IN-PLACE BURNING OF CRUDE OIL IN BROKEN ICE[1]
1985 TESTING AT OHMSETT

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ABSTRACT

In January and March of 1985, 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. In-place combustion of Prudhoe Bay and Amauligak crude oil slicks was attempted in varying ice coverages, oil conditions, and ambient conditions. It was found that fresh and sparged (or topped) Prudhoe Bay crude oil burned successfully in ice coverages ranging from 75 to 90% of the available area, removing 60 to 80% of the oil (by mass). Fresh and sparged Amauligak crude oils were burned in 80 to 90% ice coverages removing 60 to 70% of the oil by mass. Emulsions of Prudhoe Bay oil and water were ignited three times each and burned in similar ice fields removing 10 to 35% of the emulsion. An emulsion of Amauligak crude oil and water was also ignited three times and burned in 80% ice cover, removing nearly 50% of the emulsion. The tests were sponsored by the OHMSETT Interagency Technical Committee (OITC), which is comprised of representatives from the U.S. Minerals Management Service, Canadian Environmental Protection Service, U.S. Coast Guard, U.S. Environmental Protection Agency, and the U.S. Navy.

INTRODUCTION

In response to the need for practical oil spill cleanup techniques in the Arctic, the OHMSETT Interagency Technical Committee (OITC) sponsors test programs investigating alternative technologies for oil spill cleanup in broken ice fields at the U.S. Environmental Protection Agency's OHMSETT facility in Leonardo, New Jersey. A significant portion of the current effort is the investigation of in-place burning of crude oil slicks as an efficient alternative to the more traditional means of mechanical cleanup which may not be feasible in broken ice conditions.

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Environment Canada. Arctic and Marine Oilspill Program (AMOP) Technical Seminar, 8th. Proceedings. June 18-20, 1985, Edmonton, Alberta, Canada, Environment Canada, Ottawa, Ontario, 176-191 pp, 1985.

The first series of tests, performed in February 1984 yielded encouraging results of 85 to 95% removal by in-place burning (Smith, 1985) and prompted the second test program, performed in January and March 1985. In the 1985 test programs, Prudhoe Bay and Amauligak crude were distributed among ice coverages ranging from 75 to 90% of the test area. Emulsions, fresh oil, and sparged stages of the oils were tested.

TEST SETUP

Test Fluid Preparation

Sparged Prudhoe Bay crude oil was prepared by placing 0.3 m^3 of oil in a 1-m^3 capacity rectangular tank, 0.6-m x 1.5-m x 1.1-m deep. This yielded an oil depth of 0.34 m. A 5.6-cm diameter x 58-cm long air sparger was placed in the tank below the oil surface and operated for 37 hours at an air flow rate of approximately 0.1-m^3/min. Ambient temperatures averaged 1 C and peaked at 13 C. The flash point increased from less than 1 C to 24 C, and the specific gravity increased from 0.910 to 0.920 (measured at 0 C). A 0.15-m^3 volume of Prudhoe Bay oil was aerated further for a total of 85.5 hours aerating time, raising the flash point to 40 C.

Two 0.09-m^3 volumes each of emulsions of fresh Prudhoe Bay crude oil and Sandy Hook Bay water were prepared in 55-gallon (0.2-m^3) drums using 18% water and 82% oil for the first emulsion and 8% water and 92% oil for the second. The emulsions were formed by recirculating each oil/water mixture through a 2-inch (5.1-cm) Viking gear pump and exiting through a 3/4-inch (1.9-cm) nozzle into the drum. The flow rate for the first emulsion was approximately 225 lpm over a 1 hour recirculation time. The second emulsion was formed in 2.75 hours at an average flow rate of 135 lpm (maximum 225 lpm).

The sparged Amauligak crude was created by aerating for 17 hours at a flow rate of approximately 0.1 m^3/min. Ambient temperatures averaged 5 C and peaked at 14 C during the aeration process. The Amauligak crude oil emulsion was formed by recirculating 0.06 m^3 of a mixture of 8% Bay water and 92% fresh Amauligak crude oil through the previously mentioned system for 1.33 hours at a flow rate of approximately 160 lpm.

Broken Ice Field

Tests were conducted in the OHMSETT tank in a 5.8 m by 7.3 m test area enclosed by a rigid wood boom. The test area was positioned midtank near the underwater photo/video windows. Ice was provided by placing 140-kg freshwater ice cakes, nominally 55 cm x 120 cm x 22 cm, in individual wooden cradles with a design spacing of 3 to 4 cm between ice cakes. (See Figure 1.)

Slick Distribution System

A low flow rate oil distribution system consisting of an air-driven sandpiper diaphragm pump delivered the test fluid from a 55-gallon (0.2-m^3) drum through 1½-inch (3.8-cm) hose to a point approximately 0.6 m beneath the test area. (See Figure 2.)

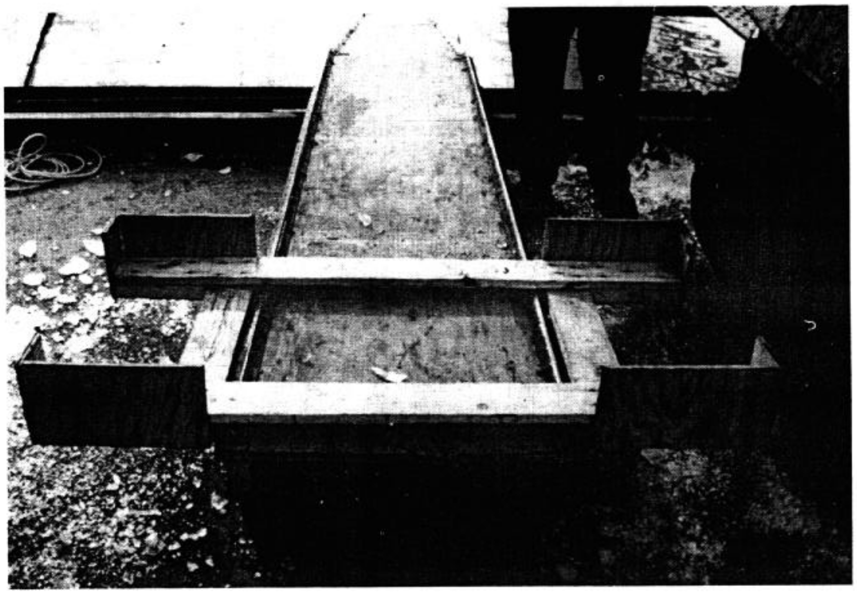

Figure 1. Each ice cake was placed in an ice cradle and pushed down a deployment ramp. Each cradle was constructed of plywood and 1 x 4's, then placed on the ramp as shown above. The ice cradles were designed to fit snugly around each ice cake and float beneath the water surface when deployed.

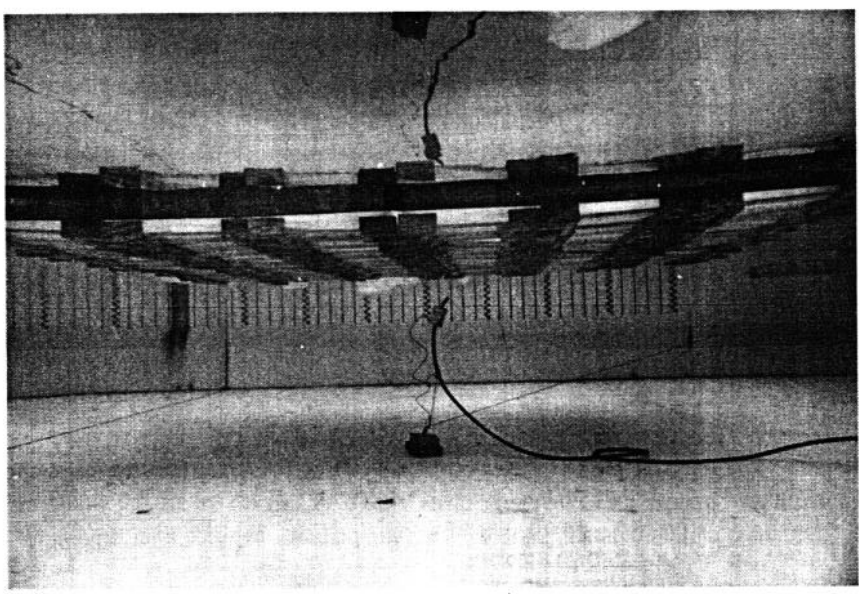

Figure 2. The test fluid was distributed through a hose beneath the water surface near the center of the test area.

Incendiary Devices

Two ignition devices were used during testing. The first, a "firelog," was constructed of an Ethafoam log approximately 13 cm in diameter and 32 cm long, wrapped in sorbent. This combination was soaked in crude oil and sprayed with an ether-based starting fluid immediately prior to ignition. (See Figure 3.) In nine of the eleven tests, a pyrotechnic ignition device (supplied by the Canadian Environmental Protection Service) was used to ignite the slick. (See Figure 4 and Twardawa, 1983.)

Data Acquisition Instrumentation

A color video camera 15 m above the test area on the end of a crane boom and a 3/4-inch (1.9-cm) videotape recorder provided a recording of the overhead view of the tests for use in data acquisition.

A Climatronics weather station, mercury thermometer, and handheld anemometer were used for environmental measurements during the tests as described in the Data Acquisition section. Sorbent pads, 45 cm x 90 cm, were used to retrieve the oil residue and were weighed on a Pelouze Model D-60 spring scale.

Fire Control

A fire control system was provided to insure against the event that burning oil escaped the boom or flames otherwise spread, creating a hazardous situation. OHMSETT crew members manned fire hoses, and the Naval Weapons Station Earle Fire Department was on stand-by during each test.

PROCEDURE

After deployment of the ice, 29 to 36 liters of test fluid were distributed through the distribution system exiting beneath the water surface near the center of the test area. The test fluid was pumped at a low flow rate by a diaphragm pump and the line was purged with water after each distribution of oil. The oil was allowed to spread until the spread rate diminished to a rate visually determined to be insignificant.

The slick was ignited using one of two ignition devices. The firelog was deployed from an elevated bridge (the OHMSETT photo/video bridge) and allowed to slide along a wire cable across the test area to the desired ignition location. (See Figure 3.) The pyrotechnic device was deployed from a workboat by activating the igniter and then tossing the igniter to the desired location during the 15 second ignition delay period. A stopwatch was triggered when black smoke first appeared. The burn was considered to be completed when the fire on free-floating oil went out.

Data Acquisition

Percentage ice cover was determined using the overhead video recording displayed on a 12-inch (30-cm) color TV monitor in conjunction with other measurements and calculations. (See Calculations section.) For Test Nos. 1 through 8A, ambient air temperature, water temperature, and wind speed were measured using a mercury thermometer mounted on the main bridge, a Climatronics soil thermistor at a water depth of 2 m, and a handheld anemometer used at the top of the 3-story OHMSETT control tower. For Test Nos. 9A through 11A, air temperature, water temperature, wind speed and direction

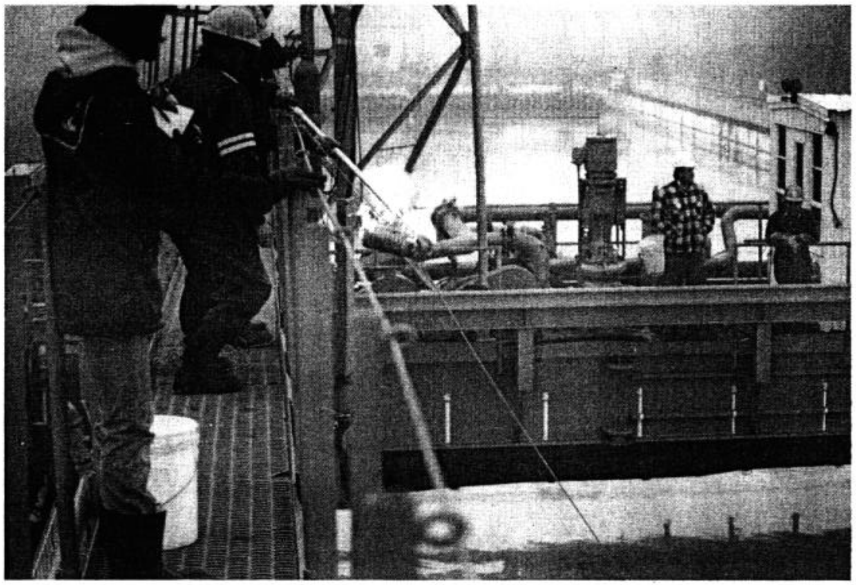

Figure 3. The firelog igniter, developed at OHMSETT, was deployed from the elevated photo/video bridge in Test Nos. 1, 4, 5A (as the third igniter), and 11A (as the third igniter).

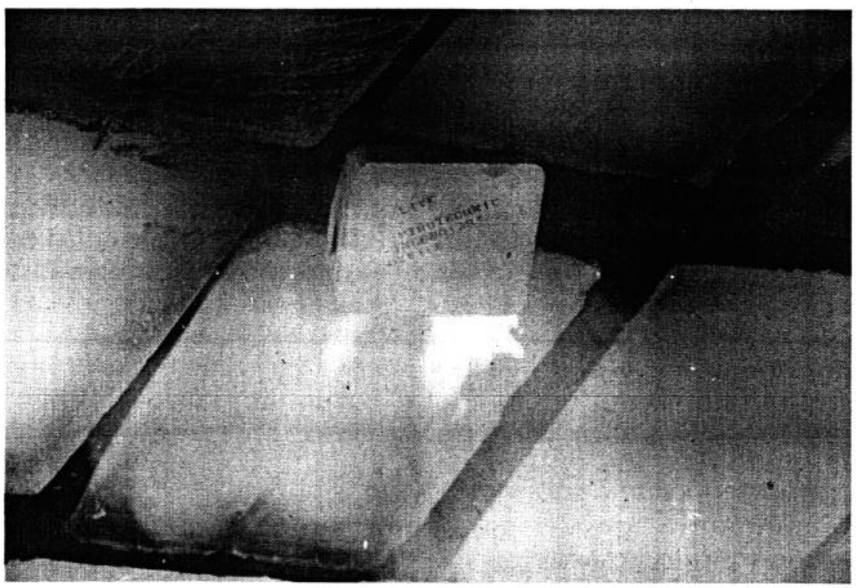

Figure 4. A pyrotechnic incendiary device was used in Test Nos. 1R, 1R2, and 5A through 11A. The device measured approximately 25 cm x 25 cm x 11.5 cm.

were obtained with a Climatronics Weather Station which takes air and wind readings from the top of the control tower. To determine percentage burned by mass, 3M brand oil sorbent pads were pre-weighed on a spring scale, then deployed to absorb the burn residue from the water and ice surfaces, and re-weighed. (It was found that the sorbent pads absorbed no appreciable quantities of water. In a test of the water absorption, individual pads were placed on the clean tank water surface and allowed to soak for 2 minutes 20 seconds. Then the sorbent was allowed to drain for 30 seconds. The amount of water absorbed by the sorbent correlates to less than $\pm$ 2% of the average percentage burned in the test series.)

ASTM Standard Tests

The crude oils used in the tests were characterized for reference purposes by specific gravity, viscosity, flash point, surface tension, interfacial tension, percentage water, and gas chromatogram. Specific gravity was measured using hydrometers as specified by American Society for Testing and Materials (ASTM) D1298-67. Viscosity was measured using a Brookfield Model LVT viscometer at temperatures of 20 C and 37 C. 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 Tensiomat. Percentage water and bottom solids was determined as specified in ASTM D1796-75. The results of these analyses are given in Table 1. The emulsion droplet sizes were determined to be 1 to 2 µm in the Prudhoe Bay crude emulsions and 2 to 5 µm in the Amauligak emulsion as determined in photomicrographs. The gas chromatograms of the fresh oil and sparged (topped) oil samples are shown in Figures 5 and 6.

CALCULATIONS

The ice coverage was measured gravimetrically, using a photocopy of an 8 x 10 photograph of the pre-test video display and a Mettler H31 analytical balance. Percentage ice cover was calculated using the relative weight of the ice cake surface area divided by the total test area weight.

Burn efficiency was calculated using the following equation

$$\text{B.E.} = \left[1 - \frac{R}{I}\right] \times 100\%$$

where R = weight of burn residue, and
I = weight of test fluid distributed
B.E. = burn efficiency

The oil residue was weighed directly and the initial oil weight was calculated using specific gravity and oil volume. Initial oil volume was measured to a precision of $\pm$ 0.4 liters. The oil residue and sorbent were weighed with a precision of $\pm$ 0.07 Kg.

TABLE 1. TEST FLUID CHARACTERISTICS

Test No.	Test Fluid Description	Flash Point (C)	S.G. @ Test Temp[1]	Viscosity (cSt) @ Test Temp[2]	Surface Tension (Dynes/cm)	Interfacial Tension Oil & Tank Water (Dynes/cm)	$\%H_2O$
1	Fresh Prudhoe Bay crude	< 1	0.904	160	25	30	< 0.02
1R	Fresh Prudhoe Bay crude	< 2	0.918	220	23	30	< 0.02
1R2	Fresh Prudhoe Bay crude	< 1	0.911	280	24	30	< 0.02
4	Sparged Prudhoe Bay crude	24	0.920	1,300	25	30	< 0.02
5A	Emulsion 18% Bay water/ 82% fresh Prudhoe Bay crude	18	0.924*	82*	N/A	N/A	18
6A	Sparged Prudhoe Bay crude	40	0.918	420	24	31	< 0.02
7A	Emulsion 8% Bay water/ 92% fresh Prudhoe Bay crude	20	0.916*	92*	N/A	N/A	8
8A	Sparged Prudhoe Bay crude	40	0.924	320	26	32	< 0.02
9A	Fresh Amauligak crude	< 1	0.893	20	24	31	0.4
10A	Sparged Amauligak crude	38	0.882	22	20	31	0.2
11A	Emulsion-9% Bay water 91% fresh Amauligak crude	35	0.893*	14*	N/A	N/A	9

1. At air temperature
2. At water temperature

N/A = Not applicable

* At room temperature (20 to 21C)

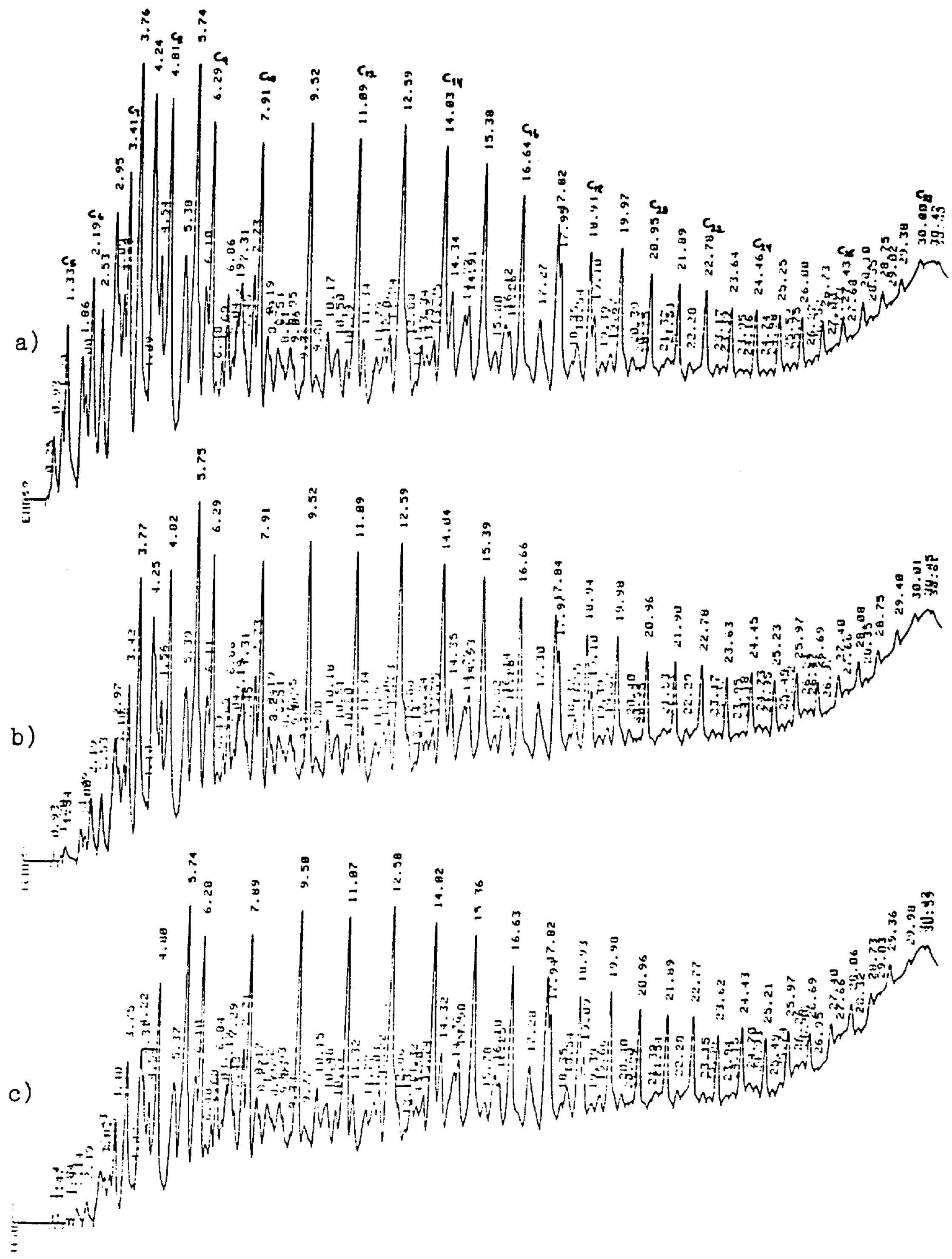

Figure 5. The gas chromatograms allow comparison of the: a) fresh Prudhoe Bay crude oil used in Test Nos. 1, 1R, and 1R2, b) sparged Prudhoe Bay crude oil with a flash point of 24 C, (Test No. 4), and c) sparged Prudhoe Bay crude oil with a flash point of 40 C, (Test Nos. 6A and 8A). Notice the loss of hydrocarbons below heptane (C_7).

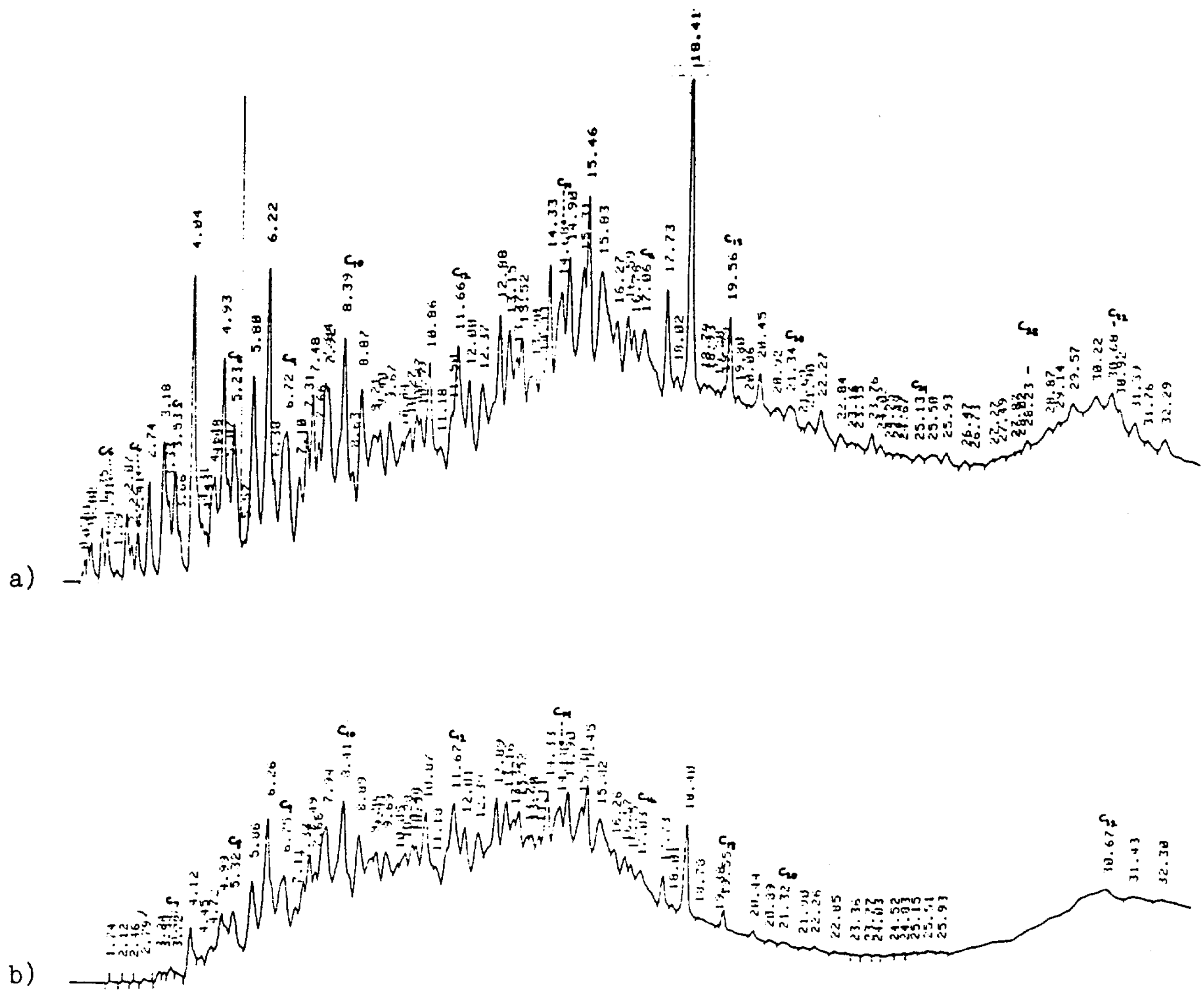

Figure 6. The gas chromatograms of a) fresh Amauligak crude oil and b) sparged Amauligak crude oil illustrate the loss of low ends due to the sparging process.

RESULTS

Results of the tests are given in Table 2. Photographs depicting the test setup and testing are shown in Figures 7 through 11. Overall, fresh and sparged Prudhoe Bay crude oil burned in ice coverages of 75 to 90% removing 60 to 80% of the oil slick (by mass). Fresh and sparged Amauligak crude oil yielded burn efficiencies of 60 to 70% in 80 to 90% ice coverages. The emulsions were altogether more difficult to burn than the non-emulsified oils.

Each emulsified oil slick was ignited three times (in different locations in the slick). A 92% oil and an 82% oil emulsion of Prudhoe Bay crude and Sandy Hook Bay water achieved burn efficiencies of 35% and 10%, respectively. A 91% oil emulsion of Amauligak crude and Sandy Hook Bay water yielded a burn efficiency of 50%. In one test (No. 7A) two pyrotechnic igniters were tossed from a work boat into the test area, only to miss the slick entirely. (These two attempts are not included in Table 2.) The appropriately placed igniters appeared to ignite the emulsified slicks within a fairly consistent distance of the igniter (approximately 1 to 2 m).

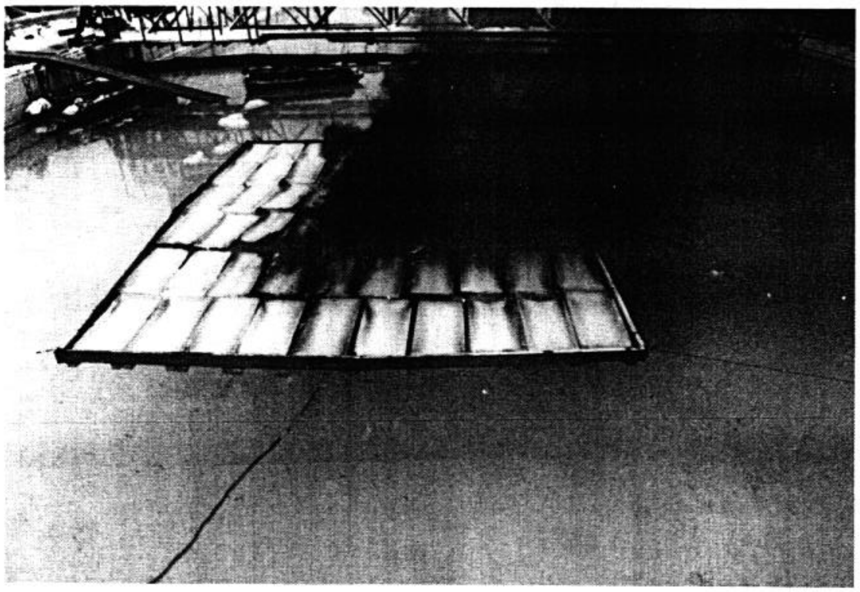

Figure 7. Burning fresh Prudhoe Bay crude oil in 85% ice cover yielded a burn efficiency of 60% (Test No. 1R2). The slick burned for 13 minutes 45 seconds with the air temperature at -1 C, the water temperature at 0 C, and with winds at 2 m/s.

TABLE 2. TEST RESULTS

Test No.	Test Fluid Description	Fluid Volume (liters)	Ice Coverage* (%)	Ignition/Burn Time (min:sec/min:sec)	Air Temp (C)	Water Temp (C)	Wind Speed (m/s)	Burn Efficiency (%)
1	Fresh Prudhoe Bay crude	35.6	76-81	0:15/11:31	5	4	2	72.4 ± 2.3
1R	Fresh Prudhoe Bay crude	29.0	84-86	0:15/24:03	-6	0	8	62.5 ± 3.8
1R2	Fresh Prudhoe Bay crude	35.6	82-89	0:06/13:45	-1	0	2	58.3 ± 2.4
4	Sparged Prudhoe Bay Bay crude. Flash Point: 24C	35.6	75-84	0:15/15:50	-3	0	4	79.1 ± 2.2
5A	Emulsion 18% Bay water/82% fresh Prudhoe Bay crude	35.6	81-86	1st 0:17/2:30 2nd 0:21/15:45 3rd None**/33:04	4	0	6	9.6 ± 2.7
6A	Sparged Prudhoe Bay crude. Flash Point: 40C	35.6	75-80	0:13/9:21	7	0	6	61.9 ± 2.3

* Range based on average ice coverage measurement ± standard deviation of measurements. Magnitude of range indirectly indicative of ambient light levels which affect the quality of video recording.

** 3rd igniter placed while 2nd still ongoing.

TABLE 2. TEST RESULTS (continued)

Test No.	Test Fluid Description	Fluid Volume (liters)	Ice Coverage* (%)	Ignition/Burn Time (min:sec/min:sec)	Air Temp (C)	Water Temp (C)	Wind Speed (m/s)	Burn Efficiency (%)
7A	Emulsion 8% Bay water/92% fresh Prudhoe Bay crude	35.6	79-85	1st 0:11/25:27 2nd 0:15/11:05 3rd 0:07/5:10	4	0	7	34.7 ± 2.5
8A	Sparged Prudhoe Bay crude. Flash point: 40C	35.6	78-84	0:07/8:07	-1	0	< 2	68.3 ± 2.3
9A	Fresh Amauligak crude	35.6	82-88	0:07/16:32	3	5	4	62.9 ± 2.4
10A	Sparged Amauligak crude. Flash Point: 38C	35.6	82-83	0:08/27:15	11	7	1	68.3 ± 2.4
11A	Emulsion-9% Bay water 91% fresh Amauligak crude	35.6	76-80	1st 0:08/21:32 2nd 0:10/4:58 3rd 0:43/17:11	12	7	5	51.7 ± 2.5

* Range based on average ice coverage measurement $\pm$ standard deviation of measurements. Magnitude of range indirectly indicative of ambient light levels which affect the quality of video recording.

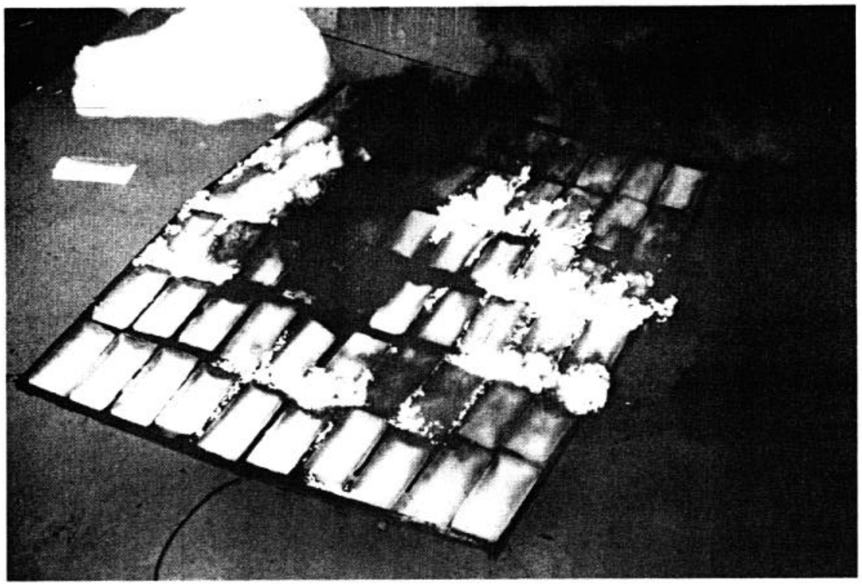

Figure 8. Prudhoe Bay crude oil, sparged to increase the flash point to 40 C, burned in a 75% ice coverage to achieve a burn efficiency of 60% during Test No. 6A. The large white object to the left of the test area is one of the naturally formed ice floes on the OHMSETT tank.

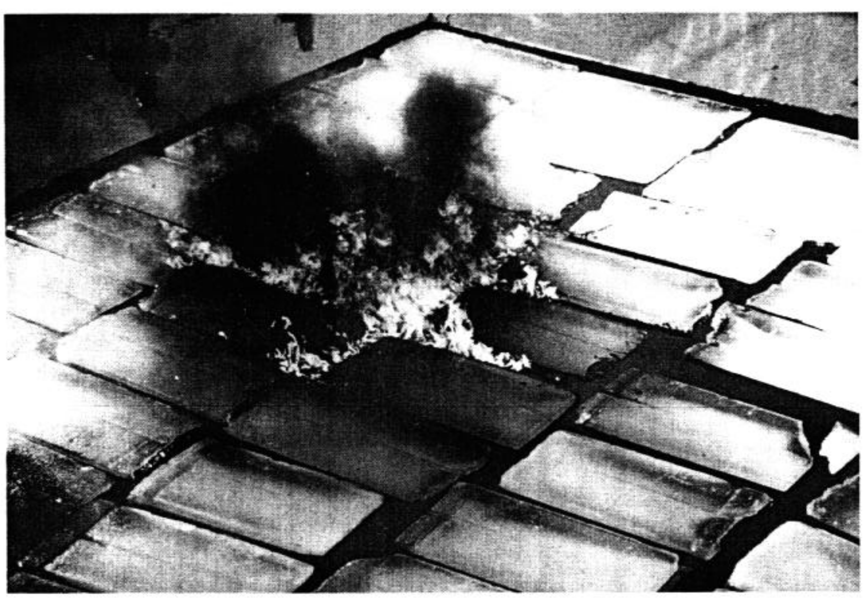

Figure 9. Test No. 7A demonstrated the burnability of an emulsion of 92% Prudhoe Bay crude oil and 8% bay water. A burn efficiency of 35% was achieved using three igniters in an 80% ice coverage over a total burn time of 41 minutes 42 seconds.

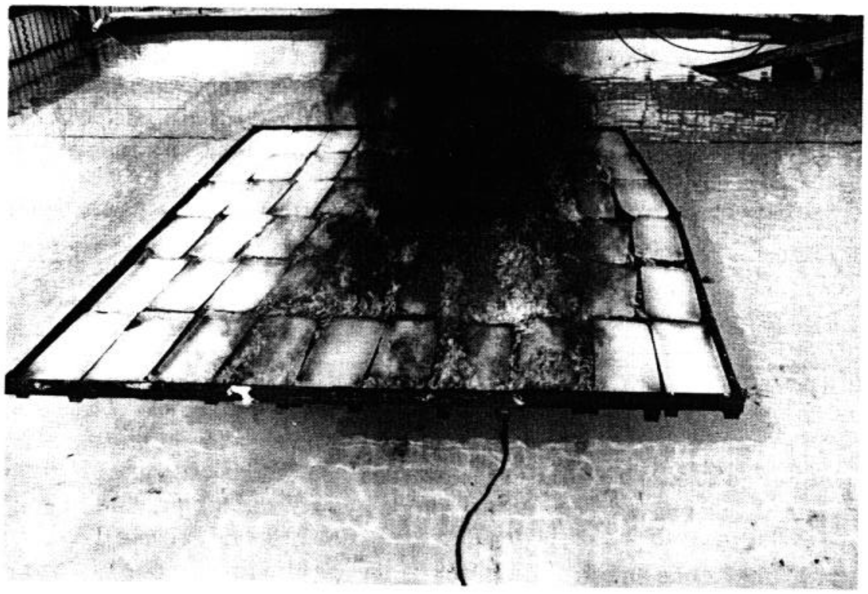

Figure 10. The Amauligak crude oil yielded a burn efficiency of 65% in ice covering 85% of the test area during Test No. 9A. The slick burned for 16 minutes 32 seconds in an air temperature of 3 C, water temperature of 5 C and wind speed of 4 m/s.

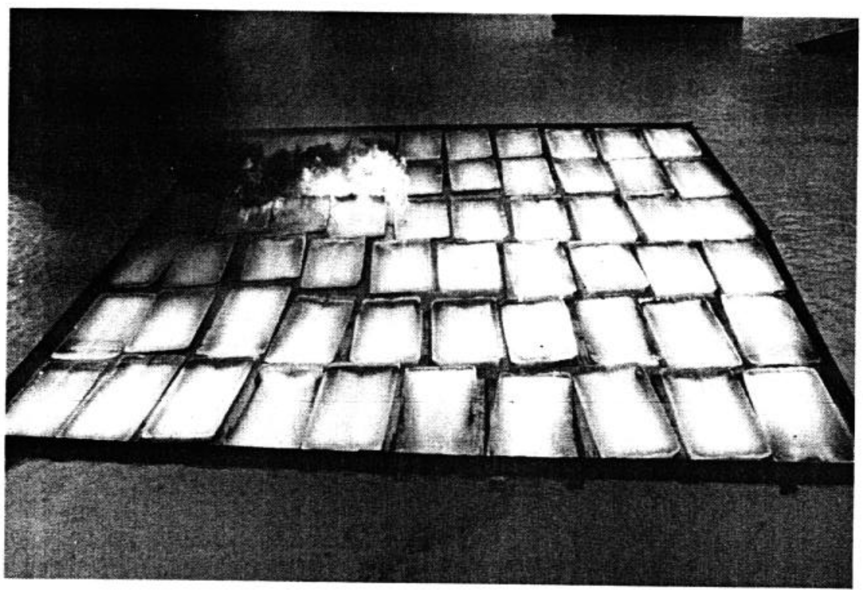

Figure 11. In Test No. 11A an emulsion of 91% Amauligak crude oil, and 9% bay water was ignited in 3 locations within the test area. The slick burned for a total of 43 minutes 41 seconds yielding a burn efficiency of 50% in ice covering 80% of the test area.

The intermediate stage of sparged Prudhoe Bay crude oil (flash point: 24 C) yielded a higher burn efficiency than that achieved using fresh oil. This trend was observed in the previous tests (Smith 1985) and may be attributed to the changes induced on the oil physical properties or chemical composition during the sparging process. The data necessary to derive the relationship, however, is not available.

The cleanup operation, using fire hoses to herd the oil through the ice field, was quite effective in removing oil from the ice cakes, however small quantities of residue were observed temporarily suspended below the water surface due to jet action too close to the herded slick.

CLOSURE

The 1985 testing indicates that burn efficiencies decrease with increasing water content in emulsified oil slicks. Overall, the 1985 testing yielded burn efficiencies consistently lower than the 1984 OHMSETT test program (Smith 1985). This may be due to the decreased oil volume in the 1985 tests and the subsequent decrease in peripheral pooling effect (thinner slicks). The results of the 1985 testing, compare well with results obtained in the June 1983 demonstrations by Shell Oil Co (1983) where 55 to 85% of the Prudhoe Bay crude oil (average slick thicknesses estimated 2.8 to 3.3 mm) was removed by in-place burning.

Several questions should be addressed before in-place burning is relied upon as a cleanup technique for the Arctic. What is the likely condition of the oil slick in broken ice fields, i.e., what degree of emulsification should be anticipated in broken ice conditions? Also, what degree of containment is afforded by the broken ice fields? What slick thicknesses can be anticipated? What burn efficiencies can be expected in a given slick thickness? What are the best methods of igniter deployment? Under what environmental and oilspill conditions are igniters reliable? Another obvious concern is the effect of fallout from the fire on the surrounding environment. This question is being partially addressed through analysis currently underway at OHMSETT. Air samples were taken during the 1985 test program for analysis of particulates and chemical composition of the smoke plume. The results of this analysis and a more detailed description of the test program will be available in an upcoming report for the U.S. Environmental Protection Agency.

ACKNOWLEDGEMENTS

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