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A STUDY OF THE BEHAVIOR
OF
OIL SPILLS IN THE ARCTIC

BY

LTJG JOHN L. GLAESER, USCGR
AND
LCDR GEORGE P. VANCE, USCG

FEBRUARY 1971
FINAL REPORT

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APPLIED TECHNOLOGY DIVISION
FINAL REPORT
A STUDY OF THE BEHAVIOR
OF
OIL SPILLS IN THE ARCTIC

BY

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ABSTRACT

A program to investigate the behavior of oil spills in the Arctic was conducted off the northern coast of Alaska in July 1970. Numerous small oil spills were made to obtain data on the following subjects: the spreading behavior of crude oil on ice and water surfaces; the interaction characteristics of crude oil with ice; the aging characteristics of crude oil which has been spilled on ice, on water, and under ice; and the effectiveness of burning and absorption as methods of removal.

Both Prudhoe Bay ("Sag" River) crude oil and diesel fuel were used in the test program. Results quantify spreading and interaction characteristics in addition to presenting qualitative information on each area of interest. Promise is shown for both burning and absorption as methods of oil removal in the summer. Data is presented on both the physical and chemical characteristics of aged crude oil.

LIST OF SYMBOLS

- g = gravitational constant
 h = average slick thickness
 l = slick length
 L = characteristic length
 s = specific gravity
 t = time
 V = oil volume
 w = channel width
 δ = boundary layer thickness
 Δ = percentage density difference
 μ = absolute viscosity of water
 ν = kinematic viscosity of water
 ρ = mass density
 σ = surface tension

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INTRODUCTION

A renewed interest in oil production in the Arctic regions has prompted several major oil companies to study methods for transporting oil to commercial centers. The development of these systems will present the possibility of spillage, either on a large or a small scale, with a resulting damage to the environment.

Responding to the future problem of having to deal with such potential oil spills, the U.S. Coast Guard has initiated a long range research effort to study the nature of oil pollution in the Arctic. The end result of the program will be methods for preventing and controlling future accidents.

One of the first steps in the research effort was to carry out the project presented in this report. Designated the Arctic Oil Spill Test Program, the purpose was to determine the most basic nature of spilled crude oil in an arctic environment and to develop an understanding of the problems which must be dealt with.

The general areas of investigation were:

1. The behavior and spreading rates of Prudhoe Bay crude oil when spilled on water and ice.
2. The interaction of spilled crude oil with ice over a period of time.
3. The physical and chemical changes which occur in the crude as a result of aging.
4. The effectiveness of burning as a method of oil removal.
5. The effectiveness of natural absorbants when used on a crude oil spill.

The experiments contained in this report were performed in July 1970 in the Chukchi Sea. Throughout the test program the U.S. Coast Guard Cutter STATEN ISLAND served as the support base. During the greater portion of the test period, the STATEN ISLAND was moored to an ice floe, which moved from 70-52 N, 160-38 W (approximately 90 miles SW of Point Barrow) on 23 July, to 71-18 N, 159-40W (15 miles NW of Point Barrow) on 30 July.

The floe chosen was typical of those in the general area at that time of year. It was of multi-year ice, approximately 15 feet thick, with many melt ponds, of which some were open to the sea through their bottom. Weather conditions were generally fair and sunny, with temperatures during the test period ranging from 31°F to 52°F.

This report is broken down into seven general areas. Sections 1, 2, and 3 discuss respectively the spreading experiments conducted on ice, on water, and under ice. The use of burning and absorption as methods of removal are presented in sections 4 and 5, and a study of the effect of oil spills on the heat budget is given in section 6. Section 7 presents the physical and chemical changes in crude oil as it is aged. Finally, conclusions and recommendations are made in section 8.

SECTION I SPREADING OF OIL ON ICE

The purpose for conducting the spreading experiments on ice was to obtain qualitative information on the spreading process in an arctic environment and to obtain quantitative data which could be used to scale the experimental spreading rates to large size spills. To accomplish this, two tanks like the one shown in Figure (1) were constructed. Each held 55 gallons of oil. Orifices ranging up to 12 inches in diameter were fitted in the bottom of each tank to vary the rate of release. The oil was released by opening a twelve inch butterfly valve.

The parameters effecting the spread rate to be investigated were:

- a. Oil volume
- b. Oil viscosity
- c. Oil density
- d. Oil temperature
- e. Oil release rate

Variations in the quantity of oil release were accomplished by either releasing the contents of one tank or simultaneously releasing the contents of both tanks. The oil viscosity and density were varied by using one of two oils, diesel oil or North Slope Crude. Further variation of the density and viscosity of the oils was accomplished by preheating them aboard the USCGC STATEN ISLAND prior to delivery to the test site. The effect of release rate was established by releasing oil through either three inch or twelve inch orifices in the discharge line.

Spreading rates were measured by timing the leading edge of the spilled oil as it passed a series of stakes. Stakes were placed at even intervals on the ice along perpendicular axes so that the oil front could be timed with stopwatches as it passed each stake.

As the size of the oil spills were small, the experiments were designed with the intention of scaling the test data so that the behavior of large size oil spills could be estimated. Scaling was to be done using non-dimensional parameters providing the ice surfaces of the scale and full size models displayed dimensional similarity.

Investigation in the field, however, showed the ice surface to be too rough and absorbant to definately provide a useable model. The surface had gradual undulations ranging up to approximately six inches and generally sloped downward from the center of the spill. In addition, the upper surface consisted of recrystallized ice which had the appearance of snow but could withstand a fairly large amount of weight. Measurements showed the recrystallized ice thickness to average approximately two inches, and core samples showed the density of the upper layer to range from .46 to .61 gm/cm³.

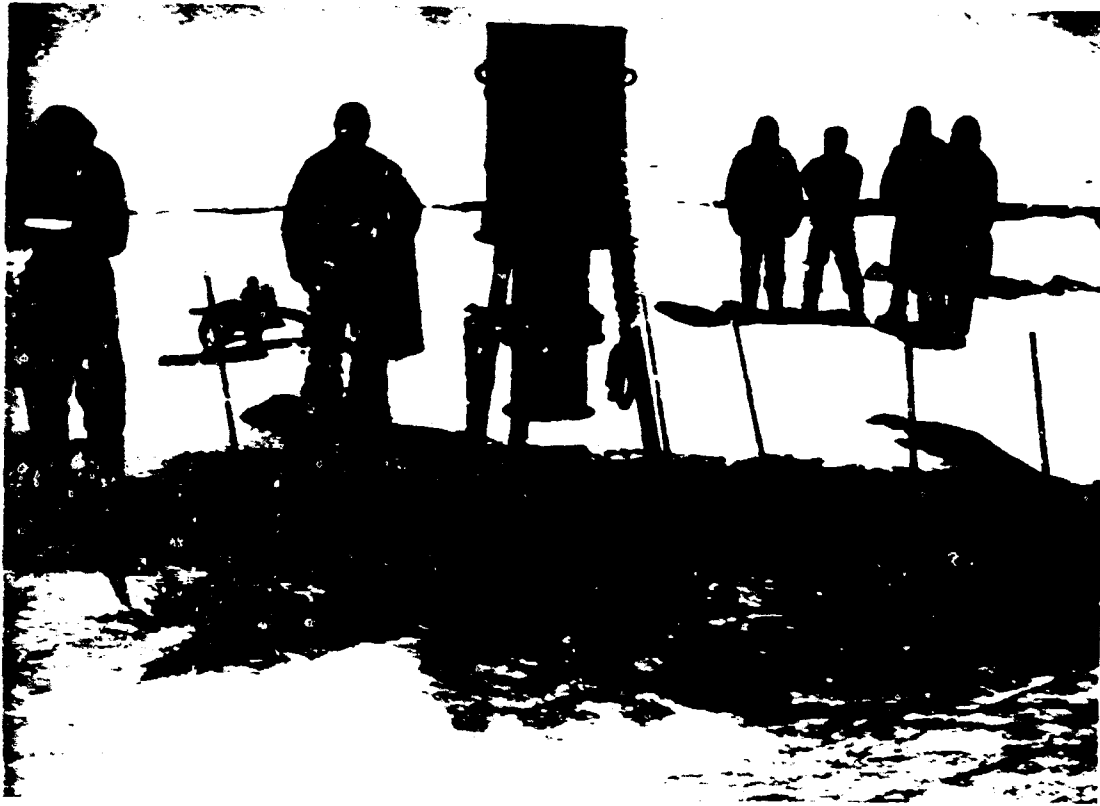


FIGURE 1.- One of the two devices used to release oil over water and ice.

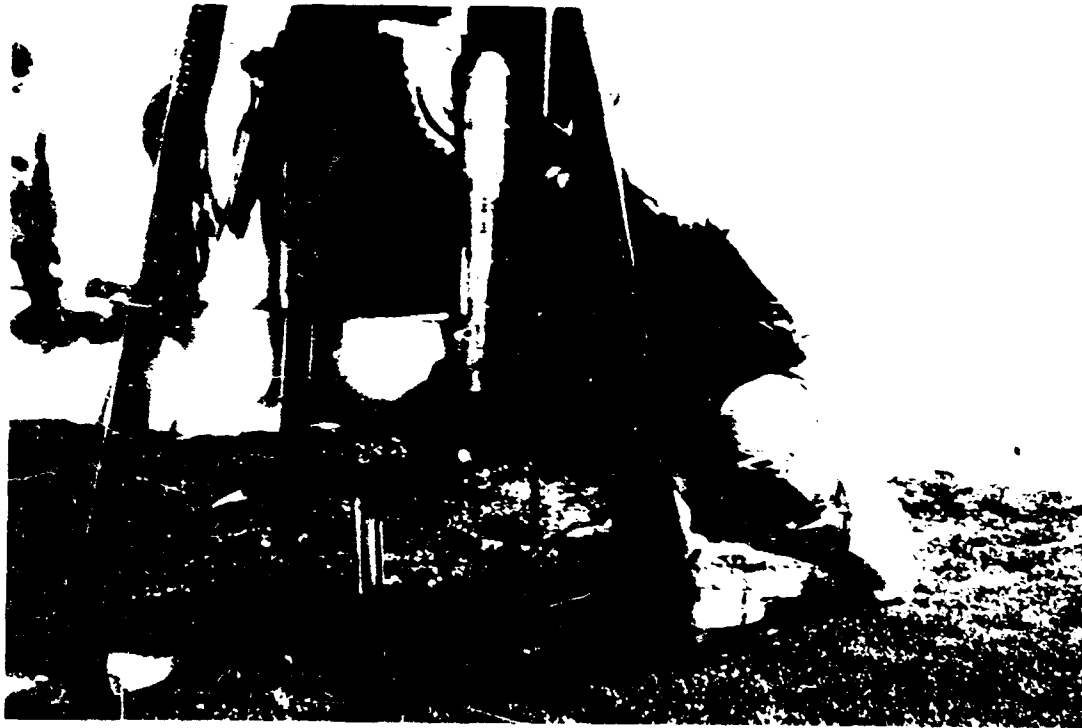


FIGURE 2.- Ice after a crude oil spill.

Any oil released on the upper surface was quickly absorbed into the ice. Core samples of the upper layer were taken and analyzed. Results show that when fully saturated, the ice absorbed approximately 25 per cent of its volume in oil. The saturated areas occurred at the center of the spills, and the percentage of absorbed oil decreased at the outward edges of the spill.

The surface ice proved to be permeable enough to allow both of the test oils the drain to lower levels due to gravity forces. As the melted ice also sought the lowest level, the oil gradually collected in the melt ponds, although a large portion of the oil appeared to remain in the ice.

As an aid in interpreting the data, a simplified theory for spreading on ice is derived as follows⁽¹⁾. Assume the oil is initially a cylinder at rest on the ice. The volume is then

$$V \sim l^2 h$$

where the notation is as given in the list of symbols. Consider the gravity forces per unit volume, F_1 ,

$$F_1 \sim \frac{\rho g h}{l} \sim \frac{\rho g V}{l^3}$$

and the inertial forces per unit volume, F_2 ,

$$F_2 \sim \frac{\rho l}{t^2}$$

The viscous forces are

$$F_3 \sim \frac{\gamma A}{V}$$

Using the turbulent stress law,

$$\gamma \approx \frac{\rho l^2}{t^2}$$

then

$$F_3 \sim \frac{\rho l^4}{V t^2}$$

Initially, spreading would be effected by only gravity-inertia forces, but would later enter into a gravity-viscous phase.

Therefore for gravity-inertia spreading,

$$F_1 \sim F_2$$

$$l \sim (\rho V)^{\frac{1}{3}} t^{\frac{1}{2}}$$

and for gravity-viscous spreading,

$$F_1 \sim F_3, \quad l \sim (\rho V^2 t^2)^{\frac{1}{7}}$$

In actuality, the transition from one phase of spreading to another will occur gradually.

The spreading data on the five spills which were made are given in Appendix (1). As the length of the oil spill along one axis was expected to vary exponentially with time, l is non-dimensionalized with $V^{1/3}$ and t with $\sqrt{V^{1/3}/g}$. The nondimensionalized data is plotted in Figure (3).

Data points for the three spills made through the large orifice plot together on a line with a slope of .75. Thus, under this mode of spreading the length of the slick approximately varies with $s^{3/4}$, \sqrt{t} , and $t^{3/4}$. It is expected that the spreading resulting from the, short duration release would follow the gravity-inertia equations, or vary with $V^{1/3}$ and $t^{1/2}$. However there are several factors which may account for the discrepancy; the release through the orifice from a height approximately four feet above the ice surface probably does not duplicate a point release adequately. The resulting mass of spreading oil appeared as a splash, and data was taken before all the oil had drained from the tank. Nevertheless, it must be realized that the theory is simplified and only approximate, and under this light does not badly match the experimental data.

An equation which closely fits the short duration release data is

$$l = 2.75 V^{1/3} t^{3/4}$$

Specific gravity, temperature, and viscosity, which are interrelated, are not taken into consideration in this equation because either the effect of each is minimal on the resulting spread or the differences in the test conditions were too small to have an effect.

The equations of gravity-inertia phase spreading for 50 and 100 gallon volumes are plotted on Figure (4) for comparison with the data.

The remaining two spills were of long duration. One was a spill of diesel oil made through a three inch orifice, and the other was of crude oil which was released extremely slowly over ice which had been presaturated with crude. Both approximately plot as straight lines with slopes of .5, although they are displaced considerably. It thus may be concluded that under this mode of spreading, the length varies approximately with $t^{1/2}$, as opposed to $t^{3/4}$ if the gravity viscous theory was correct.

An interesting observation, however, is that the slopes are approximately equal in spite of an order of magnitude difference in release rate. The release rate difference is most likely responsible for the displacement of the lines, but it is expected that the lack of agreement with theory results from the assumption of instantaneous release. The theoretical curves of gravity-viscous spreading are plotted for 50 and 100 gallon volumes in Figure (4) for comparison with the data.

Several generalized observations may be drawn from this set of experiments. Although the theory and the data do not exactly correlate,

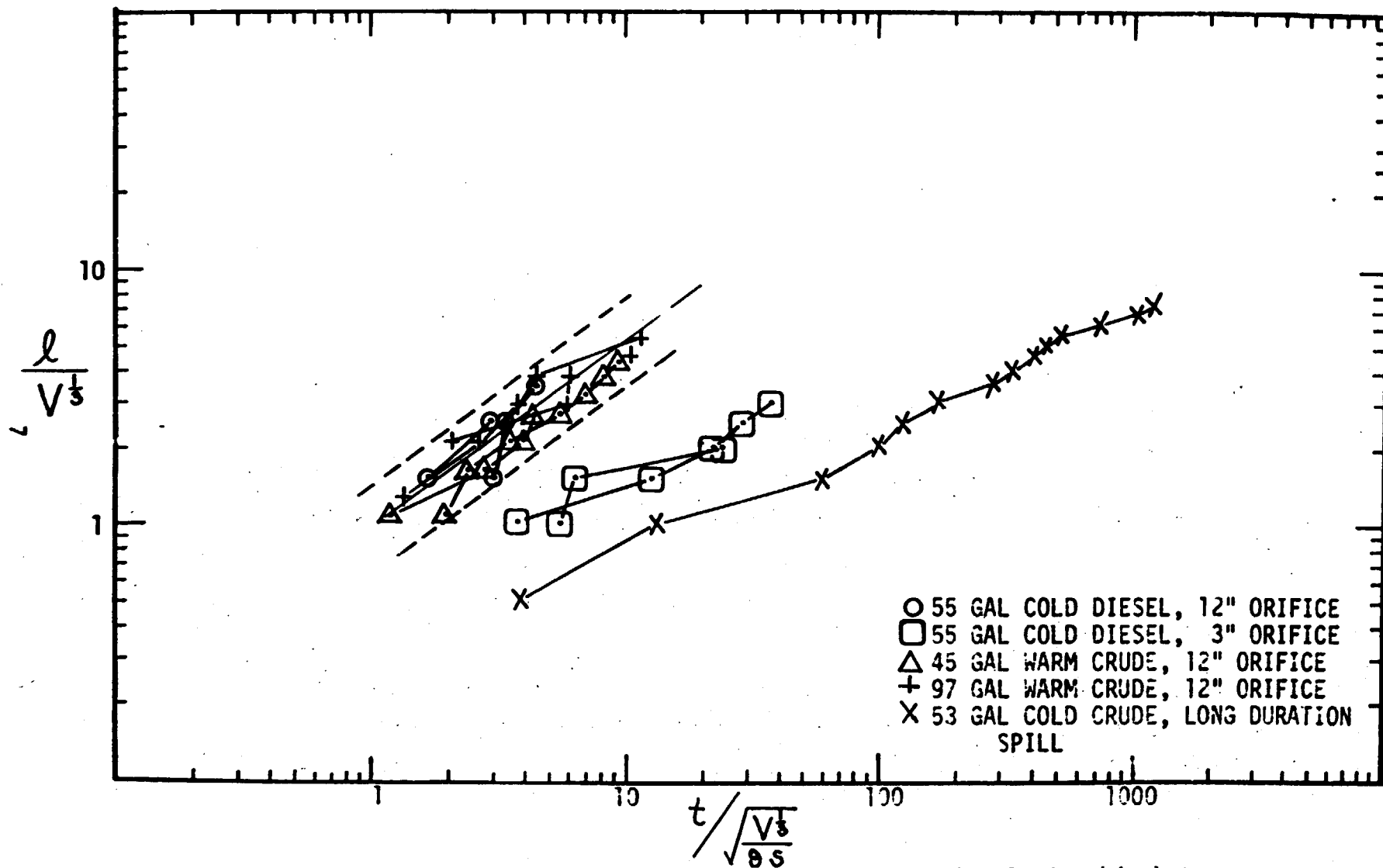


FIGURE 3.- Data for spreading of oil on ice. Nondimensional relationship between slick length and time.

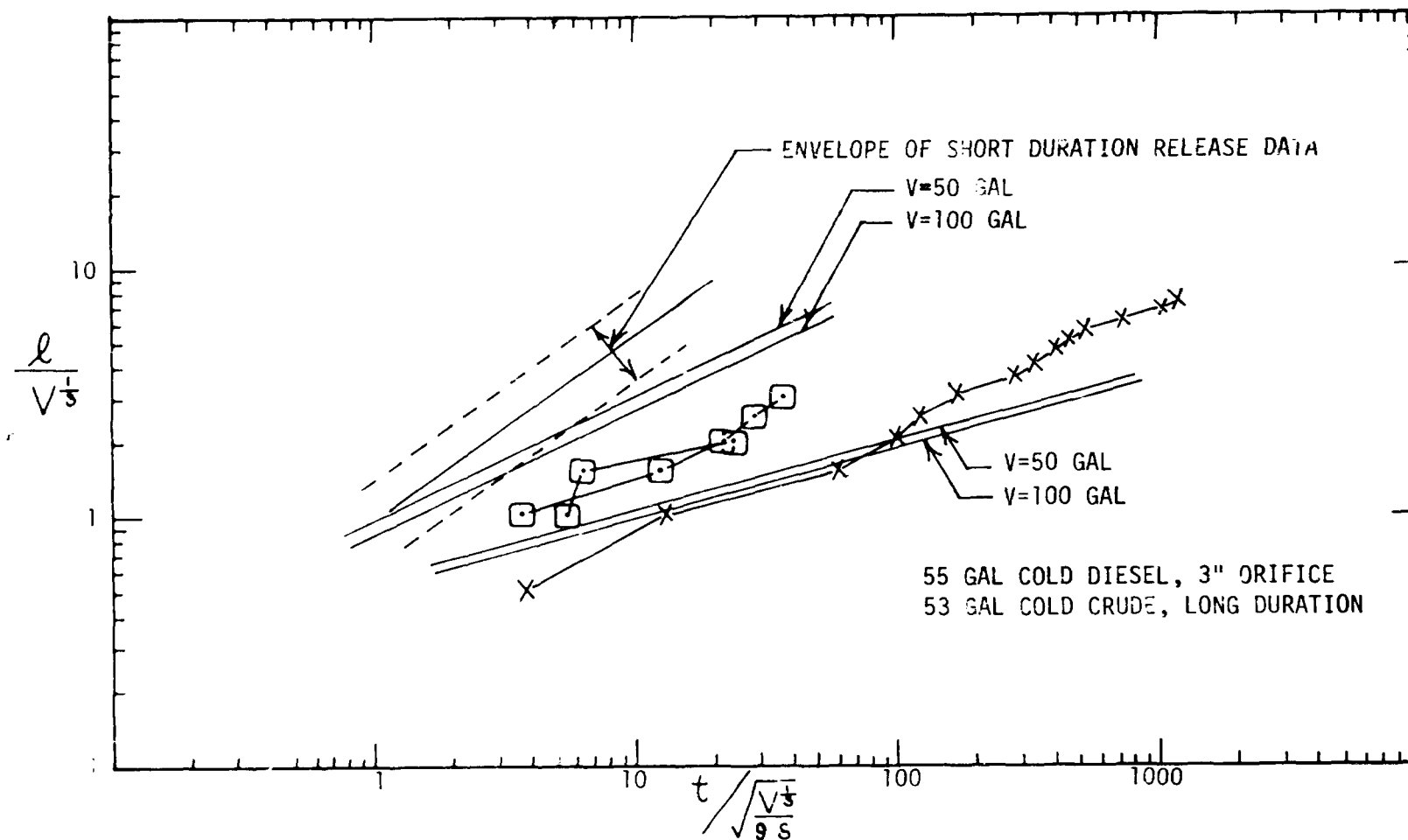


FIGURE 4.- Comparison of oil-on-ice spreading data with theory.

it does appear that with further analysis, a correct power law explanation for the data may be derived. However, scaling the data to full-sized spills using the observed power laws may produce totally erroneous results, especially considering the possible lack of dimensional similarity between the model and actual conditions. In addition, the transition point between the two modes of spreading has not been determined.

SECTION II SPREADING OF OIL ON WATER

The spreading experiments on water were conducted to obtain information on the nature of crude oil spilled on arctic waters and to determine the extent to which the spreading followed existing theory.

To simplify the experiment, the oil was restricted to flow in one dimension. As shown in Figure (5), this was accomplished by constructing a "U" shaped channel approximately 100 feet long in a large melt pond. A conventional oil boom was used to construct the channel. Oil was released through hoses connected to the two tanks used in the previous experiments. Markers were strung the length of the channel so that the progress of the oil front could be timed as it moved down the length of the channel.

The experiments were designed so that the results could be compared with the existing theory for the spreading of oil on water.

As derived by Hoult and Suchon for spreading in one direction down a closed channel⁽²⁾, the following theory is summarized for the spreading of oil released in the middle of a long channel.

Consider a volume of, wL^2 , with a density $(1-\Delta\rho)$ where ρ is the density of the water.

Neglecting viscosity and assuming Δ is small, the inertia of the oil is

$$\rho lwh \left(\frac{l}{t}\right)$$

which initially balances the gravitational forces,

The volume of the oil, $lwh = L^2w = \text{constant}$, is conserved, so it follows that for gravity-inertial spreading,

$$\frac{l}{L} \sim \left[\left(\frac{g\Delta}{L} \right)^{\frac{1}{2}} t \right]^{\frac{2}{3}}$$

The viscous retarding force, if $\delta \sim \sqrt{\nu t}$ is approximately

$$\left[\mu \left(\frac{l}{t} \right) \left(\frac{1}{\sqrt{\nu t}} \right) (lw) \right]$$

Therefore, for the gravity viscous phase of spreading, after equating the gravity and viscous forces,

$$\frac{l}{L} \sim R^{\frac{1}{3}} \left[t \left(\frac{g\Delta}{L} \right)^{\frac{1}{2}} \right]^{\frac{2}{3}}$$

$$\text{where } R = \frac{(g\Delta L)^{\frac{1}{2}} L}{\nu}$$

If σ is the net surface tension (air-oil plus oil-water minus air-water), the total surface tension force is σw which, when equated to the viscous forces, approximates the surface tension phase of spreading,

$$\frac{l}{L} \sim \left(\frac{\sigma \nu^{\frac{1}{2}} t^{\frac{1}{2}}}{\mu L^2} \right)^{\frac{1}{2}}$$

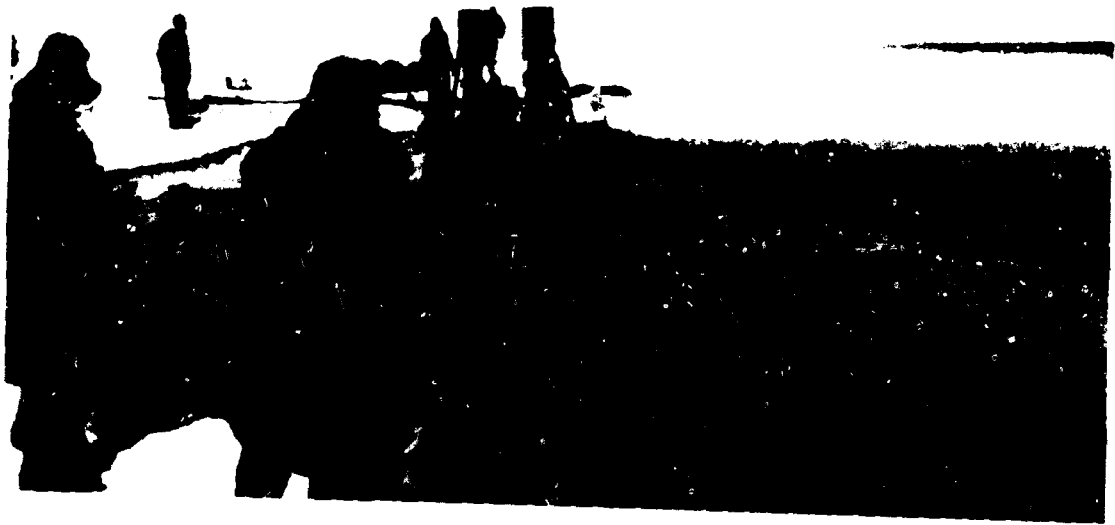


FIGURE 5.- Crude oil spreading down a channel.

In order to estimate the point at which surface tension dominated spreading replaces the gravity dominated spreading, the surface tension and gravity forces are equated,

$$\sigma w = \rho g \Delta h^2 w$$

$$h = \sqrt{\frac{\sigma}{\rho g \Delta}}$$

where h is the critical thickness.

The experiment was run first with a channel width of 22 feet. An 8 knot wind was blowing approximately perpendicular to the boom at this time. As a result, the slick separated from the windward side of the boom shortly after release and collected on the leeward side, thus making the data collected unuseable.

The experiment was subsequently run with a smaller channel width of 10.5 feet, with the wind blowing at 8 knots down the length of the channel. Data of the spreading is plotted in Figure (6). The oil slick separated from the end of the boom and traveled as a slug down the length of the channel; therefore both the leading and trailing edges of the slick are given in Figure (6).

An approximate curve of total slick length as a function of time is given in Figure (7). Some data extrapolated from the two trailing edge data points are used. Immediately apparent is the observation that the slick stops growing at a certain point and starts to shorten. This area is most likely the transition from gravity dominated to surface tension dominated spreading with a slick having a negative net spreading coefficient. The data is non-dimensionalized using the observed transition lengths and times.

The tendency of the oil to stop spreading after a certain point was observed in several other experiments and is best explained by the presence of a negative spreading coefficient. Using the transition thickness previously derived, $h = \sqrt{\sigma/\rho g \Delta}$, the net spreading coefficient is calculated to be approximately -26 dynes/cm at a transition thickness of .5 cm. As the air-oil surface tension at 0°C is approximately 75 dynes/cm, the sum of the air-oil and oil-water surface tensions should be approximately 101 dynes/cm. The measured sum of these two surface tensions at 20°C is approximately 75 dynes/cm. However this value will probably be significantly greater at 0°C .

A fluctuation in the curve is apparent as the transition phase is passed. This may be a result of dynamic effects in the slick, which is acting as an elastic body. Before the fluctuating area, the line has a slope of .45, indicating the length is varying with $t^{.45}$. For gravity-viscous spreading length is expected to vary with $t^{.75}$. However a conclusion can not be drawn concerning correlation between the theory and data because all the data in this phase has been extrapolated. Because of the dynamic effects and the tendency of the oil to stabilize at a constant thickness, a slope of surface tension dominated spreading was not observed. A gravity-inertial phase was also not observed.

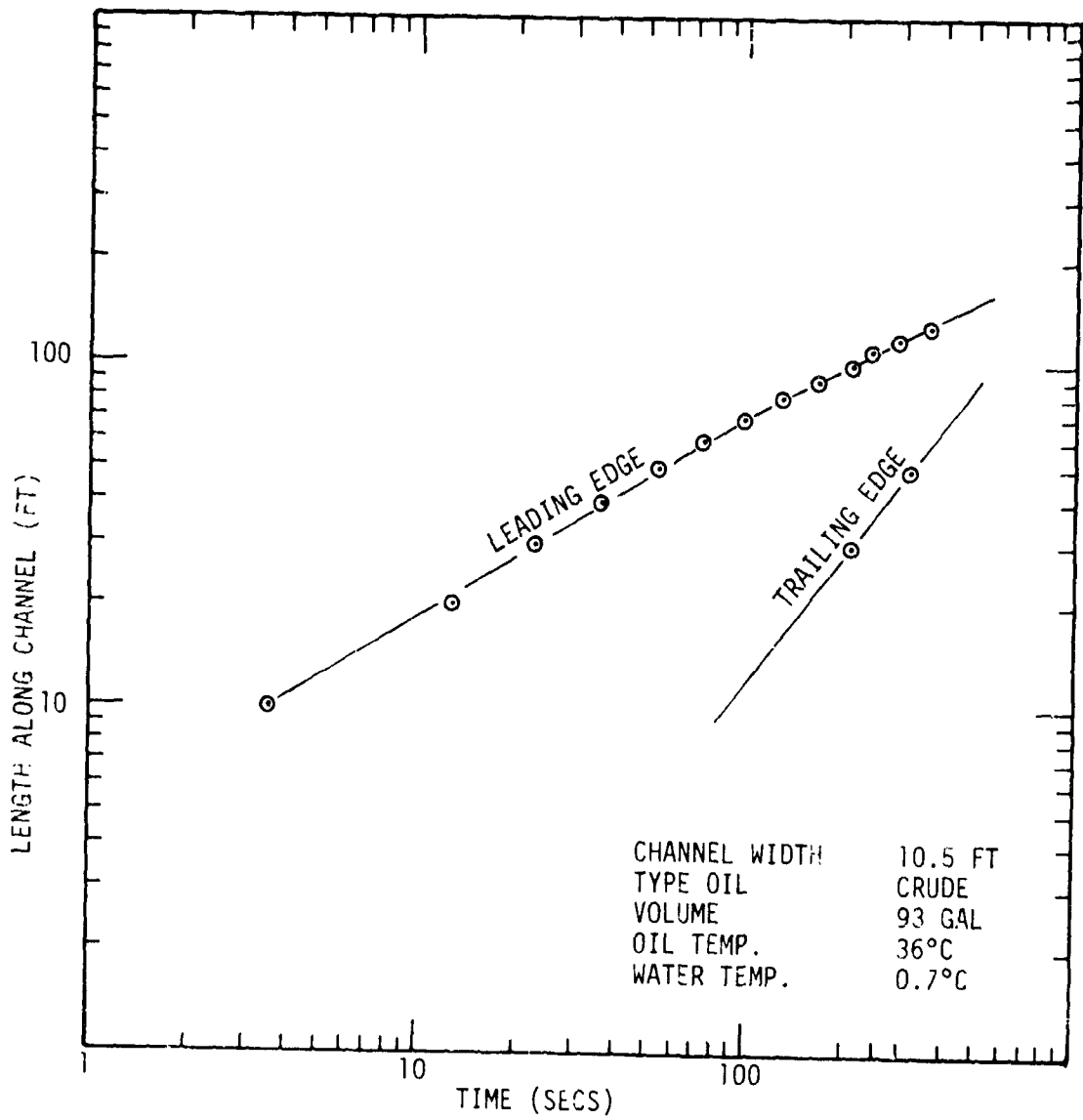


FIGURE 6.- Data for spreading of oil on water.

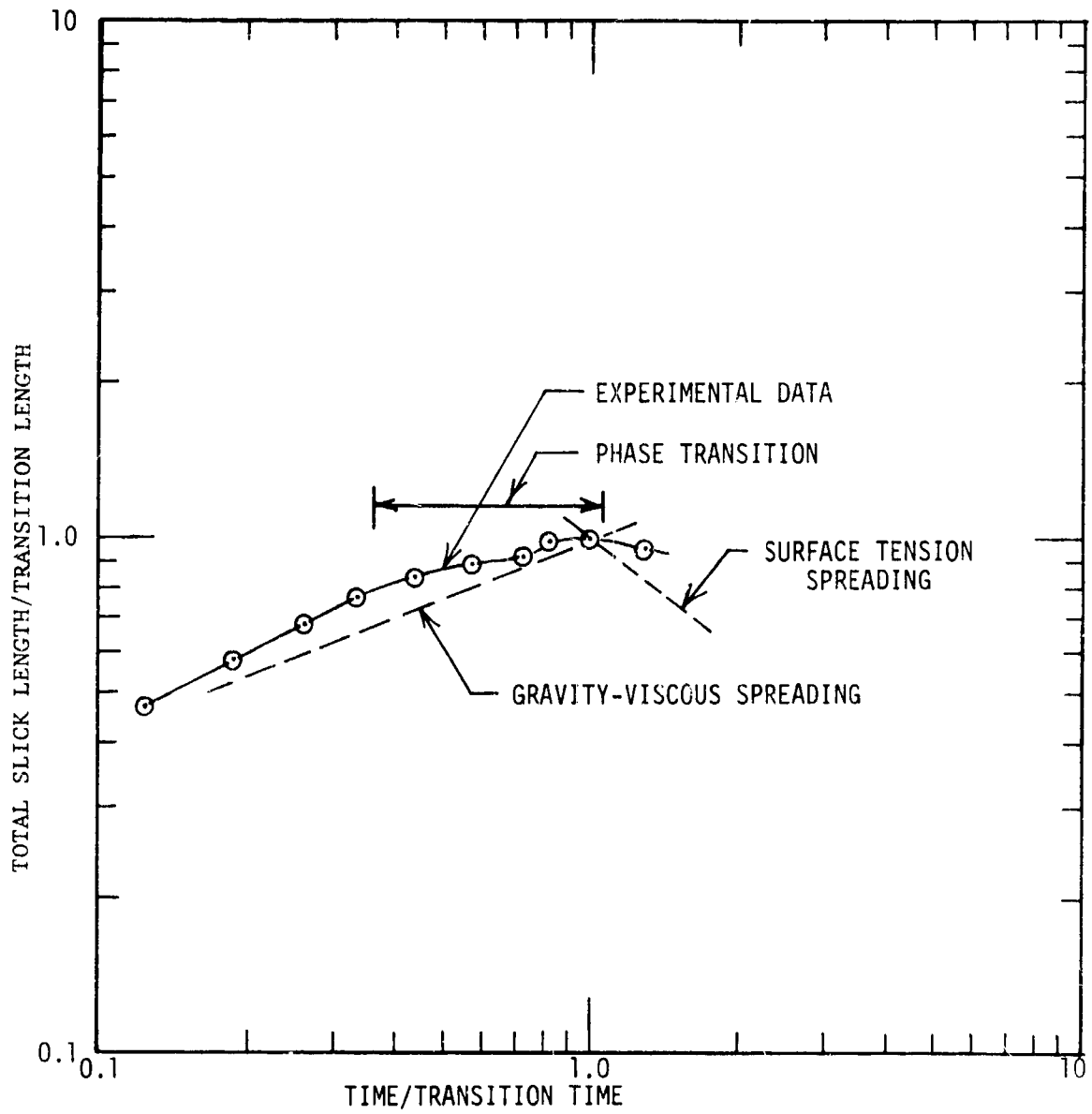


FIGURE 7.- Nondimensionalized data for spreading of oil on water compared with theory.

The center of the slick traveled downwind at a constant rate of .195 ft/sec. This value is approximately 1.5 per cent of the wind velocity which compares with observed values of approximately 3 per cent for large oil slicks in temperate areas.

The major conclusions which can be drawn from the spills on water is that slicks of Prudhoe Bay crude are significantly affected by wind and do not spread out because of surface tension forces. These two factors combine to cause the oil to gather in thick films when forced by the wind against ice. It was observed, however, that the oil would escape by traveling on water through any downwind path that was available.

SECTION III SPREADING OF OIL UNDER ICE

The under-ice spreading experiments were conducted so that some insight into the process could be attained. By visually observing the oil spread, it was planned to qualitatively determine the extent to which the oil entrained in ice pockets and was affected by any currents. As the specific gravity of the crude oil (approximately .89) was not a great deal less than water and very close to that of the sea ice, it was not known to what extent the oil would be dispersed by any turbulence present.

Three dives were made by divers using conventional diving equipment to find a suitable location for the tests. A diver described the area as follows:

"There was a distinct line 6 to 8 ft down, probably where the fresh water met the salt water. In the salt water below, there was a large quantity of suspended matter, presumably algae. There was also algae, very fine lacey type, brown in color on the underside of the ice. Also around the ice were more ice crystals suspended in the water with no apparent attachment to the ice itself.

The ice in one direction was gradually sloping downward. It went down more than 15 feet. There were similar slopes 90° either side of this. On the fourth side, about 10 feet down and greater, the ice opened up into a maze of caverns, inter-connected, with no apparent symmetry. All of the ice appeared to have smooth surfaces.

The dive was made approximately 30 yds from the edge of the flow and 30 yds from a pressure ridge. The dive was made in a melt pond open to the sea only through the bottom".

A pocket was located in the ice and a core hole was drilled into it from the surface. A hose attached to a gasoline powered pump was then inserted into the hole so that the crude oil could be directly discharged under the ice.

One drum of crude oil was subsequently pumped through the hole while divers below observed and photographed the spreading. The oil did not disperse but rose to the interface, where, as shown in Figure (8), the oil pocketed into one mass. Twenty four hours later the pool remained essentially unchanged. Current measurements showed little current in the general area of the spill.



FIGURE 8.- Crude oil pocketing at the water-ice interface.

Another drum of crude oil was pumped to the bottom of the ice floe at the edge of the large pocket, approximately 12 feet below the surface. The oil rose up and around a shelf of ice to the upper interface, filling pockets as small as one inch in diameter with oil. The oil dispersed in the upper interface covering an area of approximately 8 square feet. Inspection 24 hours later indicated that it continued to spread over a slightly larger area.

In general, the oil spreading was quite well behaved, which was most likely due to a lack of turbulence in the area at the time of the tests. As a result, it appears that the various large pockets, pressure ridges, and other under ice obstructions would be able to contain a fairly large volume of oil, providing that non-turbulent conditions exist.

SECTION IV BURNING AS A METHOD OF OIL REMOVAL

As removing oil by burning has been advocated for use in the more temperate areas, it was decided to determine how effective the method would be in the Arctic.

The tests were conducted by releasing small quantities of Prudhoe Bay crude oil to simulate oil spills on a small scale. Spills were made both on ice and on melt ponds, and ignition was made of both fresh oil and oil which had been aged up to 6 days. Fumed silica type and glass bead type burning agents as well as straw were tested as combustion promoters.

Table (1) summarizes the burning experiments and the measurements made. The average flame height of the burns were measured with a transit on the ice and the times measured were from ignition to completion.

In all cases ignition was made by tossing a rag which had been soaked in diesel oil and lighted into the pool of oil. Both the fresh and aged crude oil quickly ignited without any further effort and burned furiously, as shown in Figure (9). If a spill was lighted off on the downwind side, flames would quickly travel upwind until the entire pool was burning.

It was observed that oil pools which were burning on ice would provide enough heat to the surroundings to form channels which drained water and burning oil to lower areas. Enough heat was transmitted to the water under the burning slick for boiling to occur, which effectively atomized the oil.

In all cases a great amount of heavy, black smoke was produced which dissipated in the atmosphere. No fallout of smoke was found on the ice near the burns.

The use of burning agents on the slicks showed no noticeable change and were clearly not needed on this particular crude oil. It is probable that in each individual burn the burning agent had some effect on the residue, but the variances in each separate burn were large enough to obscure the effect.

Hay was burned on a slick after it had lain on the oil for 24 hours. Again little difference was observed during the burn. However, the residue consisted mainly of what appeared to be charred straw with apparently less oil than on other experiments.

Attempts were made to ignite thin slicks. A short ignition was attained with a burning agent. However the wind quickly forced the oil into pools thick enough to support combustion without the presence of burning agents.

The residue in all cases was a heavy tar-like substance, as shown in Figure (10). Estimates of the amount of residue left varied from 2 to 10 per cent of the original volume. Removing the residue proved to

<u>Experiment</u>	<u>Wind Veloc. (knots)</u>	<u>Volume (gal)</u>	<u>Area (ft²)</u>	<u>Time (min)</u>	<u>Flame Height (ft)</u>	<u>Burn Rate (gal/ min)</u>
Fresh crude on water -no burning agents	10-14	32	82.5	10	4-10	3.2
Fresh crude on water -fumed silica burning agent	6-8	44	63.5	12	12	3.7
Fresh crude on ice -no burning agent	8	47	20.2	9	8	5.2
Aged crude on water (5 days)-no burning agent	0	55	72.5	12	12	4.6
Aged crude on water (6 days)-fumed silica burning agent	0	35	82.5	8	12	4.4
Aged crude on water (6 days)-glass bead burning agent	0	44	73.3	10	14	4.4
Straw on oil -aged 1 day	-	40	160	13-14	-	3.0

Residue from all burns were approximately 2 to 10 per cent of the original volume.

Table 1.- Summary of burn tests.



FIGURE 9.- Crude oil burning on ice after a five day aging period.



FIGURE 10.- Typical residue left after a crude oil burning experiment.

be a fairly easy task, and could be done leaving a completely clean area of ice.

It may be concluded from these experiments that burning is an effective method of removing small quantities of Prudhoe Bay crude under the test conditions. However, this conclusion can not be extrapolated to larger volumes of oil, although the method shows a great amount of promise for eliminating large oil spills.

SECTION V ABSORBANTS

Two natural absorbants, straw and peat moss, were tested in order to establish the merits of using absorbants for recovery of oil spills in the Arctic. The absorbants were used on small Prudhoe Bay crude oil spills which had been made both on ice and water. After the absorbants had been on the slicks for 24 hours, representative samples were taken for analysis.

Straw proved to be superior to peat moss when used to absorb the oil which had been spilled on water. The straw was easy to spread over the slick and it was easily removed from the surface. A fairly large percentage of the spilled oil was carried with it. After the oil-soaked straw was removed from the surface 24 hours after the spill, it was ignited. The mass burned slowly to an ashy residue.

The peat used in the experiments had a very fine consistency and as a result was hard to spread. It was difficult to collect after absorbing the oil which had been spilled on water because the resulting material physically resembled a liquid. The peat was ignited while still on the water and allowed the oil to burn to a small residue.

Both absorbants were used to control crude oil spills on ice. The effect of the absorbants was to stop the flow and absorb a portion of the oil, although the percentage of oil absorbed visually appeared to be less than was experienced with oil spills on water.

The absorbants were ignited 24 hours after they had been spread on oil spilled on ice. Both gave long, controlled burns which resulted in almost complete reduction of the material present.

The samples of absorbants were analyzed using the procedures outlined in Appendix (2) and yielded the following information:

	Weight of Oil Adsorbed per 100 g of Adsorbent in its Natural Condition, <u>g</u>	Weight of Water Adsorbed per 100 g of adsorbent in its Natural Condition, <u>g</u>
1 - Straw on water	345	*
2 - Straw on ice	64	13
3 - Peat on water	1568	190
4 - Peat on ice	698	10

*The water content of Sample 1 was not determined. However there was no visual evidence of free water either in the sample jar or in the chloroform extract.

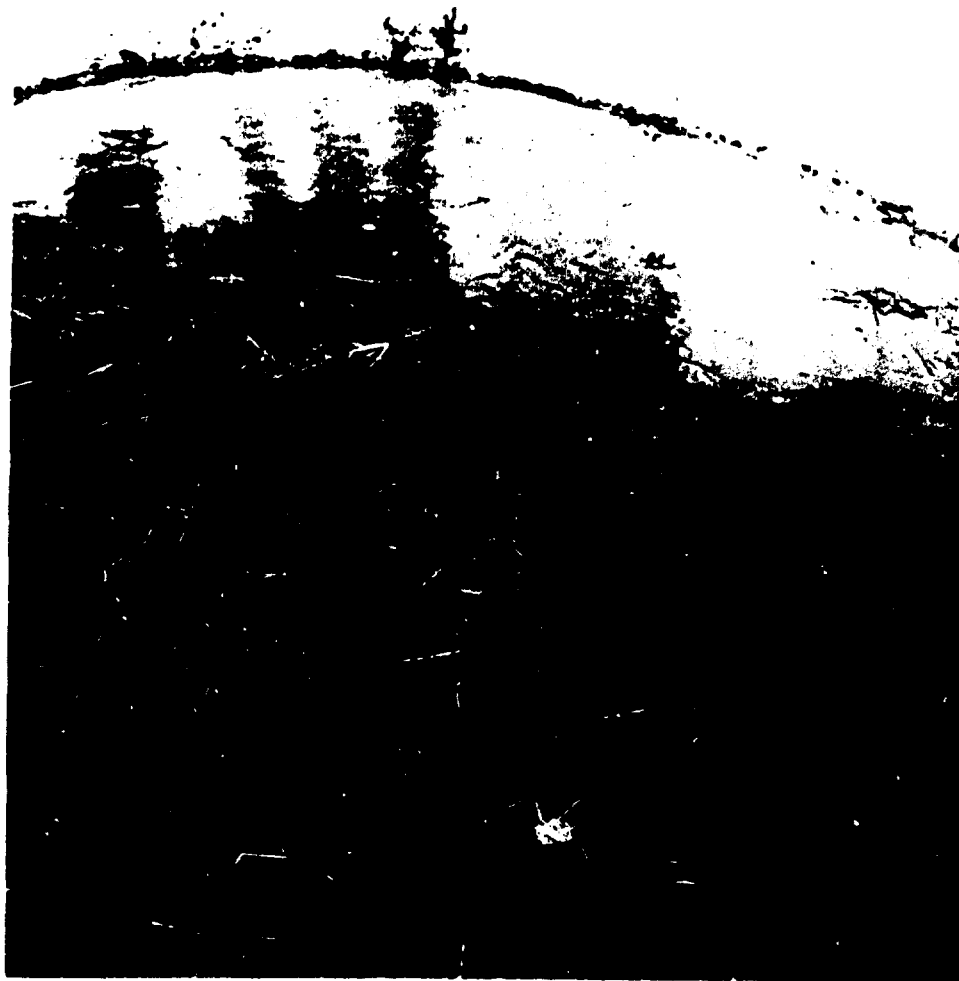


FIGURE 11.- Straw after being spread on a crude oil slick.

The values of weight of oil adsorbed/weight adsorbant for the experiments on water are roughly what would be expected for adsorbants used on warm water spills. As is expected, the adsorbants used on ice show a smaller ratio because a large portion of the oil was absorbed by the ice.

Based on the observation that 15 pounds of straw appeared to absorb more than 80 per cent of the 22 gallons of oil present on water, the actual adsorbant ratio would be two and one half times as large as is reported in the analysis. The apparent discrepancy probably resulted from errors made in measurement during the experiment and errors resulting from the use of a small sampling volume.

In conclusion, it appears quite likely that various adsorbant techniques can be used to control spills of fine crude oil such as Prudhoe Bay crude under summertime arctic conditions.

SECTION VI - A COMPARISON OF THE HEAT BUDGET OVER OIL-COVERED AND CLEAN ICE
IN THE ARCTIC ENVIRONMENT

By

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One aspect of a major oil spill in the arctic environment which must be given careful consideration is the change in the heat budget occurring at the sea ice surface due to its being covered with oil. An ice surface covered with black crude oil will naturally absorb more solar radiation than will a clean, white ice surface. One means by which the oil covered ice can get rid of this excess energy absorbed from the sun, is by melting at a faster rate. It is important to know the increased rate of melting to determine what length of time the ice will contain the oil after a spill. Such information is important in deciding the time-frame of a clean-up operation.

The purpose of this study was to make preliminary measurements of the more important physical processes which affect the heat budget of an ice surface in the Arctic during the summer, and to compare the measurements made over ice covered by crude oil with those made over clean ice.

The heat budget of an ice surface can be expressed as follows:

$$F_r + F_s + F_l + F_c + F_m = 0$$

where F_r = radiation balance at the ice surface. This takes into account the incoming solar radiation, reflected solar radiation, emitted long wave radiation from the ice and atmosphere, and reflected long wave radiation from ice and atmosphere

F_s = sensible heat to ice surface by turbulent exchange with the atmosphere

F_l = flux of latent heat by evaporation or condensation

F_c = flux of heat from below to ice surface

F_m = flux of heat utilized in melting (negative) or freezing (positive) of ice

A search through the literature showed that several heat budget studies have been made in the Arctic before (e.g., Langleben⁽³⁾ Fletcher⁽⁴⁾ Marshunova & Chernigovskiy⁽⁵⁾). Badgley looked at various Russian and American data obtained on mature ice floes near a latitude of 80°N, and compiled monthly mean values for the first three terms of the above heat budget equation. His values for the month of July are:

$$F_r = 3.11 \text{ kg-cal/cm}^2\text{mo}$$

$$F_s = 0$$

$$F_l = -.30 \text{ kg-cal/cm}^2\text{mo}$$

It was decided to concentrate our efforts towards, measuring F_r , F_c , and F_m over oil covered ice and clean ice. According to Badgley's data, these measurements would account for about 90% of the heat budget.

Two barrels of Prudhoe Bay crude oil were spilled on the surface of a large, multi-year ice floe at approximately 72°N, 158°W. The ice exceeded 5 meters in thickness, had an average salinity of less than 1%, and was weathered to the consistency and appearance of old snow in the upper 4-5 cm. The oil spread over an area approximately 10 meters in diameter, and was rapidly absorbed by the weathered ice layer.

F_r was measured hourly with a ventilated net radiometer. First a reading was made over the clean ice approximately 10 meters from the oil spill, and then a reading was made at the center of the spill.

F_c can be determined from the following equation:

$$F_c = -kA \frac{dT}{dz}$$

where k = thermal conductivity of ice

$$= 5 \times 10^{-3} \text{ g cal/sec } ^\circ\text{C cm}$$

$$A = \text{surface area} = 1 \text{ cm}^2$$

$$\frac{dT}{dz} = \text{vertical temperature gradient}$$

The vertical temperature gradient was obtained by freezing three thermistor cables into the ice. Two cables were imbedded into the oil covered ice, and one cable in the clean ice nearby. Each cable had 5 thermistors spaced at approximately 40 cm intervals. In addition an ice core was obtained from the oil covered area, and a temperature gradient was obtained from this by inserting thermistor probes into the core center at 12 cm intervals immediately after obtaining the core.

F_m could not be measured in total, but the difference in melting rate between clean ice and oil covered ice could be determined simply by measuring the rate at which the oil covered ice surface melted below the level of the surrounding clean ice surface.

Figure (12) shows the temperature vs. depth curves for the 3 thermistor cables and the ice core at the time the ice core was taken. The temperatures measured by the thermistors are warmer than those measured in the ice core because the upper part of the thermistor cables never froze solidly into the ice, and heat was probably conducted down the cable to some degree. Consequently the thermistor values are not considered reliable. This turns out to be of no great consequence, however, since the vertical temperature

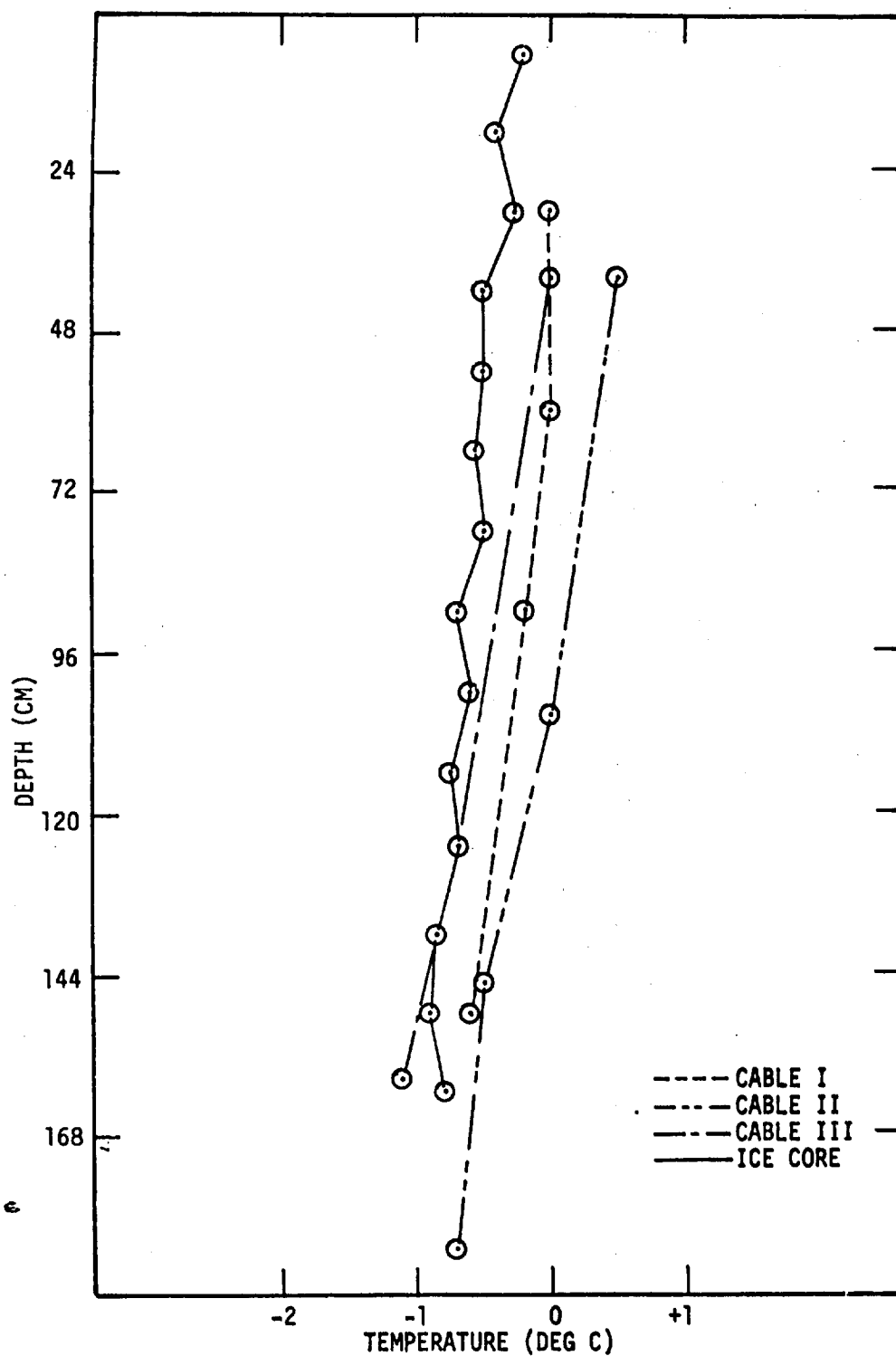


FIGURE 12.- Temperature vs. depth in ice on 28 July, 0900

gradient measured in the ice core was only 3.7×10^{-3} °C/cm.
Since

$$\begin{aligned} F_c &= -kAd \frac{dT}{dz} \\ &= -5 \times 10^{-3} \times 1 \times 3.7 \times 10^{-3} \times 3600 \\ &= -6.7 \times 10^{-2} \text{ g cal/cm}^2/\text{hr} \\ &= -.05 \text{ kg cal/cm}^2/\text{mo.} \end{aligned}$$

Comparing this with Badgley's data shows that F_c could also be neglected in the heat budget equation at this time of the year.

Therefore the only two terms that are left in the heat budget equation, F_r and F_m , should account for approximately 90% of the heat interchange at the surface in July.

The values of F_r are listed in table 2. These values are questionable for two reasons. First, the most sensitive recording device that was obtained for this experiment was a millivoltmeter with a full scale of 0-5 millivolts. The output from the net radiometer never exceeded .1 millivolt, so readings of F_r could be resolved to only one significant figure. Second, readings were made for only 10 hours before the radiometer was damaged beyond repair. (Readings over a three day period were considered the minimum requirement so that diurnal fluctuations could be determined, and so that the effect of operator errors would be minimized.)

Nevertheless the readings we obtained agree to some extent with the value of $3.11 \text{ kg cal/cm}^2/\text{mo.}$ compiled by Badgley. The average net radiation we obtained for clean ice is $7 \pm 1 \text{ kg cal/cm}^2/\text{mo.}$ But our measurements were made from 1100 to 2100 in one day, and if we had even a 24 hour period of data, the night values of F_r would have decreased our average considerably, possibly by a factor of 2. The resulting value would be in the range of $3-5 \text{ kg cal/cm}^2/\text{mo.}$

Over the 10 hours period of measurements the oil covered ice absorbed, on the average, $3 \text{ g cal/cm}^2/\text{hr}$ more than did the clean ice. The density of the weathered ice was found to be approximately $.5 \text{ g/cm}^3$. Since it requires 80 calories to melt 1 g of ice, 40 calories would melt 1 cm of the weathered ice. If ΔF_r remained at $3 \text{ g cal/cm}^2/\text{hr}$ over a 24 hr period, the oil covered surface would melt 1.8 cm below the surrounding clean ice surface.

The oil covered surface did melt below the surrounding clean ice surface at a rate of approximately 2 cm/day for the first couple of days. After that the "sinking" rate decreased when the oil came to rest on the harder, more dense ice below the weathered layer.

<u>Time</u>	<u>F_r (clean ice)</u>	<u>F_r (oil covered)</u>
1100	10 g cal/cm ² /hr	18 g cal/cm ² /hr
1300	8	20
1400	8	10
1500	8	10
1600	10	20
1700	10	4
1800	10	8
1900	10	8
2000	10	10
Average	9	12

Table 2.- Values of F_r over oil covered and clean ice.

The oil covered ice absorbed 30% more net radiation than did the clean ice over the 10 hour period of measurements. Since this 30% increase of net radiation increased the melting rate of the ice by 2 cm/day, the melting rate of the clean weathered ice had to be approximately 7-10 cm/day, assuming that factors in the heat budget equation other than F_R and F_m are negligible. This corresponds to a heat requirement of 280-400 g cal/cm²/day. This agrees fairly well with the value of $F_m = 278$ g cal/cm²/day obtained by Langleben on melting sea ice in the early summer of 1965 at Ellesmere Island.

For all practical purposes, this study produced little usable data. "Ball park" figures were obtained for the net radiation over oil covered and clean ice for a 10 hour period, but the short duration of the measurement period and the probability of operator error make these values very inaccurate. Furthermore, the difference in melting rate between oil covered ice and clean ice was never measured quantitatively, but was only estimated.

However this study has shown a means by which the total melting rate of the ice can be determined. That is, by comparative heat budget studies of oil covered ice and clean ice and by measuring the difference in melting rates between the two regimes. The heat budget equation was approximated by: $F_R + F_m = 0$. Then values of ΔF_R (obtained from measuring the rate of which the oil covered ice surface melted below the clean ice surface) and ΔF_m (obtained from measuring the rate at which the oil covered ice surface melted below the clean ice surface) were compared. If $\Delta F_R = \Delta F_m$, the above approximation is known to hold true. Therefore, if $F_R + F_m = 0$, and F_R is known, then F_m and the melting rate can be determined.

If these oil spills are conducted during the late summer months, only F_R has to be measured to obtain F_m within approximately 10%. Values of F_R can best be obtained by mounting two net radiometers on tripods, one over clean ice and one over oil covered ice. The output from these radiometers should be fed into strip chart recorders which are sensitive enough to resolve changes of at least $\pm 5\%$ of the total output. (In the case of the net radiometer used for this study, changes of $\pm .005$ mv.) Values of ΔF_m can easily be obtained by periodically measuring the difference in surface levels of the oil covered ice and adjacent clean ice. These can be compared with values of ΔF_R to check the validity of the approximation, $F_R + F_m = 0$.

If oil spill tests are conducted at any other time of the year, other parameters of the heat budget equation, F_g , F_l , F_c , would have to be considered since these parameters then become relatively important in the heat budget equation. F_c can be obtained adequately with thermistor cables of the type used in this study (12 conductor Belden cable, Fenwall thermistor #UUA 33JI). Obtaining values for the other terms, F_g and F_l , requires measuring wind velocity, temperature and humidity profiles over the ice. Such measurements were not attempted in this study.

If future Arctic oil spills experiments are planned, and ice melting rates are desired, then this method of comparative heat budget studies can be used to obtain accurate melting rates, provided that good instrumentation is made available.

SECTION VII AGING OF CRUDE OIL

One of the basic inputs to future research on oil pollution in the Arctic will be the physical and chemical characteristics of crude oil. Many of these characteristics change as the oil ages.

Under this series of experiments, samples were taken of Prudhoe Bay crude which was spilled on ice and water and allowed to age up to 13 days and the same crude spilled under ice and allowed to age one day.

The experiments were conducted by releasing one drum quantities onto the ice surface and into a melt pond. Oil which had been spilled on ice formed a pool approximately 5 mm thick on top of a very thin layer of water. The melt pond was sufficiently large for the oil to form in an isolated pool in the downwind corner. Samples were taken by scooping oil off of the ice and water surfaces, draining off any water, and sealing in glass jars.

Oil which had been pumped under the ice was sampled by inserting a suction line from a hand pump into the oil pool and pumping out the necessary amount.

Weather conditions were almost unchanged over the duration of the testing period. Air temperatures over the initial 8 day period ranged from a low of 31°F to a high of 52°F with an average daily mean of 37.9°F. Skies were generally clear and the sun did not set. Wind was always present and averaged approximately 10 knots over the period.

The water temperature stayed at 32°F in the fresh water melt ponds. Ice temperatures were always within the 29-32°F range. The only temperatures which showed significant change were the oil film temperatures, which varied up to several degrees above the air temperature on bright, clear days.

The analysis of the samples was broken down into two general efforts, an analysis for physical parameters and an analysis for chemical parameters.

Most of the physical analysis was performed onboard the ship. The samples were analyzed for density, viscosity, and air-oil and oil-water surface tensions.

The specific gravities of the aged crude are given in Figure (13). Measurements were made with hydrometers. A fairly large scatter in the data is apparent and results from variances in the samples rather than imprecision in the apparatus.

As shown in Figures (14) and (15), the viscosity measurements showed significant changes. With the passing of time the oil samples showed a pronounced increase in viscosity. Oil aged on water had a greater initial increase than the oil aged on ice, but the differences closed at longer times.

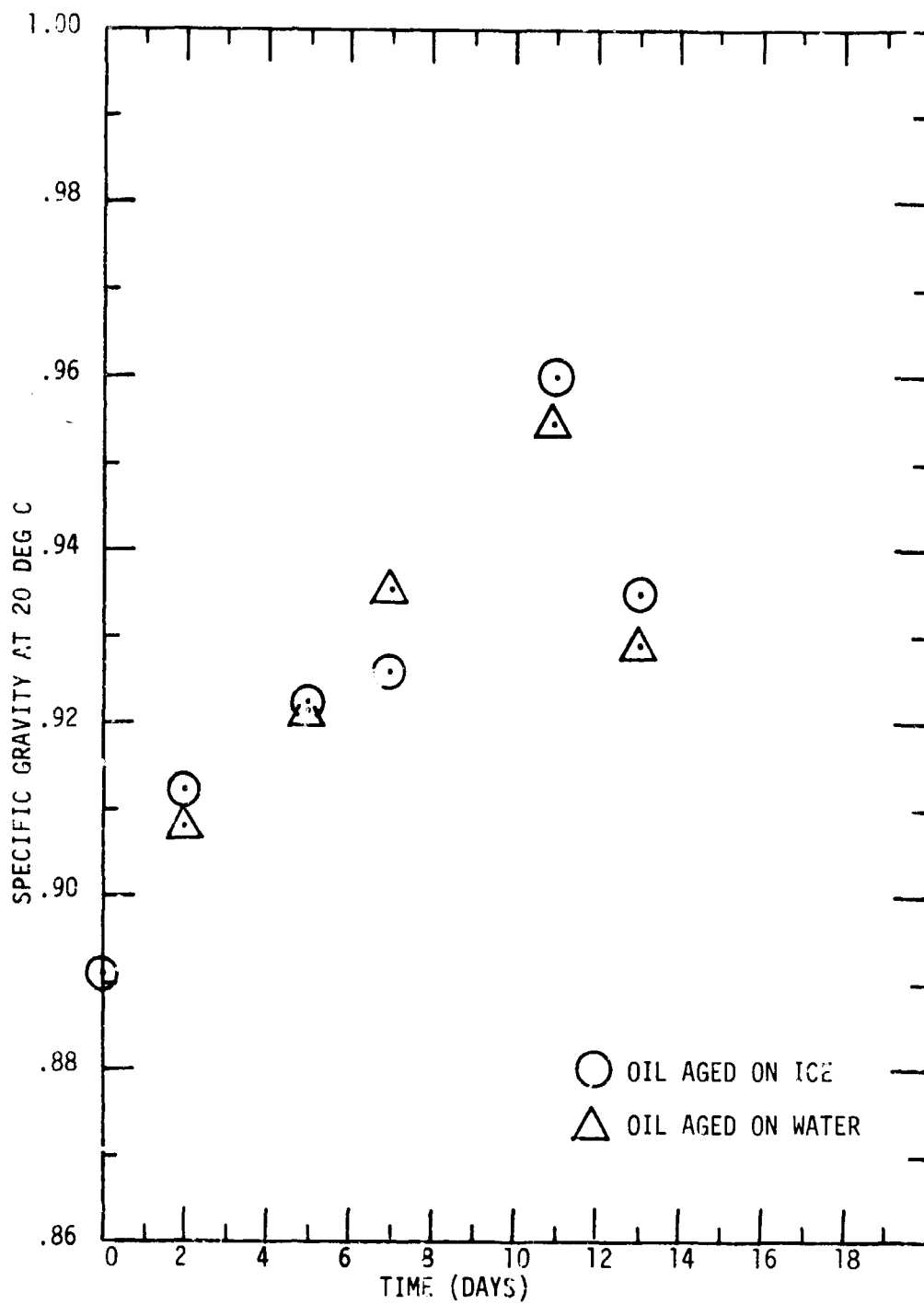


FIGURE 13.- Specific gravity of aged Prudhoe Bay crude oil.

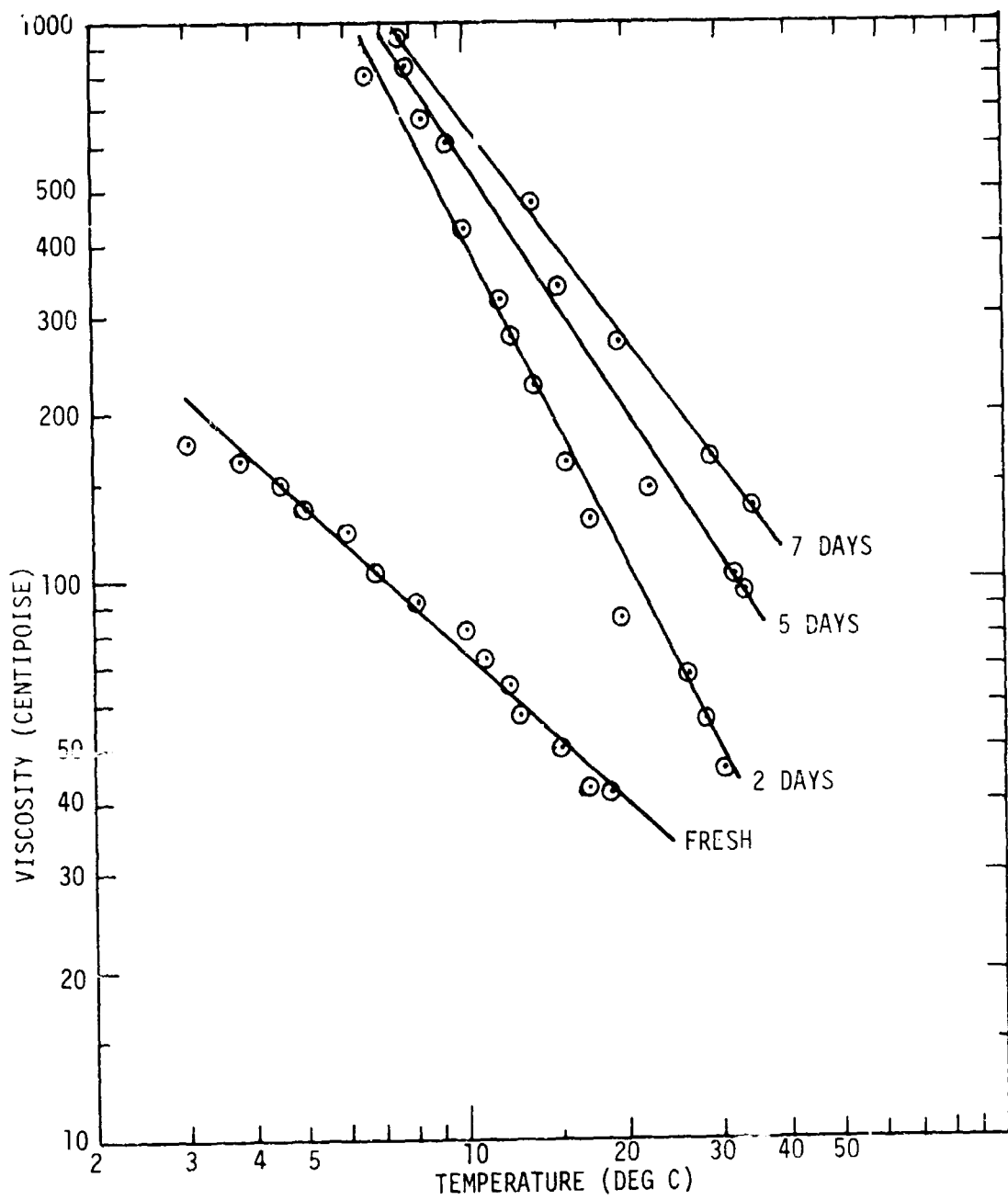


FIGURE 14.- Viscosity of Prudhoe Bay crude oil aged on water.

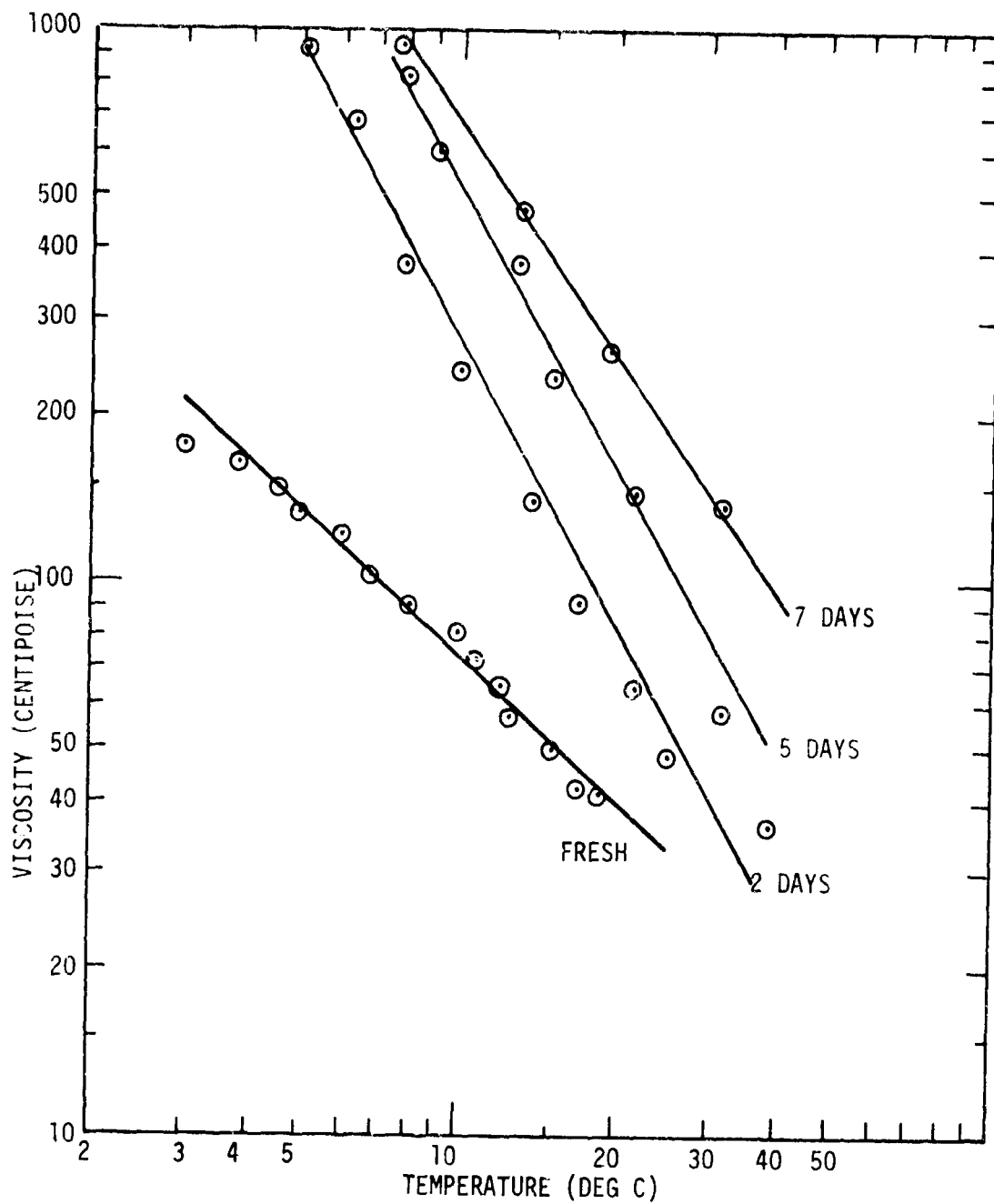


FIGURE 15.- Viscosity of Prudhoe Bay crude oil aged on ice.

The viscosity measurements were made with a Brookfield viscometer. In running the analysis, the sample was first preheated to its cloud point (approximately 150°F). Measurements were taken as the oil was cooled down to near 32°F. It was noticed that the viscosity curves measured while raising the temperature of the oil differed from curves measured while lowering the temperature. This was attributed to the formation of colloids in the cold oil which created a non-homogeneity.

Surface tension measurements proved to be the most difficult as the forces are small and easily upset by impurities. Air-oil surface tensions were calculated by measuring the oil rise in a capillary tube. The air-oil surface tensions are given in Figure (16).

Oil-water interfacial surface tension values were calculated by creating capillary waves of known frequency at the interface and measuring the wave lengths. The measurement process proved to be extremely delicate and the precision of the measurements was very low. As a result only the interfacial tension of fresh crude was adequately determined and was approximately 45 dynes/cm.

From a more general point of view, the oil became very thick and gummy by the end of the aging period. The oil physically resembled a light tar at the end of the period whereas the fresh crude had the viscosity of a motor oil. Based on the trend of the curves, it is apparent that the oil will become very viscous and hard to handle at lower temperatures, but that aging will have less of an effect on the viscosity at these temperatures.

The chemical analysis of the crude was performed on samples which were sent to shoreside laboratories for tests to determine their boiling point distribution, and the ratio of saturates to aromatics.

The distillation yield data (boiling point distribution) are given in Figures (17) and (18) for samples aged on water, on ice, and under ice. Shown are the loss of light ends due to weathering, which is more severe for aging on water than on ice, possibly due to higher temperatures. The curves indicate that almost all the changes in the boiling point distribution occurred in less than 5 days.

Table (3) lists the ratios of saturates to aromatics obtained from two independent laboratories and the percentage of the gasoline fraction. The difference between the ratios obtained from the two laboratories are most likely attributable to differences in the analysis procedure. One analysis for oil aged on water shows a rise in the ratio of saturates to aromatics. However in view of complications involved in sample handling and the complexity of the work-up procedure, it cannot be stated that the change is statistically significant. Rather, the indications are that there is little change in the ratio with time.

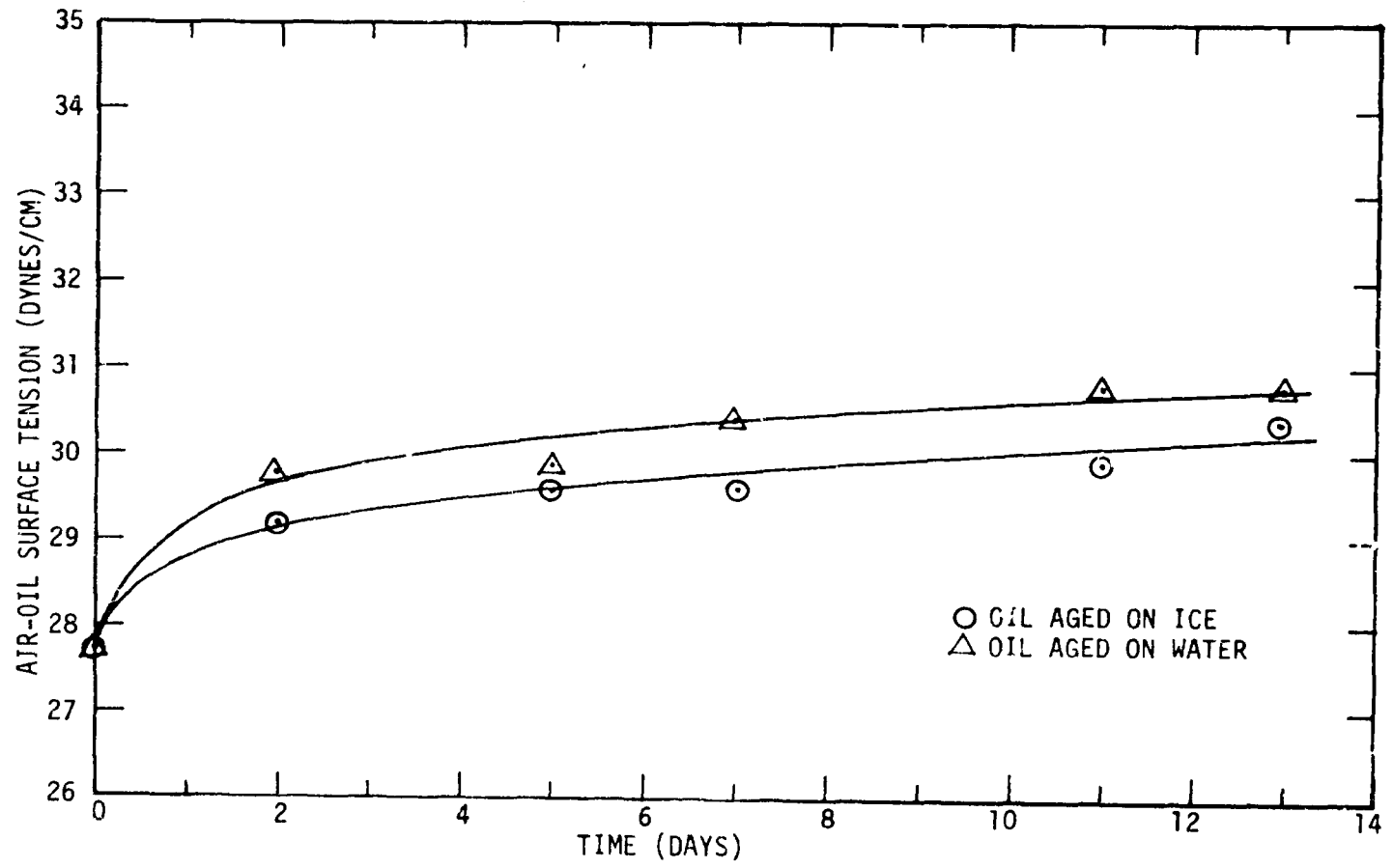


FIGURE 16.- Air-oil surface tensions for aged Prudhoe Bay crude oil.

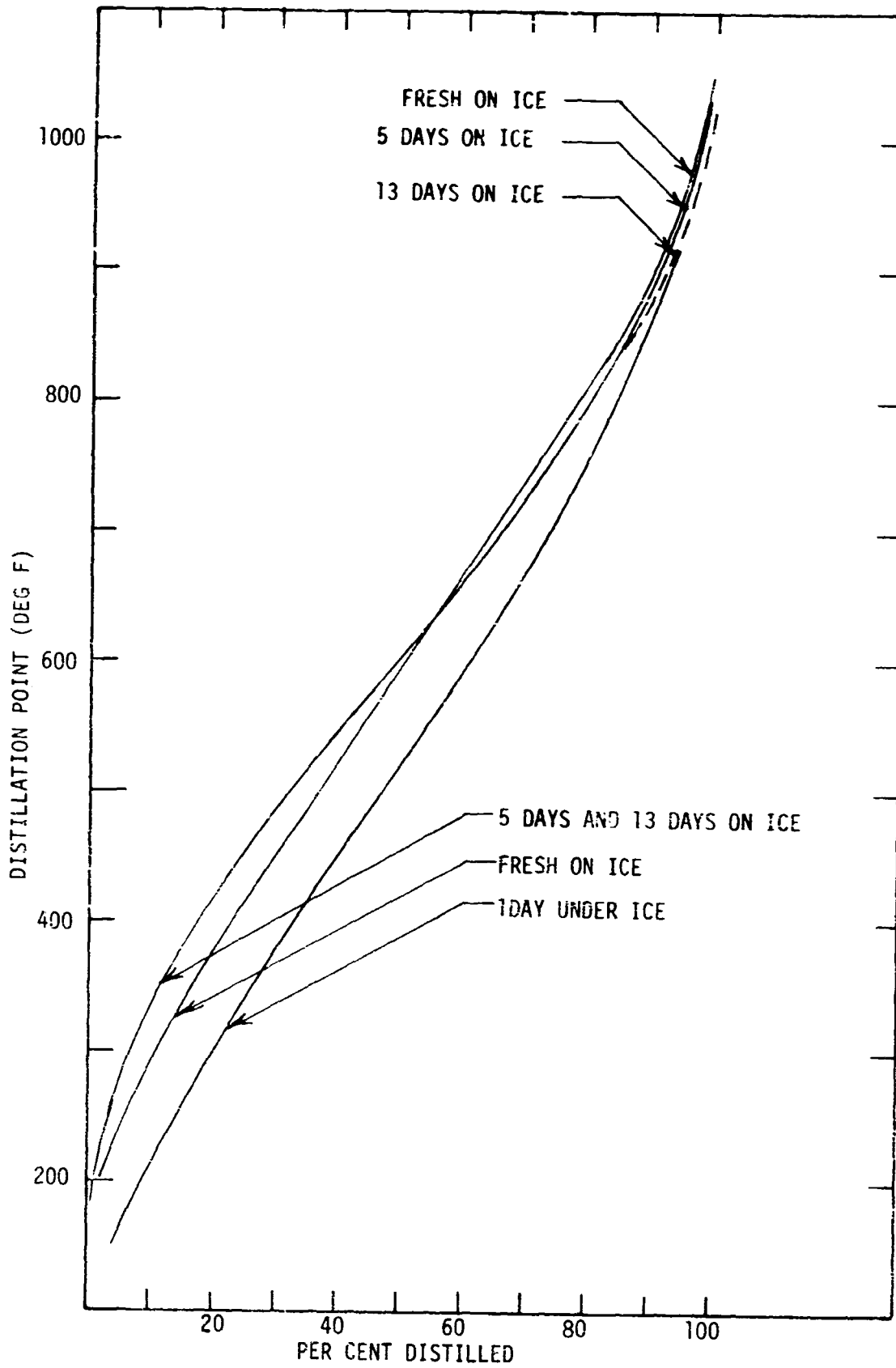


FIGURE 17.- Prudhoe Bay crude oil aged on ice and under ice.
Distillation by gas chromatography.

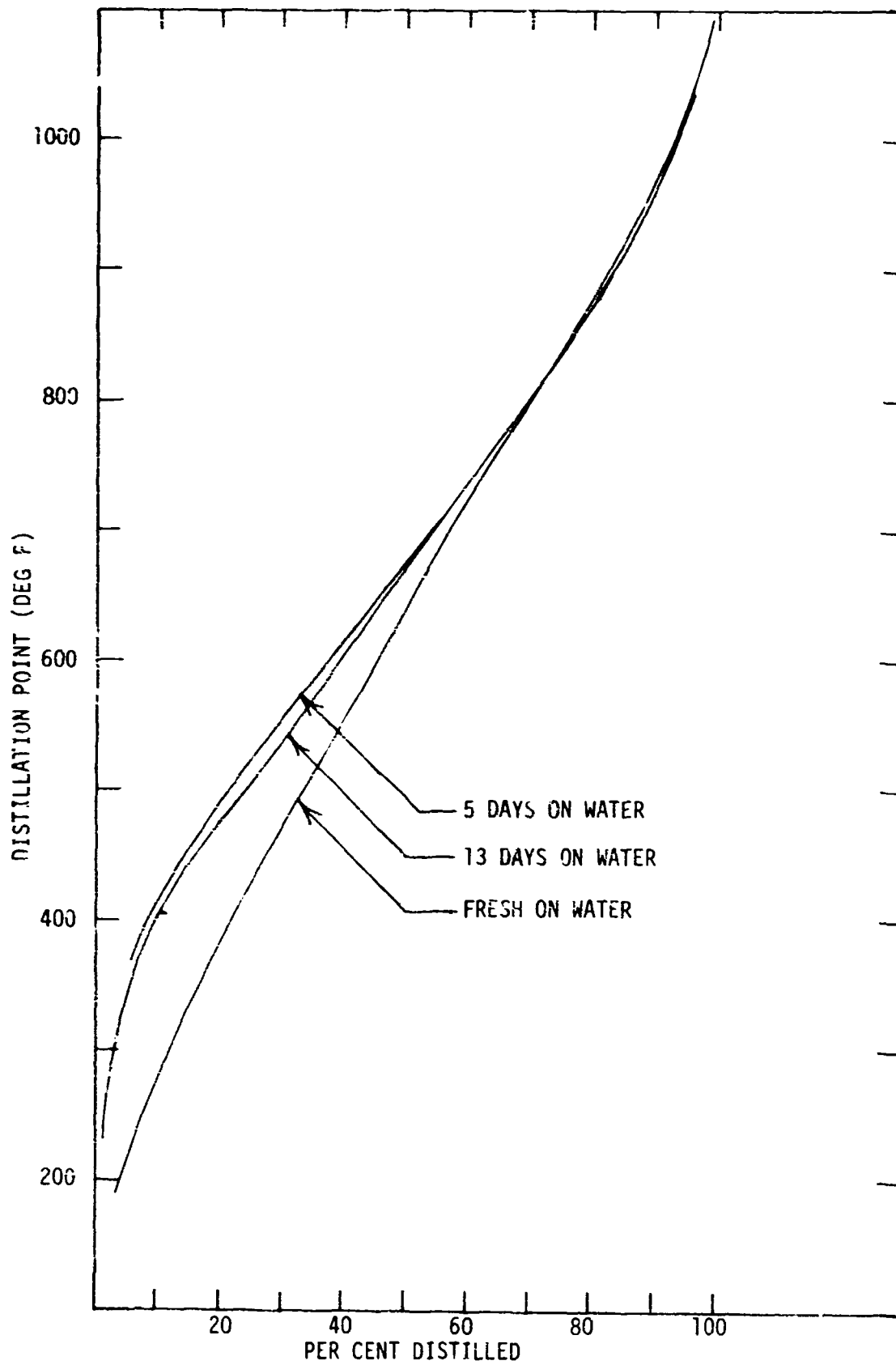


FIGURE 18.- Prudhoe Bay crude oil aged on water. Distillation by gas chromatography.

Type Sample	Aging Time in Days	Boiling Range* (deg. F)	Sat./ Arom.	Sat./Arom.	Gasoline (C ₄ -C ₇)%
Aged on Water	0	130-852	3.20	1.3	5.6
	1			1.2	4.4
	5	376-920	4.79	1.2	0.38
	8				0.27
	11	201-827	4.37		0.65
Aged on Ice	0	157-870	3.11		
	5	175-877	4.60		
	13	254-863	3.20		
Aged Under Ice	1	140-933	4.62		

*Range of maximum distillable liquid fraction by glass spiral still at pressures from 1 atm. down to 1 mm Hg.

Table 3.- Effect of Arctic aging on crude oil composition.

Surface water samples were taken for analysis to determine whether or not any hydrocarbon utilizing microorganisms were present. The analysis was carried out by two independent laboratories, whose reports are given in Appendices (3) and (4). Neither laboratory isolated any microorganisms which could degrade hydrocarbons at the ambient temperatures of the Arctic.

However, one of the laboratories isolated microorganisms which could utilize hydrocarbons at elevated temperatures, but more importantly, isolated bacteria which effectively were able to disperse #4 and #6 heating oils. It was observed during the test program that diesel oil was gradually emulsifying after remaining on water for several days. A pungent odor was also given off by the oil, indicating that some kind of bacterial action was taking place. Some emulsification of the crude oil was also observed.

It may be concluded from the sample analyses that the physical and chemical characteristics of the oil change sufficiently to require consideration in future work. In addition, microorganisms found in the surface water samples point to the possibility that other microorganisms may be present in the Arctic which would have a significant effect on the fate of spilled crude oil.

SUMMARY OF RESULTS AND CONCLUSIONS

The results of the experiments, which have been presented in the previous sections, are summarized as follow.

It was found that an upper layer of recrystallized ice in the test area absorbed up to 25 per cent of its volume in oil which had been released on the surface. The oil traveled through the upper layer seeking the lowest possible level, eventually migrating to the melt ponds present. Data from the spreading experiments on ice show power law relationships between certain of the parameters investigated.

When released on water, the spreading of the crude oil was significantly affected by the wind. As a result of a net negative spreading coefficient, the crude would not spread out as a thin film. Crude oil which was released under an ice cover rose to the surface, where it remained without dispersing to any great extent.

The North Slope crude burned easily under all conditions except when in a thin film. No burning agents were required. Burning resulted in the estimated removal of 90 to 98 per cent of the oil spilled.

Straw and peat moss were used as absorbants. Peat moss showed limited promise. Straw proved to be very effective when used on spills made on water and ice. The ratios of weight of oil absorbed to weight of absorbant were determined and found to be similar to the ratios observed under more temperate conditions.

An investigation into the effect of an oil spill on the arctic heat budget showed general agreement with past work done on the subject.

Samples were collected of oil aged in the environment up to 13 days. Physical and chemical analysis showed measurable changes in certain characteristics of the crude oil. Loss of the volatiles occurred in less than 5 days.

Analyses of surface water samples do not show the presence of any micro-organisms capable of degrading hydrocarbons at the ambient temperatures, although bacteria which effectively disperse oil were isolated.

Some generalized conclusions concerning oil pollution problems in the Arctic may be drawn from these results.

Although it will not be known for certain until a large spill occurs, it appears that a massive summertime oil spill in the Arctic would not be as difficult to control as was first expected. Unless the spill occurred in an area which is not under ice cover to any extent, the roughness of the natural ice cover would help contain the oil or slow down its spreading. The behavior of a light crude in the Arctic is similar to that in warmer climates, allowing many existing cleanup techniques to be used. In addition, the presence of ice provides a platform from which cleanup efforts can be based.

On the negative side, natural roughness on the underside of an ice field may trap large quantities of oil for an extended period. It may prove to be very difficult to remove the oil contained in the under-water ice pockets.

A spill in the winter could present a totally different set of problems. The extreme cold would most definitely hinder cleanup operations. In addition, the physical properties of the oil would be a great deal different because of the temperatures encountered.

However, it should be noted that in several ways summer presents the worst set of conditions. The relatively warm temperatures will keep the oil in a low viscosity state, thus aiding its spread over ice and water. The constant sunlight will cause the greatest addition of heat to the environment and cause the greatest melting of the ice. From a more positive point of view however, the oil removal methods of burning and absorption should be most effective in the summer.

The conditions under which the tests were performed were typical of the general area north of Alaska at that time of year. However, when considering the information presented in this report, allowances should be made for the possibility that future spills may be of a different kind of oil in a different location.

As a result of the test program a major objective was accomplished; a foundation was provided for a working knowledge of arctic oil pollution problems. In continuing the work which has been started, future efforts will be directed at better defining the various processes occurring during a spill, with the end result being the development of methods for the prevention of future damage to the fragile environment of the Arctic.

Test: 45 gal warm crude, 12" orifice

Type of oil — crude
 Volume — 45 gal
 Orifice — 12 inches
 Duration — 3.0 secs
 Temperature — 29°C

Test: 97 gal warm crude, 12" orifice

Type of oil — crude
 Volume — 97 gal
 Orifice — 12 inches
 Duration — 3.0 secs
 Temperature — 29°C

l (FT)	t (SECS)		$\frac{l}{\sqrt{3}}$	$\frac{t}{\sqrt{\frac{3}{5}}}$		l (FT)	t (SECS)		$\frac{l}{\sqrt{3}}$	$\frac{t}{\sqrt{\frac{3}{5}}}$	
	(a)	(b)		(a)	(b)		(a)	(b)		(a)	(b)
1						1					
2	.5	.3	1.10	1.98	1.13	2					
3	.6	.7	1.65	2.38	2.77	3		.39	1.28		1.35
4	.9	1.0	2.20	3.56	3.96	4					
5	1.4	1.1	2.75	5.55	4.35	5	.6	.75	2.13	2.07	2.59
6	1.8	1.2	3.30	7.13	4.75	6					
7	2.1		3.85	8.31		7	1.7	1.09	2.99	5.86	3.76
8	2.4		4.40	9.50		8					
9						9	1.75	1.3	3.84	6.35	4.49
10						10					
11						11		3.0	4.69		10.4
12						12					
13						13		3.4	5.54		11.7
14						14					

Test: 55 gal crude on saturated ice

Type of oil — crude
 Volume — 53 gal
 Orifice —
 Duration — 426 secs
 Temperature — 6°C

Test:

Type of oil —
 Volume —
 Orifice —
 Duration —
 Temperature —

l (PT)	t (SECS)		$\frac{l}{\sqrt{s}}$	$\frac{t}{\sqrt{\frac{l}{s}}}$		l (PT)	t (SECS)		$\frac{l}{\sqrt{s}}$	$\frac{t}{\sqrt{\frac{l}{s}}}$	
	(a)	(b)		(a)	(b)		(a)	(b)		(a)	(b)
1		1	.521		3.88						
2		3.4	1.04		13.2						
3		15.5	1.56		60.1						
4		26.3	2.08		102						
5		32.4	2.60		126						
6		48.3	3.12		188						
7		74.7	3.64		290						
8		88.2	4.16		342						
9		106	4.59		409						
10		119	5.21		464						
11		136	5.72		527						
12		192	6.25		745						
13		275	6.77		1067						
14		319	7.29		1203						

Appendix (2): Analysis Procedure - Adsorbant Samples

The whole sample, as received, was used in the analysis. The samples were weighed and then extracted with chloroform in a Soxhlet extractor for 24 hours. The chloroform was removed from the extract by distillation, after which the weight of the extract was recorded. Since considerable amounts of light oil components co-distilled with the chloroform, the weight of the recovered extract was corrected for this loss. This was done by comparing the volatility distribution of each extract with that of the original crude sent. The volatility distribution was determined in a simulated distillation done by gas-liquid chromatography. The reported weight of adsorbed oil is therefore a corrected weight, based on the original spilled oil.

The weight of adsorbent was determined after the extraction. Since it was thought that the extraction might have affected the original water content of either the straw or the peat, a correction was also made. The extracted adsorbents were dried for 2 hours at 105°C in a vacuum oven. The weights of dried adsorbent for the four samples were then corrected for moisture and volatile losses by comparison with the losses measured for the unused straw and peat samples that was provided. In this connection we notice that the peat sample appeared to have been previously dried. These corrected weights were used in the report above.

The water content was calculated as the difference between the original sample weight and the weight of oil and adsorbent as determined above. The water thus determined is that acquired in the course of adsorbing the spilled oil and does not include the water that is originally part of the adsorbent. Since it is determined by difference, the value for water will be subject to the accumulated errors in the determination of the oil and the adsorbent.

Appendix (3) Water Sample Analysis

(Esso Research Laboratories, Linden, N.J.)

Arctic water samples #2 and #4 received on Sept 21., 1970 have been screened by spread plate technique for the presence of microorganisms. One milliliter sample of each was spread out on Nutrient Agar (NA) and Sabourand's Maltose Agar (SMA) plates. The plates were incubated at 30°C. After 5 days of incubation the plates were examined for the presence of microorganisms. One fungus strain from sample #2 and one bacterium (Fig. 1 and 2) and one fungus strain from sample #4 were isolated. The molds (designated as fungus-A and fungus-B) appear to belong to genus fungi imperfectii. Further studies are required to establish the taxonomic position of these isolates. The bacterium is a gram-positive rod measuring 0.7 to 1.5 microns long; and exhibits a characteristic division by fragmentation. The results are summarized in Table I.

The above isolates have been investigated, for their ability to utilize hexadecane at 30, 24, 20 and 15°C. as the sole source of carbon in a basal salts medium in shake flask experiments. The bacterium was observed to grow well at 30°C, 24°C and showed slight growth at 20°C and no growth at 15°C. The two molds showed growth after 5 days of incubation at 24°C.

The culture broths of the three isolates were tested for their ability to disperse heating oils #4 and #6. Only the culture broth of bacterium was able to disperse the oils rapidly.

Conclusions:

- ° Arctic water samples submitted for microbiological analysis contain about 1000 microorganisms per liter.
- ° The two fungi isolated utilize hexadecane as carbon source slowly at 24°C.
- ° The optimum temperature for the two molds appear to be 24°C. and require extraneous organic nitrogen supplementation for growth.
- ° The culture broths of these isolates do not disperse heating oils #4 and #6.
- ° The gram-positive bacterium isolated from arctic water sample #4 can utilize hexadecane as the sole source of carbon at 30°, 24, 20°C but not at 15°C.
- ° The optimum temperature for growth appears to be between 20-24°C.
- ° The bacterial culture broth is capable of dispersing #4 and #6 oils.

TABLE 1

Distribution of Microorganisms in Two Arctic Water Samples #2 and #4.
The Samples were collected by Dr. Robert C. Ayers, Jr. EPRC - Houston.

Sample Code	Date Collected	Location	pH	Incubation		Type and Number of Microorganisms				Staining Characteristics
				Temp.	Days	NA*	SMA**	NA	SMA	
#2	7/22/70	71°N, 160°W	4.5	30°C	5	--	--	--	1(F)	--
#4	7/30/70	71°N, 158°W	5.0	30°C	5	1(B)	--	--	1(F)	Gram + ve (5)

* NA = Nutrient Agar
** SMA = Sabourand's Maltose Agar

B = Bacteria
F = Fungus

Appendix (4) Water Sample Analysis

(Scripps Institution of Oceanography)

Microbial Oxidation of Oil in Six Seawater Samples Collected

Arctic Area as Indicated by O₂ Uptake or Microbial Growth in Sterile

Seawater (75%) Enriched with Paraffin Oil and Ammonium Phosphate

Sample number	Date of collection	Station location	Volume used as "seed" (ml)	Oil oxidation after 21 days incubation at	
				5°C	26°C
1	6/22/70	71°N 160°W	1	nil	nil
			10	nil	nil
			50	nil	nil
3	6/24/70	71°N 160°W	1	nil	nil
			10	nil	nil
			50	nil	nil
5	6/30/70	71°N 158°W	1	nil	nil
			10	nil	nil
			50	nil	nil
6	6/30/70	71°N 158°W	1	nil	nil
			10	nil	nil
			50	nil	nil
7	6/30/70	71°N 158°W	1	nil	nil
			10	nil	nil
			50	nil	nil
8	6/30/70	71°N 158°W	1	nil	nil
			10	nil	nil
			50	nil	nil

The presence of living heterotrophic bacteria in all samples was indicated by their growth and O₂ uptake at both temperatures in seawater medium enriched with peptone and glucose.

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13. ABSTRACT <p>A program to investigate the behavior of oil spills in the Arctic was conducted off the northern coast of Alaska in July 1970. Numerous small oil spills were made to obtain data on the following subjects: the spreading behavior of crude oil on ice and water surfaces; the interaction characteristics of crude oil with ice; the aging characteristics of crude oil which has been spilled on ice, on water, and under ice; and the effectiveness of burning and absorption as methods of removal.</p> <p>Both Prudhoe Bay ("Sag" River) crude oil and diesel fuel were used in the test program. Results quantify spreading and interaction characteristics in addition to presenting qualitative information on each area of interest. Promise is shown for both burning and absorption as methods of oil removal in the summer. Data is presented on both the physical and chemical characteristics of aged crude oil.</p>			

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