   text;

 begin
   assign(fil,filename);
   {$I-}
   reset(fil);
   {$I+}
   exist:=(ioresult=0);
 end;

procedure readinitfile;
```

```
 begin
   initfilename:='fateinit.dta';
   assign(init_value,initfilename);
   if exist(initfilename) then
    begin
     reset(init_value);
     read(init_value,initial);
     close(init_value);
     for i:=1 to 40 do
        begin
         initial.cond[i]:=initial.cond[i]+' ';
         filvar[i]:=copy(initial.cond[i],1,pos(' ',initial.cond[i])-1)
        end;
     sTitle:= initial.cond[41];
    end;
   end;

procedure writeinitfile;
 var
     s:string[20];

 begin
   initfilename:='fateinit.dta';
   assign(init_value,initfilename);
   if exist(initfilename) then
      reset(init_value)
    else rewrite(init_value);
   for i:=1 to 40 do
    begin
      s:=filvar[i]+'          ';
      initial.cond[i]:=copy(s,1,10);
    end;
   initial.cond[41]:= copy(sTitle,1,25);
   write(init_value,initial);
   close(init_value);
end;

procedure pstring;
 begin
   p[1]:='6007N01001-000201';
   p[2]:='6008N01002-000101';
   p[3]:='6009N01003-000101';
   p[4]:='6010N01004-000101';
   p[5]:='6011N01005-000101';
   p[6]:='6012N01006-000101';
   p[7]:='6013N01007-000101';
   p[8]:='6014N01008-000101';
   p[9]:='6015N01009-000101';
   p[10]:='6016N01010-000101';
   p[11]:='';
{*}p[12]:='6007N01012-000201';
{*}p[13]:='6008N01013-000101';
{*}p[14]:='6009N01014-000101';
{*}p[15]:='6010N01015-000201';
{*}p[16]:='6011N01016-000101';
```

```
{*}p[17]:='6012N01017-000101';
{*}p[18]:='6013N01018-000101'; {spare} {used now for testing hWave}
   p[19]:='6007N01019-000201';
   p[20]:='6008N01020-000101';
   p[21]:='6009N01021-000101';
   p[22]:='6010N01022-000101';
   p[23]:='6011N01023-000101';
                                                 {6012N01024-000101';}
   p[24]:='';                                          {saved while altering}
          {other environmental conditions}
   p[25]:='';
   p[26]:='';
   p[27]:='';
   p[28]:='6007N01028-000201';
   p[29]:='6008N01029-000101';
   p[30]:='6009N01030-000101';
   p[31]:='6010N01031-000101';
   p[32]:='6011N01032-000101';
   p[33]:='6012N01033-000101';
   p[34]:='6013N01034-000101';
   p[35]:='6014N01035-000101';
   p[36]:='6015N01036-000101';
   p[37]:='6016N01037-000101';
   p[38]:='6017N01038-000101';
 end;

procedure dis_msg(msgtyp:char);
 begin
   case msgtyp of
                                                              {array index #}
     'O':begin
          msg('Emulsification delay (theta)',20,7);             {1}
          msg('Density (kg/m3)',20,8);                          {2}
          msg('Standard density temperature (K)',20,9);         {3}
          msg('Viscosity (mPas)',20,10);                        {4}
          msg('Standard viscosity temperature (K)',20,11);      {5}
          msg('Pour point (K)',20,12);                          {6}
          msg('Aqueous solubility (g/m3)',20,13);               {7}
          msg('Flash point (K)',20,14);                         {8}
          msg('Oil-water interfacial tension (N/m)',20,15);     {9}
          msg('Oil-air interfacial tension (N/m)',20,16);      {10}
        end;
{*}   'L':begin
{*}        msg('Length of lead parallel to wind (m)',20,7);     {12} {Len}
{*}        msg('Width of lead perpendicular to wind (m)',20,8);{13} {Wid}
{*}        msg('Fraction of lead initially iced',20,9);         {14} {iIce}
{*}        msg('Snowfall rate (cm/day)',20,10);                 {15} {rSnow}
{*}        msg('Lead closure rate (m/s)',20,11);                {16} {rClose}
{*}        msg('Starting distance: spill to ice (m)',20,12);    {17} {dSpill}
{&}        msg('Limit on wave height (cm)',20,13)               {18} {lWave}
{*}      end;

 (*   unused in Leads model
      'D':begin
           msg('Dispersant application time (sec)',20,7);       {15}
           msg('Reduced O-W interfacial tension (N/m)',20,8);   {16}
```

```
           msg('Dispersant effective time (sec)',20,9);           {17}
                         {Should be approx 0.125 (hr)}
         end;
           {unused as of 06/13/87}
*)
     'S':begin
           msg('Duration of spill (100sec multiples)',20,7);      {19}
           msg('Windspeed (m/s)',20,8);                           {20,WindSp}
           msg('Air temperature (K)',20,9);                       {21,AirT}
           msg('Water temperature (K)',20,10);                    {22,WaterT}
           msg('Volume of oil spilled (m3)',20,11);               {23}
(*
           msg('Increment for oil volume graph (v/5)',20,12);     {24}
 *)
          end;
     'C':begin
           msg('Density constant 1',20,7);                        {28}
           msg('Density constant 2',20,8);                        {29}
           msg('Viscosity constant 1',20,9);                      {30}
           msg('Viscosity constant 2',20,10);                     {31}
           msg('Pour point constant',20,11);                      {32}
           msg('Solubility constant',20,12);                      {33}
           msg('Flash point constant',20,13);                     {34}
           msg('Oil-water int. tension constant',20,14);          {35}
           msg('Oil-Air int. tension constant',20,15);            {36}
           msg('ASTMA constant',20,16);                           {37}{Astma}
           msg('ASTMT constant',20,17);                           {38}{Astmt}
         end;
    end;
 end;{dis_msg}

procedure initcond;

   procedure Title;

   begin
      clrscr;
      highvideo;
      center('Set title for this run',0,5,80);
      lowvideo;
      Input('A',                        {alphabetical}
            sTitle,                     {the current title}
            25,10,                       {screen position}
            25,                         {length accepted}
            false,                      {Caps returned?}
            F1,                         {true if F1 was pressed}
            F10);                       { "    " F10 "     "   }
      sTitle:= Answer
   end;

   procedure oil_prop;
    begin
     clrscr;lowvideo;
      pstring;
      highvideo;center('Fresh oil properties',0,5,80);lowvideo;
```

```
     dis_msg('O');
     input_handler('D0110',escape);
     input_handler('C0110',escape);
   end; {oilprop}
  (*
  procedure disp_info;
   begin
    clrscr;lowvideo;
     pstring;
     highvideo;center('Dispersant application information',0,5,80);
     lowvideo;
     dis_msg('D');
     input_handler('D1517',escape);
     input_handler('C1517',escape);
   end; {disp_info}
  *)
  {*}
  procedure Lead_info;
   begin
    clrscr;lowvideo;
     pstring;
     highvideo;center('Leads spill conditions',0,5,80);
     lowvideo;
     dis_msg('L');
     input_handler('D1218',escape);
     input_handler('C1218',escape);
   end; {disp_info}
  {*}

  procedure Spill_cond;
   begin
    clrscr;lowvideo;
     pstring;
     highvideo;center('Spill conditions',0,5,80);lowvideo;
     dis_msg('S');
     input_handler('D1923',escape);
     input_handler('C1923',escape);
   end; {env_cond}

  procedure Constant;
   begin
    clrscr;lowvideo;
     pstring;
     highvideo;center('Values of constants',0,5,80);lowvideo;
     dis_msg('C');
     input_handler('D2838',escape);
     input_handler('C2838',escape);
   end; {constant}

  procedure get_var;
   begin
    p[1]:='Title      .Set the title for this run';
    p[2]:='Oil_prop   .Define initial oil properties';
{*} p[3]:='Lead_info  .Define lead parameters';
    (*
```

```
     p[3]:='Disp_info  .Input dispersant application information';
     *)
     p[4]:='S&E_cond   .Define spill and environmental conditions';
     p[5]:='Constant   .Set values of constants';
     p[6]:='Quit       .Save present parameters and exit to main menu';
   end;

 begin        {initcond}
  clrscr;lowvideo;readinitfile;
   repeat
    prompt('Use arrow keys and <RETURN>','Or first letter of key word');
    get_var; hmenu(1,2,'Input Routine',ch);

    case ch of
     'T':Title;
     'O':oil_prop;
   (*  'D':disp_info;
   *)
     'L':Lead_info;
     'S':Spill_cond;
     'C':constant;
     'Q': begin
            writeinitfile;
            exit:=true;
          end;
    end; {case}
   until exit=true;
  exit:=false;
 end; {initcond}

function power(mantissa,exponent:real):real;
 begin
   power:=exp(ln(mantissa)*exponent);
 end;

procedure SEZ(var Target:String16);          {StripExtraZero to deal with
                                               Borland's stupidity}
                                              {Ammended - my stupidity:
                                              Turbo-87 uses 3 digits of exp
                                              in reals - Turbo uses 2}
var
   i:integer;

begin
   i:= 1;
   while not (Target[i] in ['E','e']) do
      i:= i + 1;
   if Target[i+1] in ['+','-'] then begin
      if Target[i+2] = '0' then
         delete (Target,i+2,1)  end
   else
      if Target[i+1] = '0' then
         delete(Target,i+1,1)
end;
```

```
procedure evap(var dftk,          {differential fraction evaporated thick slick}
                   dftn,          {    "            "         "      thin    "  }
                   fevtk,         {fraction evaporated thick slick}
                   fevtn,         {   "          "      thin    "  }
                   ththk:real;    {theta (evaporative exposure) thick slick}
                   zthick,        {thickness of thick slick}
                   winds,         {wind speed}
                   zthin,         {thickness of thin slick}
                   astma,
                   astmt,
                   airt:real);    {air temperature}
  var
     dttk,
     dttn,
     rk:real;

  begin
    if zthick < 1e-04 then
       zthick:= 1e-04;
    rk:=0.0015*power(winds,0.78);
    dttk:=rk*tstep/zthick;
    ththk:=ththk+dttk;
    dttn:=rk*tstep/zthin;
    dftk:=dttk*exp((6.3-(10.3/airt*(astmt+astma*fevtk))));
    dftn:=dttn*exp((6.3-(10.3/airt*(astmt+astma*fevtn))));
    fevtk:=fevtk+dftk;
    fevtn:=fevtn+dftn;
  end;

  procedure spread(var athick,      {thick area}
                       athin:real;  {thin area}
                       sigma,       {0.07 - oil/water interfacial tension-oil/air
                                                  interfacial tension}

                       zthick,      {thick thickness}
                       oilpp,       {pour point}
                       watert,      {water temperature}
                       sfact:real); {spreading factor}


   var
      dthin,
      dthick:real;

   begin
     if not thinspread then dthin:=0.0
     else dthin:=sfact*power(athin,0.33)*exp(-0.003/zthick)*tstep;
     if not thickspread then dthick:=0.0
     else dthick:=150*power(zthick,1.33)*power(athick,0.33)*tstep-(1.0E-6*dthin/z
  hick);
     athick:=athick+dthick;
     athin:=athin+dthin;
   end;

   procedure dispers(var fdtk,          {fraction of thick dispersed}
                         fdtn:real;     {    "     "   thin     "     }
                         winds,         {wind speed}
```

```
                      emuld,         {emulsion density}
                      oild,          {oil density}
                      owint,         {oil/water interfacial tension}
                      emulv,         {emulsion viscosity}
                      zthick,        {thick thickness}
                      zthin,         {thin thickness}
                      tnoilv,        {thin oil viscosity}
                      dispFact:real);{dispersion factor from wave height}

 const
  C1=2.4E+3;
  C2=1.0E-3;
  C3=1.16E-6;
  C4=1025;
 var
     shut,
     drho1,
     drho2,
     wss,
     dum:real;

 begin
   drho1:=c4-emuld;
   drho2:=c4-oild;
   wss:=winds/8.0;
   dum:=sqr(wss)*c1*c2*c3/(owint*emulv*drho1);
   if tnoilv>emulv then shut:=tnoilv*drho2/drho1
    else shut:=emulv;
   fdtk:=dispFact*dum/zthick*tstep;
   fdtn:=dispFact*dum/zthin*tstep*(emulv/shut);
 end;

procedure emulsion(var zthick,       {thick thickness}
                       emulv,        {emulsion viscosity}
                       emuld,        {emulsion density}
                       ww:real;      {water content}
                       winds,        {wind speed}
                       oild,         {oil density}
                       oilv,         {oil viscosity}
                       ttk,          {theta (evaporative exposure) thick slick}
                       ttke:real);   {theta thick emulsion}

 var
     dww:real;                       {delta water content}

 begin
   if ttk<ttke then
    begin
      emulv:=oilv;
      emuld:=oild;
    end
   else
    begin
      dww:=2.0E-6*sqr(winds+1.0)*(1-1.33*ww)*tstep;
      ww:=ww+dww;
```

```
    end;
    emulv:=oilv*exp(2.5*ww/(1.0-0.65*ww));
    emuld:=oild*(1.0-ww)+1025*ww;
    zthick:=zthick/(1.0-ww);
   end;

procedure fatemodel;


 var
{*}IceOil:IceProp;
   thick,
   thin,
   totslick:physprop;

   oil,
   init,
   emul,
   thnoil:chemprop;


{*}WindChill,
{*}cWid,                      {corrected width}
{*}sLen,                      {slick length}
{*}prIce,                     {production rate of ice}
{*}hWave,                     {wave height in lead}
{*}hWaveFDS,                  {Fully developed sea wave height}
{*}dispFact,                  {dispersion factor}
{*}lWave,
   SpillDur,
   WindSp,
   AirT,
   WaterT,
   Astma,
   Astmt,
   tcount,                    {time count}
   DataFreq,                  {seconds between Graphic records}
   dfevtn,                    {differential fraction evaporated thin}
   dfevtk,                    {     "           "        "      thick}
   vtotn,                     {volume thick to thin in one pass}
   estop,                     {?}
   water_content,             {yup}
   ttke,                      {theta thick emulsion}
   zthick,                    {emulsion thickness}
   ttk,                       {theta thick slick}
   sigma,                     {thin slick spreading constant}
   dvol,                      {differential volume}
   owint,                     {oil/water interfacial tension}
   oaint,                     {oil/air interfacial tension}
   oilpp:real;                {oil pour point}
   sfact,                     {spreading factor}
   RecCount,                  {count the records being saved to file}
   OutC,                      {number of passes between outputs of data}
   PointNum,                  {number of records output for graphing}
   passcount:integer;
```

```
    end;
    emulv:=oilv*exp(2.5*ww/(1.0-0.65*ww));
    emuld:=oild*(1.0-ww)+1025*ww;
    zthick:=zthick/(1.0-ww);
   end;

procedure fatemodel;


 var
{*}IceOil:IceProp;
   thick,
   thin,
   totslick:physprop;

   oil,
   init,
   emul,
   thnoil:chemprop;


{*}WindChill,
{*}cWid,                     {corrected width}
{*}sLen,                     {slick length}
{*}prIce,                    {production rate of ice}
{*}hWave,                    {wave height in lead}
{*}hWaveFDS,                 {Fully developed sea wave height}
{*}dispFact,                 {dispersion factor}
{*}lWave,
   SpillDur,
   WindSp,
   AirT,
   WaterT,
   Astma,
   Astmt,
   tcount,                   {time count}
   DataFreq,                 {seconds between Graphic records}
   dfevtn,                   {differential fraction evaporated thin}
   dfevtk,                   {    "            "         "     thick}
   vtotn,                    {volume thick to thin in one pass}
   estop,                    {?}
   water_content,            {yup}
   ttke,                     {theta thick emulsion}
   zthick,                   {emulsion thickness}
   ttk,                      {theta thick slick}
   sigma,                    {thin slick spreading constant}
   dvol,                     {differential volume}
   owint,                    {oil/water interfacial tension}
   oaint,                    {oil/air interfacial tension}
   oilpp:real;               {oil pour point}
   sfact,                    {spreading factor}
   RecCount,                 {count the records being saved to file}
   OutC,                     {number of passes between outputs of data}
   PointNum,                 {number of records output for graphing}
   passcount:integer;
```

```
   Tcheck,                        {one-time windherding flag}
   HeatWave,                      {no windchill so no ice in leads}
   IceHit,                        {slick has hit the ice}
   GraphFlag,                     {saving data to file?}
   DoubleRun,                     {making a calibration run?}
   ScreenData,                    {doing screen writes?}
   PrintData,                     {doing printer output?}
   FirstRun,                      {etc}
   Done:Boolean;

procedure OilProp;
{calculate new oil properties}

begin
   {density}
      oil.density:=init.density+r[28]*thick.fevap-r[29]*(WaterT-r[3]);
   {viscosity}
      oil.viscosity:=init.viscosity*exp(r[30]*thick.fevap)*
                    exp(r[31]*(1/WaterT-1/r[5]));
      thnoil.viscosity:=init.viscosity*exp(r[30]*0.5)*
                       exp(r[31]*(1/WaterT-1/r[5]));
   {pour point}
      oilpp:=r[6]*(1+r[32]*thick.fevap);
      if oilpp >= WaterT then thickspread:= false;
   {interfacial tension}
{*}   { if sfact=2 then owint:=r[16]               r[16] is from dispersant info
        else}
      owint:=r[9]*(1+r[35]*thick.fevap);
      oaint:=r[10]*(1+r[36]*thick.fevap);
      sigma:=0.07-oaint-owint;
      if sigma <= 0.0 then thinspread:= false
end;
procedure SlickChar;
{calculate new slick characteristics}
var
   vlost:real;

begin
   {evaporation}
      if thick.fevap>0.3 then estoq:=0.3 else estop:=thick.fevap;
      thin.vevap:=dfevtn*thin.volume+vtotn*(0.3-estop);
      with thin do
       begin
         vdis:=fdis*volume;
         vlost:=vevap+vdis;
         if vlost>volume then
          begin
            vdis:=vdis*(volume/vlost);
            vevap:=vevap*(volume/vlost);
          end:
       end:
      thick.vevap:=dfevtk*thick.volume;
 {*}  with IceOil do begin
         vevap:=dfevtk*sumvol_on;
         sumvevap:= sumvevap + vevap
```

```
      end;
{*}   totslick.vevap:=thin.vevap+thick.vevap + IceOil.vevap;
{note that IceOil.vevap isn't summed in isolation - sumvevap awaits}
      with thick do sumvevap:=sumvevap+vevap;
      with thin do sumvevap:=sumvevap+vevap;
      with totslick do sumvevap:=sumvevap+vevap;
   {dispersion}
      thick.vdis:=thick.fdis*thick.volume;
      thin.vdis:=thin.fdis*thin.volume;
      totslick.vdis:= thin.vdis+thick.vdis;
      with thick do sumvdis:=sumvdis+vdis;
      with thin do sumvdis:=sumvdis+vdis;
      with totslick do sumvdis:=sumvdis+vdis;
   {volume}
      vtotn:=thin.area*thin.thickness-thin.volume;
{*}   with thick do volume:=volume-vevap-vdis-vtotn-IceOil.vol_in-IceOil.vol_on
      if thick.volume <= 0.0 then begin
         thick.volume:=0.0;
         thick.area:=0.0
      end;
      with thin do volume:=volume+vtotn-vlost;
{*}   with IceOil do sumvol_on:= sumvol_on-vevap;
      with thick do begin
         zthick:= thickness;      {used for output of emulsion thickness only}
                                  {Thick.thickness is being used through part
                                 of the loop as storage of emulsion thickness}
{*}      thickness:= volume/(sLen*cWid);
         if thickness <= 0.0 then
            thickness:= 0.0
      end;   {with}
{&}   totslick.area:=thick.area+thin.area+IceOil.area;
{&}   totslick.volume:=thin.volume+thick.volume+IceOil.sumvol_on
end;

procedure dataout;

  begin
   clrscr;
    writeln('time',tcount/3600:3:0);
    writeln('       area     thickness   volume     evap       dispersed');
    with thick do
     writeln('thick ',area:7:0,'    ',thickness:7:7,'    ',volume:6:3,
              '    ',sumvevap:6:3,'      ',sumvdis:6:3);
    with thin do
     writeln('thin ',area:8:0,'    ',thickness:7:7,'    ',volume:6:3,
              '    ',sumvevap:6:3,'      ',sumvdis:6:3);
    with IceOil do begin
     writeln('OnIce ',area:7:0,'                   ',sumvol_on:6:3,'    ',sumvevap:
3);
     writeln('InIce                        ',sumvol_in:6:3);
    end;
    with totslick do begin
     writeln('total',area:8:0,'              ','      ',
              '    ',sumvevap:6:3,'      ',sumvdis:6:3,'      ');
     writeln('available for cleanup       ',volume:6:3);
```

```
    end;
    writeln;
    writeln('                density   viscosity  water content   thickness');
    writeln('oil              ',oil.density:5:0,'      ',oil.viscosity:6:0);
    writeln('emulsion      ',emul.density:5:0,'      ',emul.viscosity:6:0,
            '        ',water_content:5:4,'         ',zthick:7:7);
    writeln;
    writeln('theta',ttk:8:0);
    writeln('-------------------------------------------------------');
  end;

procedure dataoutP;

  begin
    writeln(lst,'time',tcount/3600:3:0);
    writeln(lst,'        area     thickness   volume     evap       dispersed');
    with thick do
     writeln(lst,'thick ',area:7:0,'    ',thickness:7:7,'    ',volume:6:3,
            '    ',sumvevap:6:3,'     ',sumvdis:6:3);
    with thin do
     writeln(lst,'thin ',area:8:0,'    ',thickness:7:7,'    ',volume:6:3,
            '    ',sumvevap:6:3,'     ',sumvdis:6:3);
    with IceOil do begin
     writeln(lst,'OnIce ',area:7:0,'                   ',sumvol_on:6:3,'    ',sumvev
p:6:3);
     writeln(lst,'InIce                              ',sumvol_in:6:3);
    end;
    with totslick do begin
     writeln(lst,'total',area:8:0,'                    ','       ',
            '    ',sumvevap:6:3,'     ',sumvdis:6:3,'      ');
     writeln(lst,'available for cleanup        ',volume:6:3);
    end;
    writeln(lst);
    writeln(Lst,'             density   viscosity  water content   thickness');
    writeln(Lst,'oil           ',oil.density:5:0,'      ',oil.viscosity:6:0);
    writeln(Lst,'emulsion    ',emul.density:5:0,'      ',emul.viscosity:6:0,
            '         ',water_content:5:4,'         ',zthick:7:7);
    writeln(lst);
    writeln(lst,'theta',ttk:8:0);
    writeln(lst,'-------------------------------------------------------');
    writeln(lst);
    writeln(lst);
    writeln(lst);
    writeln(lst);
   end;
function SaveData:Boolean;
 begin
   Clrscr;
   Center('Do you require the saving of model-run data ',1,8,80);
   Center('for graphic display? ',1,9,80);
   highvideo; Center('Answer (Y/N) ',1,11,80); lowvideo;
   repeat
     Option; if not (Ch in ['Y','N']) then beep(350,150);
   until Ch in ['Y','N'];
   SaveData:= (Ch in ['Y'])
```

```
 end;

function ScreenOut:Boolean;
 begin
   Center('Do you require screen output for data? ',1,11,80);
   highvideo; Center('Answer (Y/N) ',1,13,80); lowvideo;
   repeat
     Option; if not (Ch in ['Y','N']) then beep(350,150);
   until Ch in ['Y','N'];
   ScreenOut:= (Ch in ['Y'])
 end;

function PrintOut:Boolean;
 begin
   Center('Do you require printer output for data? ',1,14,80);
   highvideo; Center('Answer (Y/N) ',1,16,80); lowvideo;
   repeat
     Option; if not (Ch in ['Y','N']) then beep(350,150);
   until Ch in ['Y','N'];
   PrintOut:= (Ch in ['Y'])
 end;
procedure HowOften(var OutC:integer);

var
   Result,
   vCh:integer;

begin
   Center('How often should data be put to screen? ',1,16,80);
   highvideo; Center('Answer (Hours:1->9) ',1,18,80); lowvideo;
   repeat
     Option; if not (Ch in ['1'..'9']) then beep(350,150);
   until Ch in ['1'..'9'];
   val(Ch,vCh,Result);
   OutC:= vCh*3600 div tstep;
   OutC:=OutC                 {Get the debugger to stop here}
end;

procedure ResetGraphFile;

begin
     assign(Out_File,OutFileName);
   {  if Exist(OutFileName) then
        reset(Out_File)
     else
    }    rewrite(Out_File)
end;

procedure SaveGraphicData;

var
   vevap,
   vdisp,
   vice,
   vsurf,
```

```
   sthkness,
   ethkness,
   w_c,
   density,
   viscosity: string[16];

begin
   RecCount:= RecCount + 1;
     {turn the reals into strings}
        str(TotSlick.sumvevap:10,vevap);
        str(TotSlick.sumvdis:10,vdisp);
        str(IceOil.sumvol_in:10,vice);
        str(TotSlick.volume:10,vsurf);
        if thick.thickness > 2.4E-02 then
           thick.thickness:= 2.4E-02;
        str(thick.thickness:10,sthkness);
        if zthick > 2.4E-02 then
           zthick:= 2.4E-02;
        str(zthick:10,ethkness);
        str(water_content * 100:10,w_c);
        str(emul.density:10,density);
        str(emul.viscosity:10,viscosity);
     {and get rid of the extra digit in the exponent}
{don't use this if the receiving routine expects 3-digit exponentiation
   i.e. compiled by Turbo-87
}
        SEZ(vevap);
        SEZ(vdisp);
        SEZ(vice);
        SEZ(vsurf);
        SEZ(sthkness);
        SEZ(ethkness);
        SEZ(w_c);
        SEZ(density);
        SEZ(viscosity);

    writeln(Out_File,'Record #',RecCount:1);
    writeln(Out_File,vevap:16,vdisp:16,vice:16,vsurf:16);
    writeln(Out_File,sthkness:16,ethkness:16,w_c:16,density:16,viscosity:16)
end;

procedure SaveRunStats(DataFreq,
                       Vinit:real;
                       PointNum:integer;
                       sTitle:string25);

var
   sDataFreq,
   sVinit,
   sPointnum: string[16];

begin
   str(DataFreq:10,sDatafreq);
   str(Vinit:10,sVinit);
   str(Pointnum:10,sPointnum);
```

```
{  Eliminate one digit of exponentiation to make acceptable to
   the VAL routine when used in MAKEGRAF
   }
   SEZ(sDataFreq);
   SEZ(sVinit);
   SEZ(sPointnum);

   writeln(Out_File);
   writeln(Out_File,sTitle);
   writeln(Out_File,sDataFreq:16);
   writeln(Out_File,sVinit:16);
   writeln(Out_File,sPointnum:16)
end;

{Leads header}
const
   maxw_c = 0.76;   {maximum water content cutoff}

var
{*************** Leads  Inputs  ***************************}
   Len,             {length of lead parellel to wind}
   Wid,             {width of lead perpendicular to wind}
   iIce,            {initial ice cover as fraction
                                         of lead area}
   rSnow,           {snowfall rate - m/s?}
   rClose,          {lead closure rate ( '+' = close
                                         '-' = open)}
   dSpill:real;     {distance from center of spill to
                         downwind edge of lead  (m)
                                           <= Len    }
{***********************************************************}

procedure Oil_In_Leads;

var
   test,
   aOpenWater:real; {area of open water}

procedure Lead_Spread;

begin
   aOpenWater:= Len * Wid;                {Len has been adjusted for Ice cover
   with Thick do begin
      if area >= aOpenWater then            {area >= lead area}
         begin
            if Tcheck then begin
               thickness:= thickness + (0.00072 * WindSp);
               area:= volume/thickness;
               Tcheck:= false
            end;
            thickspread:= false;
            thinspread:= false;
            thin.area:=1.0;
{&}         thin.volume:=1.0e-06;
            test:= sLen;
```

```
        sLen:= Len;
        if sLen>= test then
           sLen:= test;
        cWid:= Wid
     end
  else begin                              {area < lead area}
     if sLen <= 0.0 then
        sLen:=0.0;
{&}  test:= sLen;
     sLen:= sqrt(area);
     if sLen > Wid then
        sLen:= area/Wid
     else
        cWid:= area/sLen;
{&}  if (sLen >= test) and (sLen >= 2*dSpill) then
{&}     sLen:= test;                                {sLen >= Len}
     if sLen >= Len then
        sLen:= Len;
     if (sLen >= Len) or (sLen >= 2*dSpill) then  begin  {Slick has hit ice
        if FirstRun and (not IceHit) then begin
           IceHit:= true;
           clrscr;
           gotoXY(10,14);
           writeln('The slick hit the ice after ',(100.0*passcount):6:0,
                      ' seconds');
           delay(500);
           writeln(lst,'The slick hit the ice after ',(100.0*passcount):6:0
                      ' seconds');
        end;

        if sLen = 0.0 then begin
           cWid:= Wid;
           sLen:=0.01
        end
        else
           cWid:= area/sLen;
        thin.area:= 1.0;
        thin.volume:=1.0e-06;
        thinspread:= false;
        if cWid >= Wid then begin
           if Tcheck then begin
              thickness:= thickness + 0.00072 * WindSp;
              area:= volume/thickness;
              Tcheck:= false
           end;
           thickspread:= false;
           cWid:= Wid
        end

     end      {sLen >= Len}
  end      {area < lead area}
end;      {with thick}
with thin do
   if area >= aOpenWater then
      area:= aOpenWater;
```

```
end;     {Lead_Spread}

procedure Oil_Ice_Approach;

var
   aDiff,
   ddSpill:real;          {change in distance from spill centre to ice}

begin
   aDiff:= aOpenWater - thick.area;
   if aDiff <= 0.0 then aDiff:= 0.0;
   ddSpill:= 5.0e-06 * tstep * ((prIce * aDiff/Wid)
            + (0.136 * (WaterT - AirT) * thick.area/cWid))/ WindSp;
   Len:= Len - ddSpill;
   if sLen < 2 * dSpill then
      dSpill:= dSpill - ddSpill - (0.03 * WindSp * tstep)
   else with IceOil do begin                        {slick has hit ice}
      dSpill:= dSpill - ddSpill;
{&}   sLen:= sLen - ddSpill;
{&}   if ddSpill >= sLen then
{&}      ddSpill:= sLen;
{&}   area:= area + cWid*ddSpill;
{&}   thick.area:=thick.area - ddSpill*cWid;
{&}   if thick.area <= 0.0 then thick.area:= 0.0;
{&}   vol_on:= ddSpill * cWid * thick.thickness;
      if hWave > 0.0 then
         vol_in:= (3.1e-04 * emul.density - 7.1e-05 * emul.viscosity) * vol_on
      else  begin
         vol_in:= (-0.2 + 3.1e-04 * emul.density - 7.1e-05 * emul.viscosity)
                       * vol_on;
         if vol_in <= 0.0 then
            vol_in:= 0.0;
         if vol_in >= vol_on then
            vol_in:= vol_on
      end;
      vol_on:= vol_on - vol_in;
      sumvol_in:= sumvol_in + vol_in;
      sumvol_on:= sumvol_on + vol_on
   end;
{Snow}
   water_content:= water_content + rSnow * tstep/10/thick.thickness;
   if water_content >= maxw_c then with IceOil do begin     {if snow-covered}
      water_content:= maxw_c;
      sumvol_in:= sumvol_in + sumvol_on;
      sumvol_on:= 0.0
   end;
end;

begin    {Oil_In_Leads}
   Lead_Spread;
   Oil_Ice_Approach
end;
{********************** end of Oil_In_Leads *******************************-

begin          {fatemodel}
```

```
OutC:= 36;                                       {give it a non-zero value in case the
                                                  user doesn't}
if SaveData then
   begin
      DoubleRun:= true;
      if ScreenOut then
            ScreenData:=true
      else
         begin
            ScreenData:= false;
            clrscr;
         end;
      if PrintOut then begin
         PrintData:=true;
         clrscr
      end
      else
         PrintData:= false;
      if ScreenData or PrintData then begin
         HowOften(OutC);
         clrscr
      end;
      if (not ScreenData) then begin
            textcolor(14+blink);
            Center('Doing calibration run with no screen output.',1,12,80);
            textcolor(14)
      end
   end
 else
   begin
      DoubleRun:= false;
      ScreenData:= true;
      PrintData:= true;
      HowOften(OutC)
   end;
 FirstRun:= true;
 GraphFlag:= false;
 Done:= false;
 ReadInitFile;
 repeat                                      {until Done = true}
    if (not FirstRun) and DoubleRun then
       begin
          PointNum:= 100;
          OutC:= trunc(tcount/PointNum/tstep);              {steps per output}
          DataFreq:= OutC*tstep;
          ScreenData:= false;
          PrintData:= false;
          GraphFlag:= true;
          clrscr;
          Center('Doing graphic data run - wait.......',1,12,80);
          ResetGraphFile;
          SaveRunStats(DataFreq,r[23],PointNum,sTitle);
          RecCount:= 0
       end;
```

```
   { initialize for oil fate model run }
      for i:=1 to 40 do val(filvar[i],r[i],code);
      ttke:=r[1];
      init.density:=r[2];
      init.viscosity:=r[4];
      water_content:=0.0;
      sfact:=1;ttk:=0.0;     {sfact passed to SPREAD as a real!}
      emul.density:=init.density;
      emul.viscosity:=init.viscosity;
      oil.density:=init.density;
      oil.viscosity:=init.viscosity;
      thnoil.viscosity:=init.viscosity;
      owint:=r[9];
      oaint:=r[10];
      sigma:=0.07-oaint-owint;
      SpillDur:= 100 * r[19];
      WindSp:= r[20];
      AirT:= r[21];
      WaterT:= r[22];
      Astma:= r[37];
      Astmt:= r[38];

      thinspread:= true;
      thickspread:= true;

   {initialize leads parameters}

{*}   Len:= r[12];
{*}   Wid:= r[13];
{*}   iIce:= r[14];
{*}   rSnow:= r[15];
      rSnow:= rSnow / 8640000.0;           {from m/s to cm/day}
{*}   rClose:= r[16];
{*}   dSpill:= r[17];
{%}   lWave:= r[18];

   { Initialize for First Pass }

      with thick do
        begin
          thickness:=0.02;
          fevap:=0.0;
          fdis:=0.0;
          vevap:=0.0;
          sumvevap:=0.0;
          vdis:=0.0;
          sumvdis:=0.0
        end;
      with thin do
        begin
          thickness:=0.000001;
          fevap:=0.3;
          fdis:=0.0;
          vdis:=0.0;
          sumvdis:=0.0;
```

```
        end;
      with totslick do
        begin
          fdis:=0.0;
          vevap:=0.0;
          sumvevap:=0.0;
          vdis:=0.0;
          sumvdis:=0.0;
        end;

      with IceOil do
        begin
          sumvevap:= 0.0;
          vevap:= 0.0;
          fevap:= 0.0;
          vol_in:= 0.0;
          vol_on:= 0.0;
          sumvol_in:= 0.0;
          sumvol_on:= 0.0;
          area:= 0.0
        end;

      dvol:=r[23]*(tstep/SpillDur);
      totslick.volume:=dvol;
      thick.area:=totslick.volume/(thick.thickness+8.0*thin.thickness);
      thin.area:=8.0*thick.area;
      totslick.area:=thin.area+thick.area;
      with thick do volume:=thickness*area;
      with thin do volume:=thickness*area;
      vtotn:=thin.volume;
      thin.vevap:=thin.volume*thin.fevap;
      thin.sumvevap:=thin.vevap;
      tcount:=tstep;
      passcount:=0;

{Initialize leads}

{*} cWid:= Wid;                   {corrected.width}
{*} Len:= Len * (1 - iIce);       {rough}
{*} sLen:=10000000000.0;                   {slick length}
    IceHit:= false;
    Tcheck:= false;

{Ice stuff}

{*}    HeatWave:= false;
{*}    WindChill:= WindSp * (WaterT - AirT);
{*}    if WindChill >= 200.0 then
{*}       prIce:= 3.0 + 0.0204 * WindChill       {kg/m*m*s}
{*}    else if (WindChill < 200.0) and (WindChill > 0) then
{*}       prIce:= 1.2 + 0.0312 * WindChill
{*}    else       {WindChill <= 0.0: i.e. it's a heat wave}
{*}       HeatWave:= true;
{*}    Tcheck:= true;
{*}
```

```
if not HeatWave then
{*}begin
   { Repeat until done }

      while (thick.volume > 0.0) and (thick.thickness>15e-6)
                     do
                                    {should be 0.0001*r[23] - testing only}
       begin
          if tcount< SpillDur then
            begin
              thick.volume:=thick.volume+dvol;
              thick.thickness:=thick.thickness+dvol/thick.area;
            end;
          tcount:=tcount+tstep;
          passcount:=passcount+1;
{*}       hWave:= 5.112e-04 * sqrt(Len) * WindSp;
{*}       hWaveFDS:= 2.482e-02 * sqr(WindSp);
{*}       dispFact:= hWave/hWaveFDS;
{*}       if hWave <= lWave then
             hWave:= 0.0;
          evap(dfevtk,dfevtn,thick.fevap,thin.fevap,ttk,thick.thickness,
             WindSp,thin.thickness,Astma,Astmt,AirT);
          spread(thick.area,thin.area,sigma,thick.thickness,r[6],WaterT,
             sfact);
          emulsion(thick.thickness,emul.viscosity,emul.density,
             water_content,WindSp,oil.density,oil.viscosity,ttk,ttke);
          dispers(thick.fdis,thin.fdis,WindSp,emul.density,oil.density,owint,
             emul.viscosity,thick.thickness,thin.thickness,thnoil.viscosity,
{*}          dispFact);
{*}       Oil_In_Leads;
          OilProp;

SlickChar;

          if (passcount mod outc) = 0 then begin
             if ScreenData then
                dataout;
             if PrintData then begin
                if passcount = outc then    {Print the title on the first line}
                   CentrePrint(sTitle);
                dataoutP
             end;
             if GraphFlag then
                SaveGraphicData
          end;
          if (thick.volume <= 0.0) and (not GraphFlag) then begin
             writeln('Oil is entirely on or in ice.');
             writeln;
             writeln(lst,'Oil is entirely on or in ice.');
             writeln(lst)
          end
     end           {while}
end;       {not HeatWave}

   {finish output}
```

```
      if PrintData then begin
         dataoutP;
{*}      if HeatWave then
{*}         writeln(lst,'No windchill - fix the temperatures, dummy!')
{*}      else
            writeln(lst,'Passes = ',Passcount:0,'  Time (sec) = ',tcount:0:0);
      end;
      if ScreenData then begin
         dataout;
         gotoXY(1,23);
{*}      if HeatWave then
{*}         writeln('No windchill - fix the temperatures, dummy!')
{*}      else
            writeln('Passes = ',Passcount:0,'  Time (sec) = ',tcount:0:0);
         writeln('Hit any key to continue with data generation for graphing.');
         repeat until Keypressed
      end;
      if GraphFlag and not HeatWave then begin
         SaveGraphicData;
         close(Out_File)
      end;
{*}   if (not FirstRun) or (not DoubleRun) or (HeatWave) then
         Done:= true;
      FirstRun:= false
   until Done;
   writeln('model complete',passcount)
end;


{****************** Procedures for using external programs ****************}

procedure NameError(i:integer);

begin
   write('Error - ',i,' :');
   case i of
      1: writeln('Invalid function');
      2: writeln('File/Path not found');
      8: writeln('Not enough memory to load program');
     10: writeln('Bad environment (greater than 32k)');
     11: writeln('Illegal .EXE file format')
   end
end;

{ EXEC.PAS version 1.3

  This file contains 2 functions for Turbo Pascal that allow you to run other
  programs from within a Turbo program.  The first function, SubProcess,
  actually calls up a different program using MS-DOS call 4BH, EXEC.  The
  second function, GetComSpec, returns the path name of the command
  interpreter, which is necessary to do certain operations.  There is also a
  main program that allows you to test the functions.

  Revision history
```

```
  ----------------
  Version 1.3 works with MS-DOS 2.0 and up, TURBO PASCAL version 1.0 and up.
  Version 1.2 had a subtle but dangerous bug: I set a variable that was
              addressed relative to BP, using a destroyed BP!
  Version 1.1 didn't work with Turbo 2.0 because I used Turbo 3.0 features
  Version 1.0 only worked with DOS 3.0 due to a subtle bug in DOS 2.x

    -  Bela Lubkin
       Borland International Technical Support
       CompuServe 71016,1573
}

Type
  Str66=String[66];

Function SubProcess(CommandLine: Str255): Integer;
  { Pass this function a string of the form
      'D:\FULL\PATH\NAME\OF\FILE.TYP parameter1 parameter2 ...'

    For example,
      'C:\SYSTEM\CHKDSK.COM'
      'A:\WS.COM DOCUMENT.1'
      'C:\DOS\LINK.EXE TEST;'
      'C:\COMMAND.COM /C COPY *.* B:\BACKUP >FILESCOP.IED'

    The third example shows several things.  To do any of the following, you
    must invoke the command processor and let it do the work: redirection;
    piping; path searching; searching for the extension of a program (.COM,
    .EXE, or .BAT); batch files; and internal DOS commands.  The name of the
    command processor file is stored in the DOS environment.  The function
    GetComSpec in this file returns the path name of the command processor.
    Also note that you must use the /C parameter or COMMAND will not work
    correctly.  You can also call COMMAND with no parameters.  This will allow
    the user to use the DOS prompt to run anything (as long as there is enough
    memory).  To get back to your program, he can type the command EXIT.

    Actual example:
      I:=SubProcess(GetComSpec+' /C COPY *.* B:\BACKUP >FILESCOP.IED');

    The value returned is the result returned by DOS after the EXEC call.  The
    most common values are:

       0: Success
       1: Invalid function (should never happen with this routine)
       2: File/path not found
       8: Not enough memory to load program
      10: Bad environment (greater than 32K)
      11: Illegal .EXE file format

    If you get any other result, consult an MS-DOS Technical Reference manual.

    VERY IMPORTANT NOTE: you MUST use the Options menu of Turbo Pascal to
    restrict the amount of free dynamic memory used by your program.  Only the
    memory that is not used by the heap is available for use by other
    programs. }
```

```
Const
  SSSave: Integer=0;
  SPSave: Integer=0;

Var
  Regs: Record Case Integer Of
          1: (AX,BX,CX,DX,BP,SI,DI,DS,ES,Flags: Integer);
          2: (AL,AH,BL,BH,CL,CH,DL,DH: Byte);
        End;
  FCB1,FCB2: Array [0..36] Of Byte;
  PathName: Str66;
  CommandTail: Str255;
  ParmTable: Record
               EnvSeg: Integer;
               ComLin: ^Integer;
               FCB1Pr: ^Integer;
               FCB2Pr: ^Integer;
             End;
  I,RegsFlags: Integer;

Begin
  If Pos(' ',CommandLine)=0 Then
   Begin
    PathName:=CommandLine+#0;
    CommandTail:=^M;
   End
  Else
   Begin
    PathName:=Copy(CommandLine,1,Pos(' ',CommandLine)-1)+#0;
    CommandTail:=Copy(CommandLine,Pos(' ',CommandLine),255)+^M;
   End;
  CommandTail[0]:=Pred(CommandTail[0]);
  With Regs Do
   Begin
    FillChar(FCB1,Sizeof(FCB1),0);
    AX:=$2901;
    DS:=Seg(CommandTail[1]);
    SI:=Ofs(CommandTail[1]);
    ES:=Seg(FCB1);
    DI:=Ofs(FCB1);
    MsDos(Regs); { Create FCB 1 }
    FillChar(FCB2,Sizeof(FCB2),0);
    AX:=$2901;
    ES:=Seg(FCB2);
    DI:=Ofs(FCB2);
    MsDos(Regs); { Create FCB 2 }
    ES:=CSeg;
    BX:=SSeg-CSeg+MemW[CSeg:MemW[CSeg:$0101]+$112];
    AH:=$4A;
    MsDos(Regs); { Deallocate unused memory }
    With ParmTable Do
     Begin
      EnvSeg:=MemW[CSeg:$002C];
      ComLin:=Addr(CommandTail);
```

```
        FCB1Pr:=Addr(FCB1);
        FCB2Pr:=Addr(FCB2);
       End;
      InLine($8D/$96/ PathName /$42/  { <DX>:=Ofs(PathName[1]); }
             $8D/$9E/ ParmTable /     { <BX>:=Ofs(ParmTable);   }
             $B8/$00/$4B/             { <AX>:=$4B00;            }
             $1E/$55/                 { Save <DS>, <BP>         }
             $16/$1F/                 { <DS>:=Seg(PathName[1]); }
             $16/$07/                 { <ES>:=Seg(ParmTable);   }
             $2E/$8C/$16/ SSSave /    { Save <SS> in SSSave     }
             $2E/$89/$26/ SPSave /    { Save <SP> in SPSave     }
             $FA/                     { Disable interrupts      }
             $CD/$21/                 { Call MS-DOS             }
             $FA/                     { Disable interrupts      }
             $2E/$8B/$26/ SPSave /    { Restore <SP>            }
             $2E/$8E/$16/ SSSave /    { Restore <SS>            }
             $FB/                     { Enable interrupts       }
             $5D/$1F/                 { Restore <BP>,<DS>       }
             $9C/$8F/$86/ RegsFlags / { Flags:=<CPU flags>      }
             $89/$86/ Regs );         { Regs.AX:=<AX>;          }
      { The messing around with SS and SP is necessary because under DOS 2.x,
        after returning from an EXEC call, ALL registers are destroyed except
        CS and IP!  I wish I'd known that before I released this package the
        first time... }
      If (RegsFlags And 1)<>0 Then SubProcess:=AX
      Else SubProcess:=0;
     End;
  End;

Function GetComSpec: Str66;
  Type
    Env=Array [0..32767] Of Char;
  Var
    EPtr: ^Env;
    EStr: Str255;
    Done: Boolean;
    I: Integer;

  Begin
    EPtr:=Ptr(MemW[CSeg:$002C],0);
    I:=0;
    Done:=False;
    EStr:='';
    Repeat
      If EPtr^[I]=#0 Then
       Begin
        If EPtr^[I+1]=#0 Then Done:=True;
        If Copy(EStr,1,8)='COMSPEC=' Then
         Begin
          GetComSpec:=Copy(EStr,9,100);
          Done:=True;
         End;
        EStr:='';
       End
      Else EStr:=EStr+EPtr^[I];
```

```
      I:=I+1;
    Until Done;
  End;

procedure UseDos;

Var Command: Str255;
    I: Integer;

Begin
  ClrScr;
  WriteLn('Enter a * to quit.');
  Repeat
    Write('-=-=->');
    ReadLn(Command);
    If Command<>'*' Then
       If Command<>'' Then
        Begin
         Command:=GetComSpec+' /C '+Command;
         I:=SubProcess(Command);
         If I<>0 Then NameError(I)
        End;
  Until Command = '*'
End;

procedure RunGraph;

{Simply call MakeGraf.com using Bela Lubkin's routine: SubProcess}

var
   Command:Str255;
   I:integer;

begin
    ClrScr;
    Command:= GetComSpec+' /c MakeGraf';
    I:= SubProcess(Command);
    if I<>0 then
       begin
          NameError(I);
          writeln('Press a key to continue');
          repeat until KeyPressed
       end
end;                   {** end of exec rutines **}
{*************************************************************************}

procedure ListInputs;

var
   s1,s2,s3,s4,s5,s6,s7,s8,s9,s10,s11,s12,s13,s14,s15,s16,s17,s18,s19,s20,
   s21,s22,s23,s24,s25,s26,s27,s28,s29,s30,
   s31,s32,s33,s34,s35,s36,s37,s38,s39,s40:real;
   i:integer;

begin
```

```
readinitfile;
for i:=1 to 40 do val(filvar[i],r[i],code);
s1:= r[1];
s2:= r[2];
s3:= r[3];
s4:= r[4];
s5:= r[5];
s6:= r[6];
s7:= r[7];
s8:= r[8];
s9:= r[9];
s10:= r[10];
s11:= r[11];
s12:= r[12];
s13:= r[13];
s14:= r[14];
s15:= r[15];
s16:= r[16];
s17:= r[17];
s18:= r[18];
s19:= r[19];
s20:= r[20];
s21:= r[21];
s22:= r[22];
s23:= r[23];
s24:= r[24];
s25:= r[25];
s26:= r[26];
s27:= r[27];
s28:= r[28];
s29:= r[29];
s30:= r[30];
s31:= r[31];
s32:= r[32];
s33:= r[33];
s34:= r[34];
s35:= r[35];
s36:= r[36];
s37:= r[37];
s38:= r[38];
s39:= r[39];
CentrePrint(sTitle);
writeln(lst);
writeln(lst);
writeln(lst,'Fresh oil properties');
writeln(lst);
writeln(lst,'   Emulsification delay (theta)           ',s1:8:1);
writeln(lst,'   Density (kg/m3)                        ',s2:8:2);
writeln(lst,'   Standard density temperature (K)       ',s3:8:2);
writeln(lst,'   Viscosity (mPas)                       ',s4:8:2);
writeln(lst,'   Standard viscosity temperature (K)     ',s5:8:2);
writeln(lst,'   Pour point (K)                         ',s6:8:2);
writeln(lst,'   Aqueous solubility (g/m3)              ',s7:8:2);
writeln(lst,'   Flash point (K)                        ',s8:8:2);
writeln(lst,'   Oil-water interfacial tension (N/m)    ',s9:8:2);
```

```
   writeln(lst,'   Oil-air interfacial tension (N/m)        ',s10:9:3);
   writeln(lst);
   writeln(lst,'Leads spill conditions');
   writeln(lst);
   writeln(lst,'   Length of lead parallel to wind (m)      ',s12:8:2);
   writeln(lst,'   Width of lead perpendicular to wind (m)',s13:8:2);
   writeln(lst,'   Fraction of lead initially iced          ',s14:8:2);
   writeln(lst,'   Snowfall rate (cm/day)                   ',s15:9:3);
   writeln(lst,'   Lead closure rate (m/s)                  ',s16:8:2);
   writeln(lst,'   Starting distance: spill to ice (m)      ',s17:8:2);
   writeln(lst);
(*   unused in Leads model
   writeln(lst,'   Dispersant application time (sec)',s:8:2);        {15}
   writeln(lst,'   Reduced O-W interfacial tension (N/m)',s:8:2);    {16}
   writeln(lst,'   Dispersant effective time (sec)',s:8:2);          {17}
                         {Should be approx 0.125 (hr)}
*)
   writeln(lst,'Spill conditions');
   writeln(lst);
   writeln(lst,'   Duration of spill (100sec)                ',s19:8:2);
   writeln(lst,'   Windspeed (m/s)                           ',s20:8:2);
   writeln(lst,'   Air temperature (K)                       ',s21:8:2);
   writeln(lst,'   Water temperature (K)                     ',s22:8:2);
   writeln(lst,'   Volume of oil spilled (m3)                ',s23:8:2);
   writeln(lst);
   writeln(lst,'Constants');
   writeln(lst);
   writeln(lst,'   Density constant 1                        ',s28:13:7);
   writeln(lst,'   Density constant 2                        ',s29:13:7);
   writeln(lst,'   Viscosity constant 1                      ',s30:13:7);
   writeln(lst,'   Viscosity constant 2                      ',s31:8:2);
   writeln(lst,'   Pour point constant                       ',s32:13:7);
   writeln(lst,'   Solubility constant                       ',s33:13:7);
   writeln(lst,'   Flash point constant                      ',s34:13:7);
   writeln(lst,'   Oil-water int. tension constant           ',s35:13:7);
   writeln(lst,'   Oil-Air int. tension constant             ',s36:13:7);
   writeln(lst,'   ASTMA constant                            ',s37:8:2);
   writeln(lst,'   ASTMT constant                            ',s38:8:2);
   writeln(lst);
end;


procedure ProgramExit;
 begin
   Clrscr; Center('This Program is about to end',1,11,80);
   highvideo; Center('Verify Ok (Y/N)',1,13,80); lowvideo;
   repeat
     Option; if not (Ch in ['Y','N']) then beep(350,150);
   until Ch in ['Y','N'];
 end;

procedure MainMenu;
 var I,Tab: integer;
     Okchoices: set of char;
  begin
```

```
   if First_run then
    begin
     clrscr;highvideo;
     center('Oil In Ice Leads Model',0,6,80);
     center('developed for Environment Canada,',0,11,80);
     center('Environmental Emergencies Technology Division',0,12,80);
     center('by S.L.Ross Environmental Research Ltd.',0,13,80);
     center('(C) 1987, S.L.Ross Environmental Research Ltd.',0,24,80);
     box(14,4,65,16,8);
     writeln('');
{     repeat until keypressed;}
     delay(5000);
     ClrScr; HighVideo;
     center('S. L. ROSS ENVIRONMENTAL RESEARCH',0,4,80);
     center('LEADFATE MODEL',0,5,80);
     for I:= 1 to 4 do  writeln('');
     Tab:= 25;
     writeln('':Tab,'<1> Define initial conditions ');
     writeln('':Tab,'<2> Run oilfate model ');
     writeln('':Tab,'<3> List the current inputs');
     writeln('':Tab,'             to the model ');
     writeln('':Tab,'<4> Graph the results ');
     writeln('':Tab,'<5> Future option ');
     writeln('':Tab,'<6> Use DOS commands '); writeln('');
     writeln('':Tab,'<7> Exit the Program');
     Box(20,2,60,20,6);writeln('');
     SaveScreen; First_run:=false;
    end else FlashScreen;
    Set_Cap_num(' ','N',' '); Say_Cap_Num;
    Highvideo; Center('Press Your Selection',21,19,38); LowVideo;
    OKchoices:=['1'..'7'];
    repeat
      Option; if not (Ch in OKchoices) then Beep(350,150);
    until Ch in OKchoices;
    case Ch of
      '1' : initcond;
      '2' : fatemodel;
      '3' : ListInputs;
      '4' : RunGraph;
      '5' :  ;
      '6' : UseDOS;
      '7' :  begin
               ProgramExit;
               if Ch='Y' then Exit := true;
             end;
    end; { case }
  end;

{************************************************************}
{*              Program Starts Execution                   *}
{************************************************************}

begin
  ClrScr; Exit:=false; First_run:=true;
  repeat
```

```
    MainMenu;
  until Exit = true;
  ClrScr
end.
```