

IN-PLACE BURNING OF CRUDE OILS IN BROKEN ICE¹

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ABSTRACT: In March 1986, in-place oil-burning tests were conducted at the U.S. Environmental Protection Agency's Oil and Hazardous Materials Simulated Environmental Test Tank (OHMSETT) facility in Leonardo, New Jersey. These tests culminated a three-year effort to explore the range of conditions under which in-place burning of oil is possible in broken-ice conditions. Four tests were conducted in the OHMSETT test tank in a 42 m² area, and 19 follow-on tests were conducted in a 1 m² pan. The tank tests used Hibernia A and Prudhoe Bay crude oils. The oil was burned in an area having 60% to 75% ice cover. In tests with Hibernia A, both neat and aerated to raise the flash point to 14° C, a total of 65% to 75% of the oil was removed by burning. The neat Prudhoe Bay crude was aerated to a flash point of 46° C and only allowed removal of 18% of the oil. An emulsion of 9% Sandy Hook Bay water and 91% Hibernia crude burned, removing 55% of the emulsion.

The pan tests used four crude oils in neat, aerated, and emulsified conditions. These included Prudhoe Bay, Hibernia A, Hibernia B, and Hibernia C crude oils. The pan tests confirmed trends observed in the tank tests: the removal efficiency of burning decreases by the presence of water in the oil and as the flash point of the oil increases. This phenomenon may be attributed to changes in chemical composition and loss of more volatile (flammable) components of the oil.

These tests were sponsored by the OHMSETT Interagency Technical Committee, which includes representatives from the U.S. Minerals Management Service, Canadian Environmental Protection Service, U.S. Coast Guard, and U.S. Environmental Protection Agency.

In Arctic broken-ice conditions, where oil spill cleanup operations are hindered and mechanical means of cleanup may not be possible, in-place burning of the slick may be an alternative. To determine the feasibility of in-place burning, a series of tests was sponsored by the OHMSETT Interagency Technical Committee (OITC). The tests were conducted at the U.S. Environmental Protection Agency's OHMSETT facility in Leonardo, New Jersey.²

The 1986 test season is the culmination of a three-year program.^{3,4} The results of the first season of testing indicated that in-place burning may indeed be an effective technique for use in broken-ice conditions. Removal efficiencies of 85% to 95% were observed. The results of the second season of testing illustrated the burn-inhibiting effects of water emulsified in the oil and of increased flash point. The goals of the third season of testing were to gather more data on the decrease of

removal efficiency with respect to flash point of the oil and to obtain additional data using other crude oils. The pan tests during this third test season were to provide further data establishing trends in removal efficiency.

The practical benefits of the test results included the acquisition of information for oil spill control in the northern regions. In fact, the study of the particular oil properties and ice coverage will allow estimation of expected burn efficiencies and permit an on-scene coordinator to decide if it is feasible to burn the oil.

Tank tests

Test fluid preparation. Three drums of Hibernia crude oil from the Canadian Environmental Protection Service and Prudhoe Bay crude oil from the OHMSETT stock were selected for the tests. The Hibernia crudes will be referred to as Hibernia A, B, and C, reflecting their different physical properties. The tank tests used neat Hibernia A oil, emulsified Hibernia A oil, and aerated Hibernia A and Prudhoe Bay crude oils.

Both Prudhoe Bay and Hibernia A were aerated to increase the flash point for the tank tests. A volume of oil was placed in a 1 m³ capacity rectangular tank measuring 0.6 m × 1.5 m × 1.1 m deep. A 5.6 cm diameter, 58 cm long air sparger was placed in the tank below the oil surface and operated until the desired flash point was reached. The flash point of the Prudhoe Bay crude oil increased from 1° to 46° C. This required 36.5 h for the Prudhoe Bay crude at varying air flow rates with heat added. The flash point of the Hibernia A crude increased from -1.7° to 14° C, at 4.5 h at an air flow rate of 17 to 25 m³/h.

Several emulsions were prepared to determine the effect of water in the oil. The oil was mixed with the appropriate volume of saline water from nearby Sandy Hook Bay in a 55 gal (0.2 m³) drum. The emulsion was formed by recirculating the oil-water mixture through a 2 in. (5.1 cm) Viking gear pump, exiting through a 0.75 in. (1.9 cm) nozzle into the drum. The flow rates ranged from 60 to 120 L per min over a 2 h, 45 min recirculation time.

The test fluids were analyzed in the OHMSETT laboratory according to standard analytical procedures. The procedures and results are described below.

Broken-ice fields. Tests were conducted in the OHMSETT tank in a 5.8 × 7.3 m test area enclosed by a rigid wood boom constructed from 5.1 × 20.3 cm boards. The test area was positioned midtank near the underwater photo-video windows. Ice was provided by placing 140 kg freshwater ice cakes, nominally 55 × 120 × 22 cm, in individual wooden spacers to maintain a clearance of 3 to 4 cm between ice cakes (Figure 1).

Slick distribution system. A low flow rate oil distribution system employing an air-driven Sandpiper diaphragm pump delivered the test fluid from a 55 gal (0.2 m³) drum through a 1.5 in. (3.8 cm) hose to a point approximately 0.6 m beneath the center of the test area (Figure 2).

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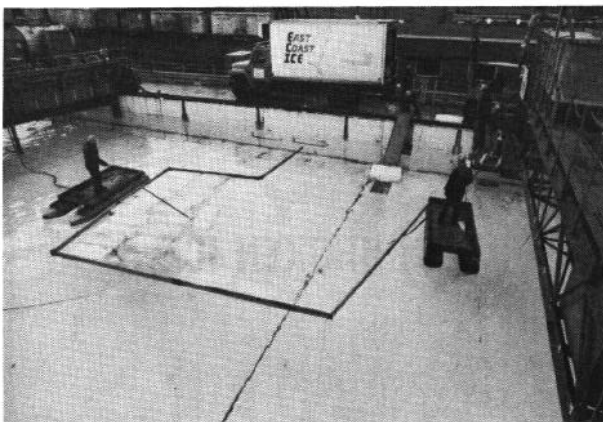


Figure 1. Machine-made ice cakes being deployed

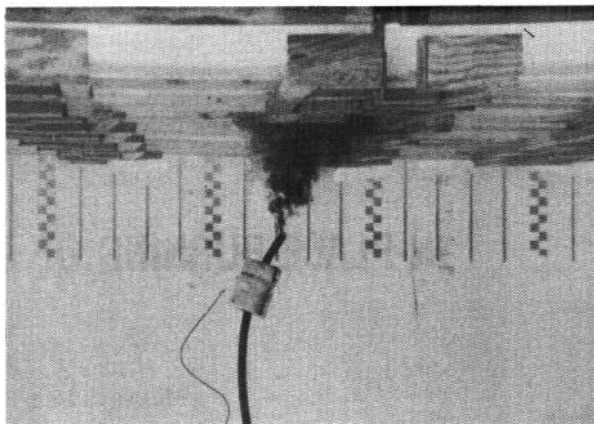


Figure 2. Test fluid being distributed beneath the water surface

Ignition devices. Two ignition devices were used during testing. The first was a site-fabricated igniter constructed from an Ethafoam flotation log approximately 13 cm in diameter and 32 cm long. This was wrapped in a sorbent pad, soaked in diesel fuel, and sprayed with an ether-based starting fluid just prior to ignition. The second igniter was a pin-activated, delay pyrotechnic device provided by the Canadian Environmental Protection Service.⁵

Instrumentation. A color video camera was mounted on the end of a crane boom and suspended 15 m above the test area to provide an overhead view of the tests. This view was used to determine the percentage of the test area covered by ice. A Climatronics weather station, mercury thermometer, and hand-held anemometer were used for environmental measurements throughout the tests. Perhaps the most important type of data, that on percentage of oil removed, was

determined by retrieving the oil residue onto preweighed oleophilic sorbent pads measuring 45 × 45 cm or onto preweighed household colanders, depending on the viscosity of the residue. The residue-laden sorbent pads were then weighed on a calibrated platform scale. The amount of water held by the sorbent was insignificant and not considered in the mass balance calculation.

Backup safety system. The Naval Weapons Station Earle Fire Department special assignment crew was standing by during each test. This was a precautionary measure in the event that burning oil escaped the boomed test area.

Procedure. After deployment of the ice, 35.6 L of test fluid were distributed beneath the water surface near the center of the test area. The distribution hose was purged with water, and the oil was allowed to spread until the slick appeared to reach equilibrium.

Table 1. Results of tank testing with neat and aerated oils

Test no.	Oil designation	Oil state ₁	Air temperature (°C) ₂	Water temperature (°C) ₂	Wind speed (mph) ₂	Ignition time (min : s)	Burn time (min : s)	Ice coverage (%) ₃	Percentage burned off (15%) ₄
1986									
1	Hibernia A	Neat (FP 1.7° C)	5.5	1.9	17	0 : 02	8 : 15	60	65
2	Prudhoe Bay	Aerated (FP = 46° C)	19.6	4.1	15-50	0 : 05	21 : 41 ₅	65	18
3	Hibernia A	Aerated (FP = 14° C)	12.6	4.6	10	0 : 02	6 : 30	75	75
1985									
1	Prudhoe Bay	Fresh (FP < 0.5° C)	5	4	2	0 : 15	11 : 31	76-81	72.4
1R	Prudhoe Bay ₆	Fresh (FP < 1.7° C)	-6	0	8	0 : 15	24 : 03	84-86	62.5
1R2	Prudhoe Bay	Fresh (FP < 0.5° C)	-1	0	2	0 : 06	13 : 45	82-89	58.3
4	Prudhoe Bay	Sparged (FP = 24° C)	-3	0	4	0 : 15	15 : 50	75-84	79.1
6A	Prudhoe Bay	Sparged (FP = 40° C)	7	0	6	0 : 13	9 : 21	75-80	61.9
8A	Prudhoe Bay	Sparged (FP = 40° C)	-1	0	2	0 : 07	8 : 07	78-84	68.3
9A	Amauligak	Fresh (FP < 0° C)	3	5	4	0 : 07	16 : 32	82-88	62.9
10A	Amauligak ₇	Sparged (FP = 38° C)	11	7	1	0 : 08	27 : 15	82-83	68.3
1984									
1	Prudhoe Bay	Neat (FP < 0.5° C)	4.9	3.8	12		7 : 53	45-35	85
6	Prudhoe Bay	Neat (FP < 0.5° C)	8.2	5.4	14		8 : 15	45-30	95
A1	Prudhoe Bay	Aerated (FP = 27° C)	4.3	7.7	8		11 : 00	60-45	90
10	Prudhoe Bay	Neat (FP < 0.5° C)	4.8	7.7	13		9 : 40	≈ 45	85

1. FP = flash point

2. Measured prior to testing

3. Range based on average ice coverage measurement

4. Based on estimated measurement errors and not statistical analysis

5. Slick had to be reignited twice

6. With 6.6 L oil lost during oil distribution

7. Light brown emulsion observed on test surface after oil distribution

Table 2. Results of tank testing with oil and water emulsions

Test no.	Oil designation	Air temperature (°C) ₁	Water temperature (°C) ₁	Wind speed (mph) ₁	Ignition time (min:s)	Burn time (min:s)	Ice coverage (%) ₂	Percentage burned off (15%) ₃
1986 4	9% Bay water/ 91% Hibernia A	4.7	5.1	15	0:03	7:00	70	55
1985 5A	18% Bay water/82% Prudhoe Bay crude	4	0	6	0:17– 0:21	51:19 ₄	81–86	9.6
7A	8% Bay water/92% Prudhoe Bay crude	4	0	7	0:07– 0:15	41:43 ₄	79–85	34.7
11A	9% Bay water/91% Amauligak crude	12	7	5	0:08 0:43	43:41 ₄	76–80	51.7

1. Measured prior to testing
2. Range based on average ice coverage measurement
3. Based on estimated measurement errors and not statistical analysis
4. Slick had to be reignited twice

The slick was then ignited, and a stopwatch was started when black smoke first appeared. The test was considered complete when the flames went out.

Subsequently the entire boomed area was pulled over to one side of the tank and the residue was herded into one corner of the boom by indirect fire hose spray. The ice cakes were rinsed and pushed down and out of the boomed test area, and the ice spacers were retrieved. The herded residue was picked up using sorbent pads or colanders and weighed. From this the percentage of oil removed by burning was determined.

Calculations. Removal efficiency was calculated using the following equation:

$$RE = (1 - WR/WI) * 100\% \quad (1)$$

Where: *RE* = removal efficiency

WR = weight of residue

WI = weight of initial test fluid distributed
(based on volume of fluid and specific gravity)

The initial ice coverage was measured gravimetrically. A photocopy of an 8 × 10 overhead photo was cut up to separate the ice-covered area from the remaining test area. The pieces were weighed on a Mettler H31 balance and percentage ice cover was calculated using the relative weight of the ice cake surface area on the photocopy divided by the total test area weight.

Results. The results of the four tank tests are given in Tables 1 and 2. Figures 3 and 4 show the details of the fire in test 4 using aerated Prudhoe Bay crude. The results of tests using neat, aerated, and emulsified Hibernia A crude oil match trends observed in previous

tests: the neat oil exhibited a high removal efficiency, the aerated oil a lower removal efficiency, and the emulsified oil the lowest removal efficiency.

The Hibernia A emulsion was planned to be 10% saline water/90% Hibernia A oil. Owing to the characteristics of the Hibernia A oil, the emulsion separated before the laboratory analysis was performed. The percentage of water still emulsified in the oil at the time of the test was approximately 9%.

Pan tests

Test fluid preparation. The four oils used in the pan test included Prudhoe Bay, Hibernia A, Hibernia B, and Hibernia C. The aerated samples were prepared in the fume hood at OHMSETT. Open top, metal containers containing 1 gal (3.8 L) were filled with the appropriate neat oil, and air was forced through the oil using Tygon tubing and a compressed air source. The flash point was measured frequently to determine whether the desired value had been reached. The container of oil was also heated by placing it on a steam bath to increase the rate of volatile organic loss. The emulsions were formed in the laboratory by placing a volume of the neat oil with Sandy Hook Bay water in a blender and allowing it to run for 12 1-min cycles at 10 s intervals at 9,200 rpm.¹

The physical characteristics of each of the neat oils used in the pan tests are given below.

Test setup and procedure. Tests were conducted in a 1 m² pan with a depth of 20 cm. The pan was filled with tap water and 40 to 80 lb of cube ice prior to each test. A 2.27 L preweighed volume of oil was

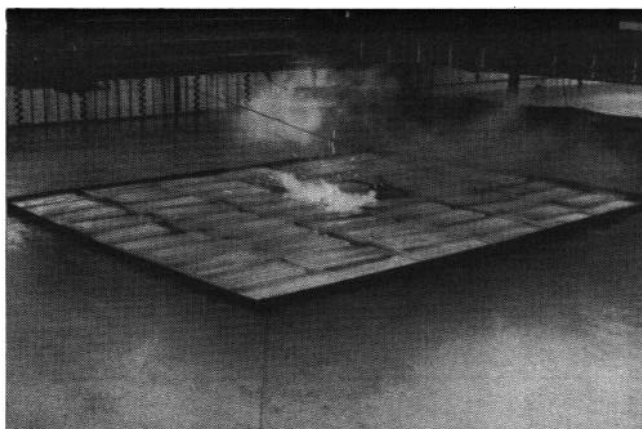


Figure 3. Slick of aerated Prudhoe Bay crude (with flash point of 46° C), ignited by pyrotechnic device

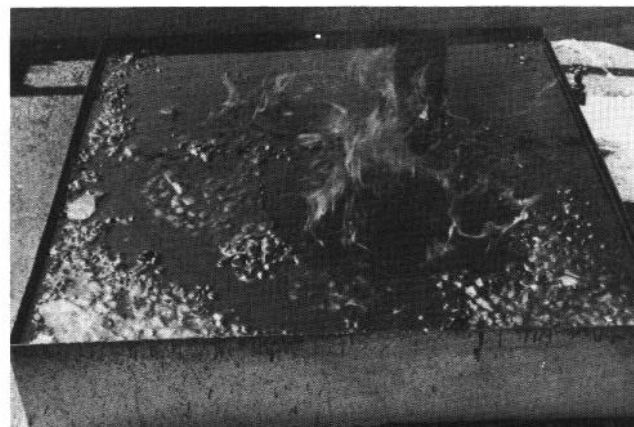


Figure 4. Flame intensity of test 4

Table 3. Results of pan testing with neat and aerated oils

Test no.	Oil designation	Target oil state	Flash point (° C)	Percent removed	Burn time (s)
S-6	Hybernia A	Flash point 10° C	14	62	190
S-7	Hybernia A	Flash point 24° C	36	20	601
S-11	Hybernia B	Neat	-1	52	418
S-16	Hybernia B	Flash point 10° C	18	35	360
S-17	Hybernia B	Flash point 24° C	29	47	321
S-18	Hybernia B	Flash point 38° C	39	12	384
S-26	Hybernia C	Flash point 10° C	18	39	708
S-27	Hybernia C	Flash point 24° C	33	43	383
S-28	Hybernia C	Flash point 38° C	40	41 ₁	736
S-31	Prudhoe Bay	Neat	0	50	211
S-36	Prudhoe Bay	Flash point 10° C	23	35	324
S-37	Prudhoe Bay	Flash point 24° C	29	29 ₁	921

1. Estimated owing to lack of primary documentation

Table 4. Results of pan testing with oil and water emulsions

Test no.	Oil designation	Target oil state	Flash point (° C) ₁	Percent removed	Burn time (s)
S-3	Hybernia A	20% Water emulsion	NA	23	328
S-12	Hybernia B	10% Water emulsion	NA	48	367
S-13	Hybernia B	12% Water emulsion	NA	19	543
S-32	Prudhoe Bay	10% Water emulsion	NA	5	417

1. NA = not applicable

distributed in the center of the test area and allowed to spread to equilibrium. Temperature and other environmental measurements were taken. Then the slick was ignited using a 10 × 10 cm segment of sorbent rolled up and soaked with 75 mL of a 50:50 diesel/gasoline mixture. This material was ignited and dropped onto the upwind edge of the slick. The burn time was recorded. After the test, the residue was retrieved on sorbent pads and weighed on an Ohaus Dual-Pan Balance to determine the percentage of oil burned off. Because of the limited available volume of Hybernia A oil, only three tests were performed on this oil.

Results. The results of the pan tests are given in Tables 3 and 4. Figure 5 shows test S-7.

During the preparation of the emulsions, it was found that certain ratios of water to oil did not create a stable emulsion. For example,

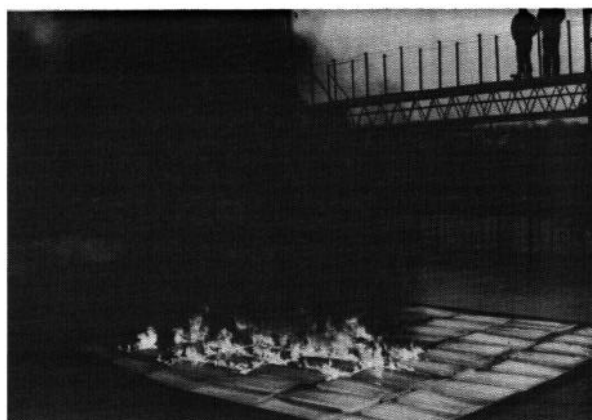


Figure 5. Overhead view of the 1 m² pan, showing the ice, oil slick, and flames in test S-7

mixtures containing 15% and 20% saline water in Hybernia B did not emulsify. Any mixture that separated greater than 5% of the initial water volume in 15 min was disqualified from testing. Hence, a 12% saline water/88% Hybernia B oil emulsion was used in lieu of the 15% water emulsion.

In several tests the entire slick surface did not ignite. This was expected in the tests using emulsions. However, it was also observed in the tests using the Prudhoe Bay crude with a flash point of 46° C. In this test only one-fourth of the slick surface ignited.

Laboratory analyses

The test fluids used were characterized for reference purposes by specific gravity, viscosity, flash point, surface tension, interfacial tension, percentage of water, and relative hydrocarbon composition. Specific gravity was measured using hydrometers as specified by the American Society for Testing and Materials (ASTM) D1298-67. Viscosity was measured using a Brookfield Model LVT viscometer at room temperature and an elevated temperature. Viscometer measurements were converted to centistokes using the relationship expressed in ASTM D2161-74, Section 6, and plotted on ASTM D341 viscosity temperature charts for interpolation to ambient conditions. Flash point was measured using a Fisher/Tag closed-cup tester as described by ASTM D56-70. Surface tension and interfacial tension with tank water were measured at approximately 22.5° C using a Fisher Scientific Model 21 Surface Tensiometer. Percentage water and

Table 5. Physical properties of the tank test fluids

Test no.	Test fluid	Flash point (° C)	Specific gravity	Viscosity (cs)	@ Temp. (° C)	Surface tension (dynes/cm)	Interfacial tension with tank water (dynes/cm)	Percentage water
1.	Neat Hybernia A	<-1.7	0.838	21.3 11.4 7.2	11.6 23.0 34.4	29	29	0.2
2.	Aerated Prudhoe Bay	46	0.903	67.3 38.4	22.2 34.8	32	25	0.2
3.	Aerated Hybernia A	14	0.852	45.0 17.1	22.2 34.7	30	27	0.6
4.	Emulsified Hybernia A/ Bay water	1	0.863	105.5 14.1	17.0 35.6	—	—	9 ₁

1. Not a homogeneous emulsion; sample not representative of test fluid; overall percentage water estimated at 9 percent

Table 6. Physical properties of the neat oils used in pan tests

Oil designation	Flash point (° C)	Specific gravity	Viscosity (cs)	@ Temp. (° C)	Surface tension (dynes/cm)	Interfacial tension with tank water (dynes/cm)	Percentage water
Hybernia A	<-1.7	0.838	21.3	11.6	29	29	0.2
			11.4	23.0			
			7.2	34.4			
Hybernia B	<-1.1	8.877	65.0	22.0	16	30	0.1
		0.871	21.8	37.0			
		0.884	30.5	23.6			
Hybernia C	<-2.2	0.875	19.4	37.0	28	28	4.8
		0.895	40.4	21.0			
Prudhoe Bay	8.9	0.887	21.4	35.0	24	32	0.1

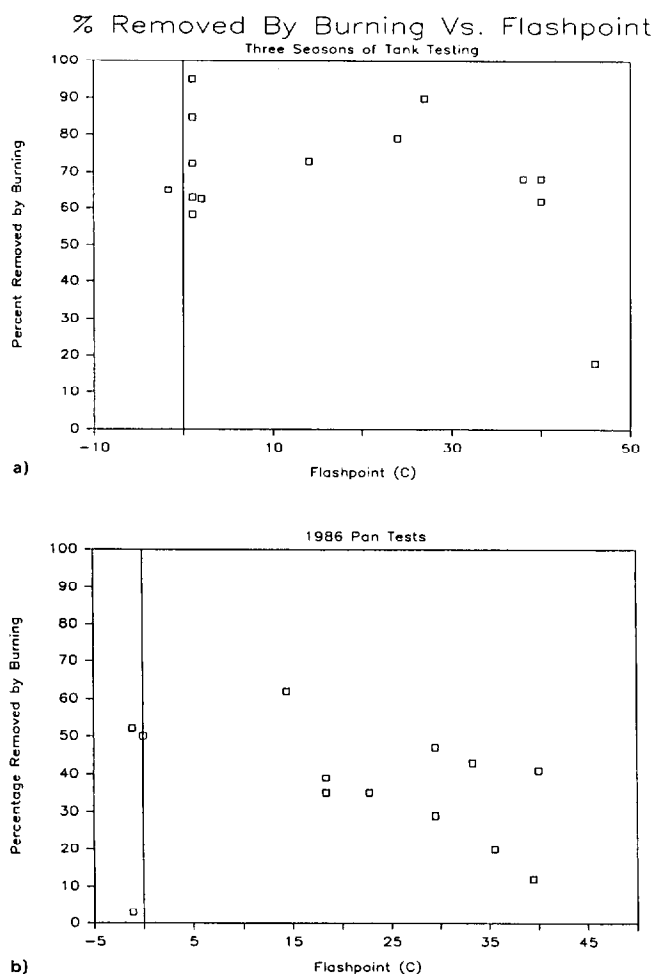


Figure 6. Plot of percentage removed by burning vs oil flash point, showing the overall decrease of removal efficiency as the flash point increases, in (a) OHMSETT tank tests and (b) pan tests

bottom solids were determined as specified in ASTM D1796-75. drocarbon contents were established by gas chromatography.

The results of analyses of the tank test fluids are given in Table 6. The emulsion used in the tank tests was examined with a microscope and found not to be homogeneous. Emulsion droplet sizes were determined, owing to the lack of homogeneity of the mixture.

Only the neat oils used in the pan tests underwent all of the analyses outlined above. The results of these analyses are given in Table 6.

Summary

This third series of tests in the investigation on the efficiency of burning as an oil spill removal technique confirmed the effect of aeration of neat oils and the effects of water emulsified in the oil. It is certain that removal efficiency decreases as flash point and concentration of water in the oil increase. Both the tank and the pan tests confirmed these trends (Figure 6).

The OHMSETT tests have demonstrated the potential of in-place burning as an oil spill cleanup technique in broken ice. Furthermore, the data obtained should provide guidance for determining the feasibility of burning any oil spill in the Arctic.

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