DISPOSAL OF SPILLED HIBERNIA CRUDE OILS AND EMULSIONS

IN-SITU BURNING AND THE "SWIRLFIRE" BURNER

by

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This study was a continuation of previous work (S.L. Ross 1988) on combustion techniques for the disposal of recovered oily materials from spill cleanups. The present study focused on two subject areas identified earlier as requiring further research and development, namely: in-situ burning of Grand Banks' crude oils and their emulsions on water and testing of a novel rotary-cup burner for the disposal of oil and emulsions recovered by skimming operations.

OBJECTIVES

The two objectives of the study were:

* to conduct small-scale tests of in-situ burning of Grand Banks crude oils and their emulsions to determine the effect of weathering and emulsion water content on their ignitability, removal efficiency and removal rate; and
* to test a prototype of the "Swirlfire" rotary cup burner to determine the effect of oil type, weathering and emulsion water content on its ability to dispose of oils recovered by skimming operations.

PAPER CONTENTS

Although related, the two subject areas of the study were distinct from each other in objective, experimental techniques and product. As such, this paper contains separate accounts of the methods and results of each subject. The in-situ burning tests are presented first followed by the rotary cup burner tests. The conclusions and recommendations are combined at the end of the paper.

Environment Canada. Arctic and Marine Oilspill Program (AMOP) Technical Seminar, 12th. Proceedings. June 7-9, 1989, Calgary, Alberta, Canada, Environment Canada, Ottawa, Ontario, 245-277 pp, 1989.

IN–SITU BURNING OF HIBERNIA CRUDE OILS AND EMULSIONS

EQUIPMENT AND METHODS

The Oils

Two oils discovered on the Grand Banks were used for this study, Hibernia B–27 and Hibernia C–96. The physical properties of these oils are listed in Table 1. The B–27 crude is a medium gravity crude that exhibits moderately waxy characteristics; the C–96 crude is a light gravity crude that exhibits very waxy characteristics. Portions of each oil were weathered by air sparging to simulate evaporative loss when spilled. For the C–96 crude, samples were weathered to 5 and 10% loss by weight, equivalent to evaporative exposures (Stiver and Mackay 1983) of about 4000 and 40,000 respectively or about 1.25 and 12 hours at sea for a 5 mm thick slick in a 5 m/s wind at 10°C (S.L. Ross and DMER 1988). Portions of the B–27 crude were similarly weathered to 8 and 14% mass loss (equivalent to exposures of the C–96 oil).

TABLE 1

Physical Properties of the Hibernia Crude Oils Used for the In–Situ Burning Tests

OIL	DENSITY (kg/m^3) @10°C	@20°C	@30°C	VISCOSITY (mPas) @10°C	@20°C	@30°C	POUR POINT (°C)	FLASH POINT (°C)
HIBERNIA C–96	844	837	830	*	90	30	18	14
HIBERNIA B–27	878	870	862	240	80	25	9	11

* below pour point
from S.L. Ross and DMER 1988

Artificial water–in–oil emulsions were prepared for each fresh and weathered oil sample by adding appropriate volumes of fresh water to oil in a mixer to produce 25%, 50% and 75% water emulsions. The emulsions were stirred vigorously until a homogeneous mixture, containing small water droplets, was created.

The Test Apparatus

The test burns were conducted in an 28 cm diameter metal ring supported in a 1 m diameter, 40 cm deep pan of water. This pan was situated under a hood connected to a roof–mounted vent fan (Figure 1). The freeboard of the ring was 1 cm to avoid creating vortices in the air drawn into the burns.

Test Measurements

The weight of a measured volume of oil or emulsion (required to create a 2, 5 or 10 mm thick slick in the metal ring) was determined with a triple beam balance. The weight of residue left after each test burn was determined by recovering the residue

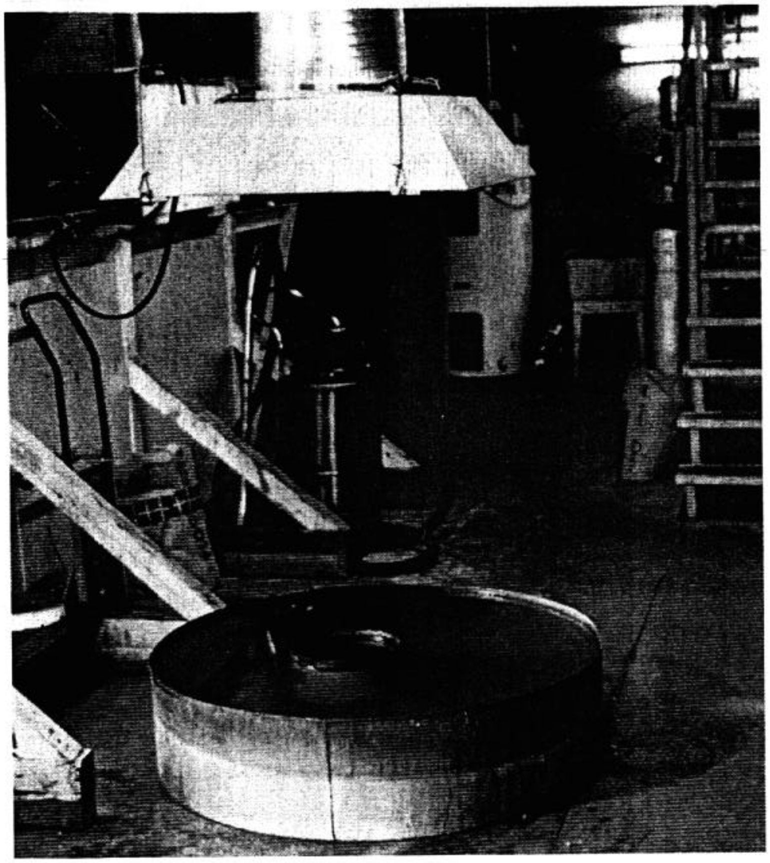


Figure 1 – In–situ burning apparatus

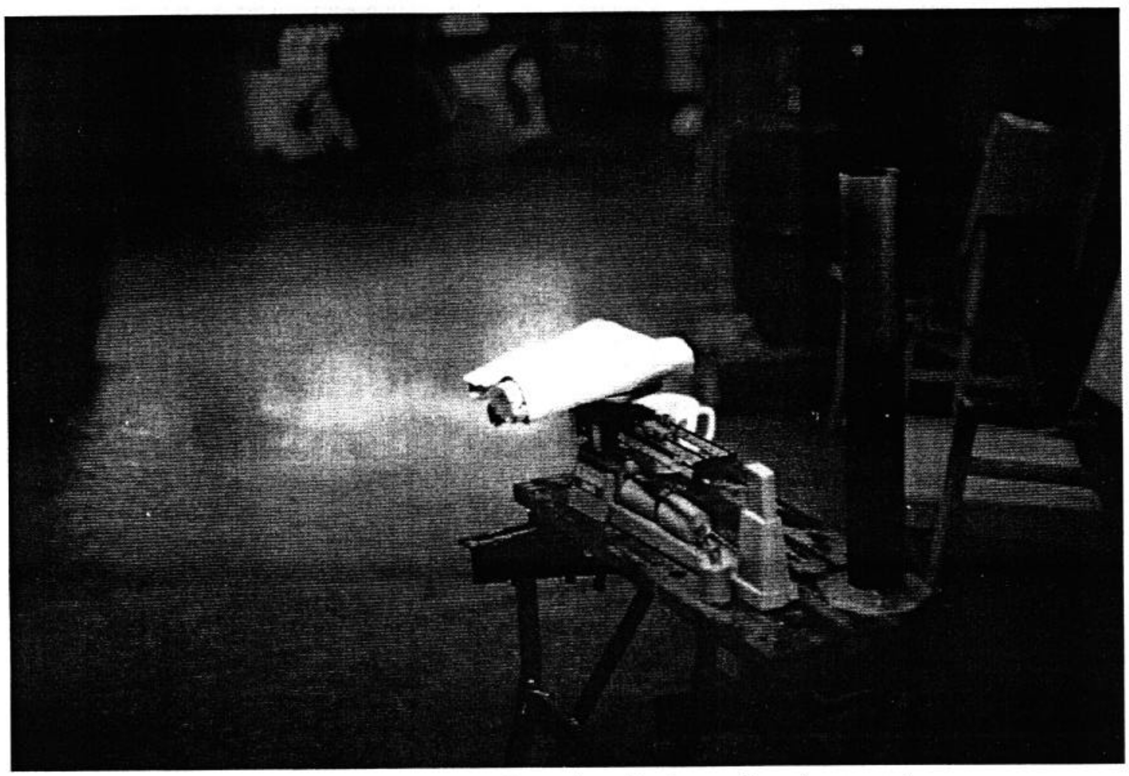


Figure 2 – Balance, graduated cylinder and sorbent pad

on a preweighed sorbent pad, shaking out any water, then weighing the pad on the balance (Figure 2).

Ignition times (the time required for the entire surface area of the slick to catch fire) and burn time (the incremental time from complete ignition to flame extinction) were measured with a stopwatch. Each burn was also videotaped.

Ignition Techniques

Three increasing levels of ignition were available for use on each test. First, a 5 cm square of sorbent pad saturated with about 15–20 grams of fresh crude was lit and placed in the centre of the test slick (Figure 3). This burned for about 1 minute. If the slick had not ignited after this, a 10 cm square piece of sorbent containing about 45–50 grams of oil was lit and placed in the centre of the test slick (Figure 4). This burned for about 2 minutes. If the slick had still not ignited after this, 120 ml (equivalent to 2 mm thick) of fresh crude was poured on top of the test slick and ignited. If, after 2 minutes (the approximate time for the 120 ml of fresh crude to be consumed), the flames extinguished the test slick was denoted as unignitable.

The sizes of the pieces of saturated sorbent were specifically selected to represent sizes of burning globules of gelled gasoline produced by the "Helitorch" aerial ignition system (Spiltec 1987; S.L. Ross 1988) for ignition of oil slicks.

The 5 cm square represented the minimum size of globule required to achieve ignition of oil under relatively calm conditions (winds less than 16 km/hr).

The 10 cm square represented the minimum globule size to achieve ignition of oil in winds up to 30 km/hr and the average size of globules produced by the "Helitorch" system when rigged for oil slick ignition.

The use of 120 ml of burning fresh crude as a final attempt at ignition was designed to determine whether or not the oil or emulsion could be sufficiently preheated to support combustion. This would be analogous to oil or emulsion being swept into a fireproof boom in which oil is already burning (e.g., Buist et al. 1983; Allen 1989).

Test Procedures

The following procedure was followed for each test:

1. measure out required volume of oil or emulsion into graduated cylinder;
2. weigh cylinder;
3. pour oil or emulsion gently onto water inside metal ring;
4. spread oil evenly over water surface;
5. allow oil to cool to water temperature (10–13°C) and gel;
6. reweigh graduated cylinder;
7. start television camera;
8. light 5 cm square oil–soaked sorbent pad and place in centre of test slick;
9. record time for flames to cover entire test slick area;
10. if ignition fails repeat 8 and 9 with 10 cm square oil–soaked sorbent pad and then 120 ml fresh crude;
11. record time when flames extinguish;

Figure 3 – 5 cm square oil–soaked sorbent pad used for first ignition attempt

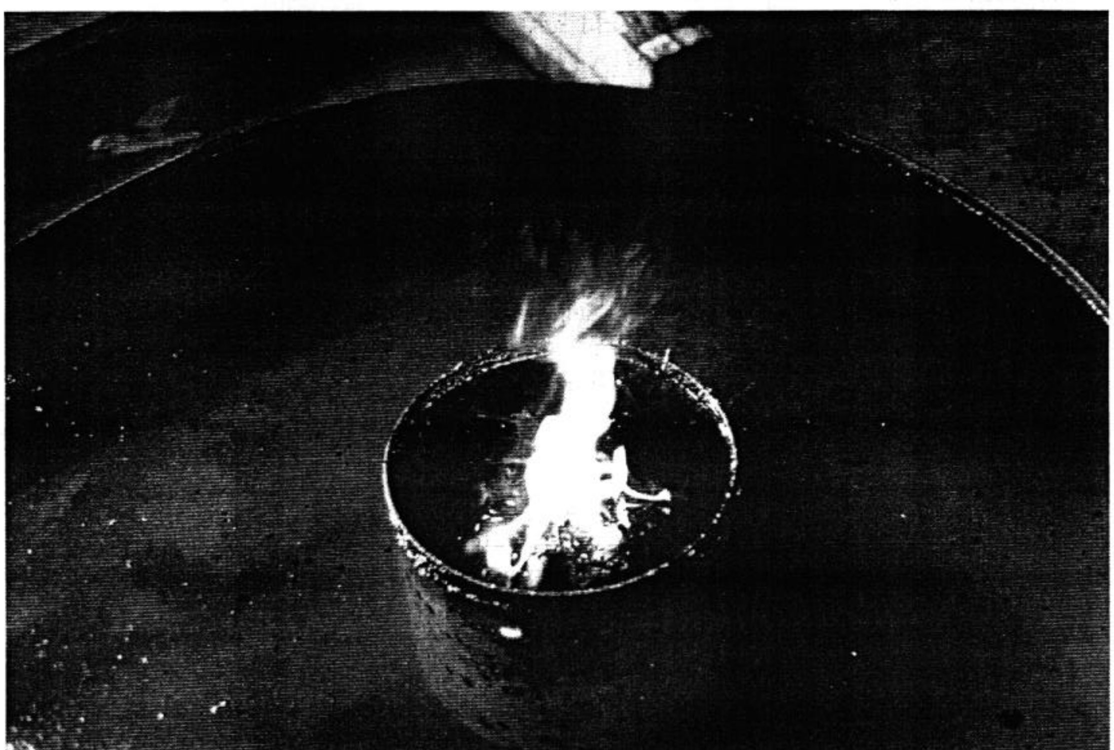


Figure 4 – 10 cm square oil–soaked sorbent pad used for second ignition attempt

12. recover oil residue on water outside ring and weigh sorbent pad;
13. recover oil residue on water inside ring and weigh sorbent pad;
14. pick up ring and swirl in pan to remove warm water and replace with cold.

RESULTS AND DISCUSSION

The report (S.L. Ross 1989) contains the conditions of and results for the 53 tests conducted.

Ignition Times

Figure 5 illustrates the effect of weathering on ignition time (defined as the time required for the flame to spread to cover the entire area of the slick) of unemulsified oils at the test temperature (10–13°C). In general, there was a slow increase in ignition time (i.e., reduction in flame spreading velocity) with increasing evaporative loss. The B–27 crude generally ignited faster than the C–96 crude. In all cases, ignition of the unemulsified oil was accomplished with the 5 cm square sorbent pad.

Figure 6 shows the effect of emulsification on ignition time. Ignition times for the fresh and 5% weathered C–96 crude increased from the 25–50s range with no water to the 50–75s range with the incorporation of 25% water in an emulsion. The ignition time for the 10% weathered C–96 crude increased from the 25–75s range with no water to the 250–500s range with a 25% water emulsion. The 2 mm thick slick of 10% weathered C–96 25% water emulsion could not be ignited.

At 50% water content, none of the C–96 test slicks could be ignited, except the 5% weathered oil which burned for a short while after the addition of 120 ml of fresh oil to 5 and 10 mm thick slicks. Needless to say it was not possible to ignite the 75% water content C–96 slicks.

Ignition times for the B–27 crude showed a less dramatic increase with emulsification. In the case of the fresh B–27 ignition times increased from the 25–50s range with both no emulsification and 25% water to the 80–100s range with 50% water. The 10 mm thick fresh, 75% water emulsion could only be ignited with the addition of 2 mm of fresh crude. The 8% weathered B–27 crude had ignition times in the 25–35s range with no emulsification, in the 50–110s range with 25% water and in the 115–135s range with 50% water. The 10 mm thick, 8% weathered emulsion with 75% water was successfully ignited with a 10 cm square oil soaked sorbent over a period of 344s. The 14% weathered B–27 had ignition times in the 30–45s range with no emulsification, in the 65–100s range with 25% water and in the 150–270s range with 50% water. The 75% water emulsion was almost fully ignited with a 10 cm square sorbent (it burned over 60% of the slick area for 326s) but required the addition of 2 mm of fresh crude for full ignition.

FIGURE 5

EFFECT OF WEATHERING ON IGNITION

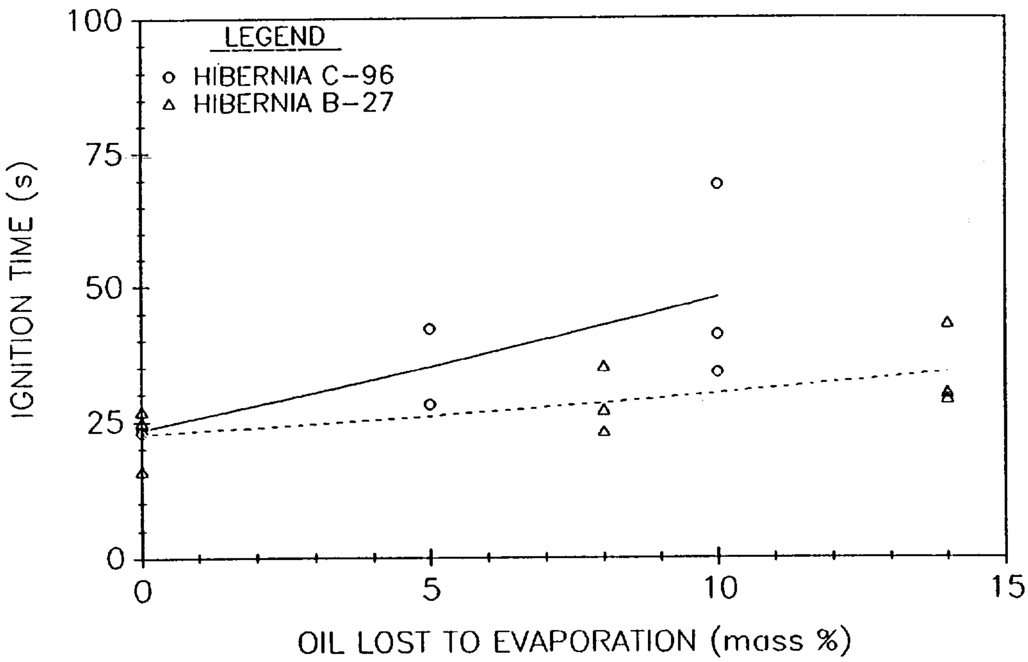
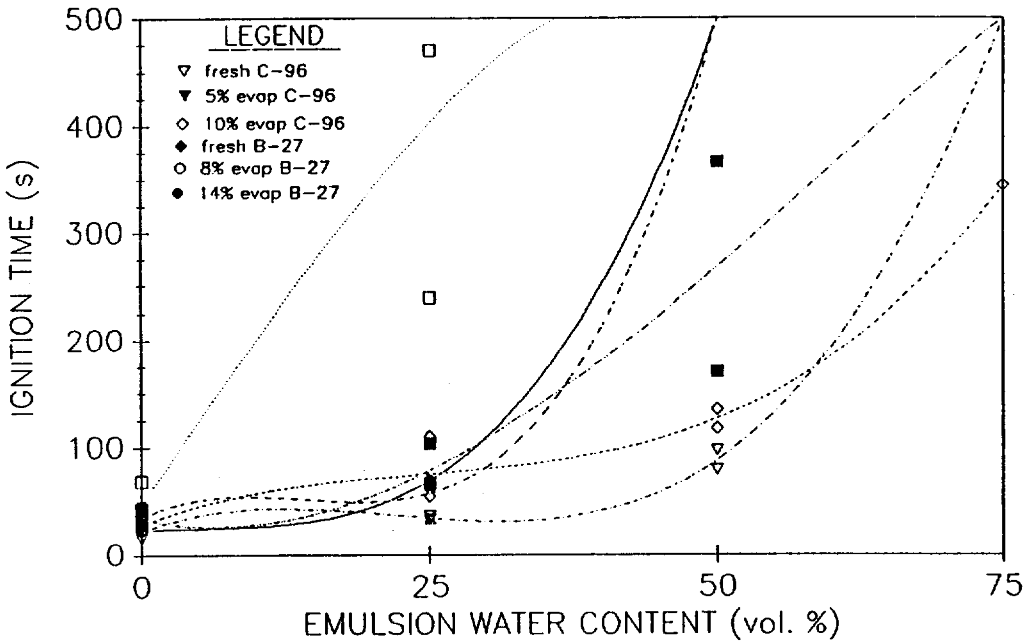


FIGURE 6

EFFECT OF EMULSION WATER CONTENT ON IGNITION



Ignition Source

Table 2 documents the success or failure of each of the three possible ignition sources (5 or 10 cm square oil–soaked sorbent or 2 mm of fresh crude) for the combinations of oil type, slick thickness, weathering and emulsion water content tested. The results indicate that the "Helitorch" aerial ignition system should be able to ignite relatively fresh (up to 12 hrs at sea) C–96 crude and emulsions with water contents in excess of 25% but less than 50%. Emulsions of C–96 with water contents in the 50% range and greater required the addition of fresh oil for any chance of ignition. In the case of the B–27 crude, the "Helitorch" should be able to ignite relatively fresh crude and emulsions with water contents up to 50%. Emulsions with 75% water required the addition of 2 mm of fresh oil, except in the case of the 8% weathered case which was successfully ignited with a 10 cm square sorbent.

Ejected Oil During Combustion – Effects on Burn Calculations

During the combustion process, heat radiated from the flame is transferred to the slick and from there to the underlying water. In the case of an unemulsified oil, when the slick has burned down to a thickness thin enough that the underlying water boils, droplets of oil are ejected into the flame by the rapid vaporization of the water (Figure 7). When emulsions are burned a similar process of rapid vaporization of the water droplets causes droplets of emulsion to be ejected into the flame throughout the burn process (Figure 8). The amount of oil ejected that escapes the flame (i.e., does not either burn completely in its trajectory or does not land back on the burning slick) is much greater when burning emulsions (Figure 9) rather than pure oil (Figure 10). Whether or not this ejected oil is included in determining burn efficiency affects the calculated burn efficiency and rate. Figure 11 compares the calculated burn efficiency for unemulsified oil both including and excluding the ejected oil (i.e., the mass of oil outside the metal ring after the burn). Since Figure 11 indicates that the difference in efficiency using the two bases is reasonably constant over the thickness range tested and the efficiency based on excluding the ejected oil is more representative of larger burns (in which most of the ejected oil would fall back onto the burning slick), the basis for comparison of burn efficiency was selected to be that excluding ejected oil.

Figure 12 compares oil removal rates (or burn rates) for unemulsified oil calculated using the two bases. For the reasons given above, the burn rate excluding ejected oil was chosen for comparison.

Burn Efficiency

Figure 13 shows the effect of weathering and emulsification on oil removal efficiency as a function of slick thickness calculated on an oil only basis (i.e., efficiency = 100% x (1 – mass of oil remaining inside ring/mass of oil in emulsion placed in ring)). In all tests involving successful ignition of the slick the residue remaining in the ring was composed of water–free oil.

For the case of the unemulsified oils (open symbols joined by a solid line) the degree of weathering had little effect on burn efficiency. Burn efficiencies increased from about 50% for 2 mm thick slicks to about 80% for 5 mm thick slicks to about 90% for 10 mm thick slicks, in accordance with other studies (Energetex 1976; S.L. Ross and Energetex 1985). The addition of 25% water emulsified with the oil (open

TABLE 2
In–Situ Ignition Success

Oil	% Evaporated	% Water	Smallest Thickness Ignited (mm)	Ignited By 5 cm square pad	10 cm square pad	2 mm fresh oil
C–96	0	0	2	Y		
		25	5	Y		
		50	>10	N	N	N
	5	0	2	Y		
		25	2	Y		
		50	5	N	N	Y
		75	>10	N	N	N
	10	0	2	Y		
		25	5	N	Y	
		50	>10	N	N	N
B–27	0	0	2	Y		
		25	2	Y		
		50	5	Y		
		75	10	N	N	Y
	8	0	2	Y		
		25	5	Y		
		50	5	Y		
		75	10	N	Y	
	14	0	2	Y		
		25	2	Y		
		50	5	Y		
		75	10	N	N	Y

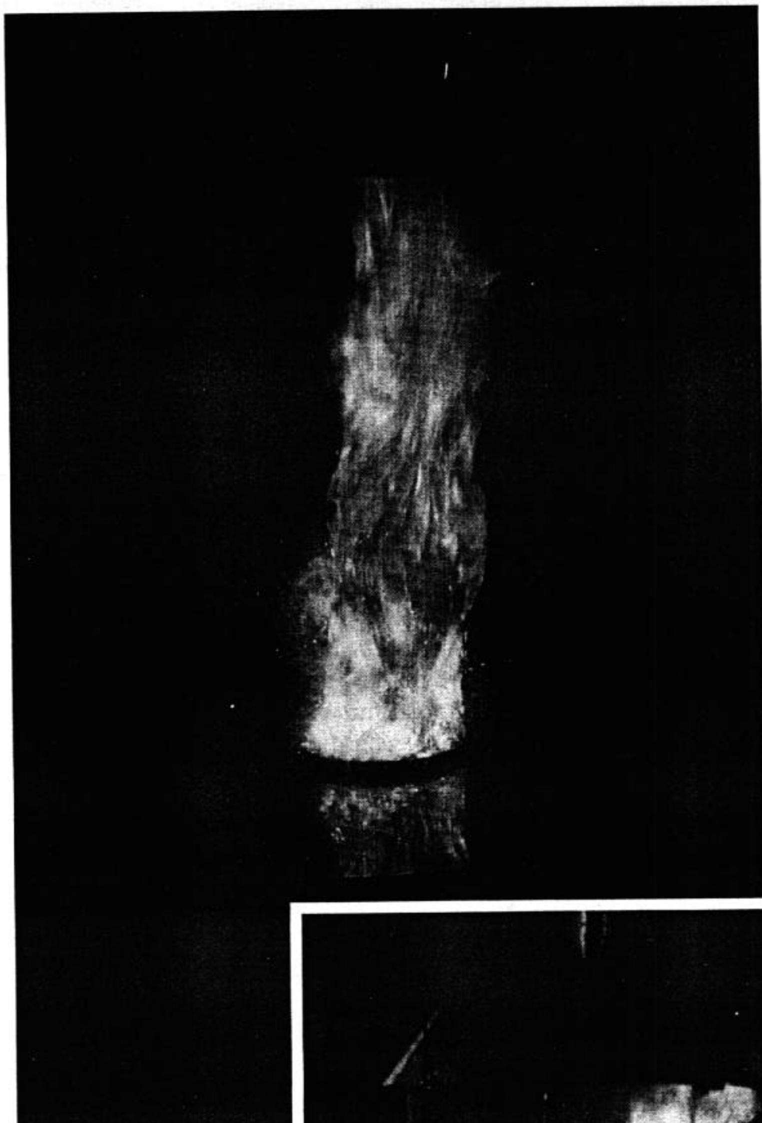


Figure 7 – Droplets being ejected from unemulsified oil near end of burn

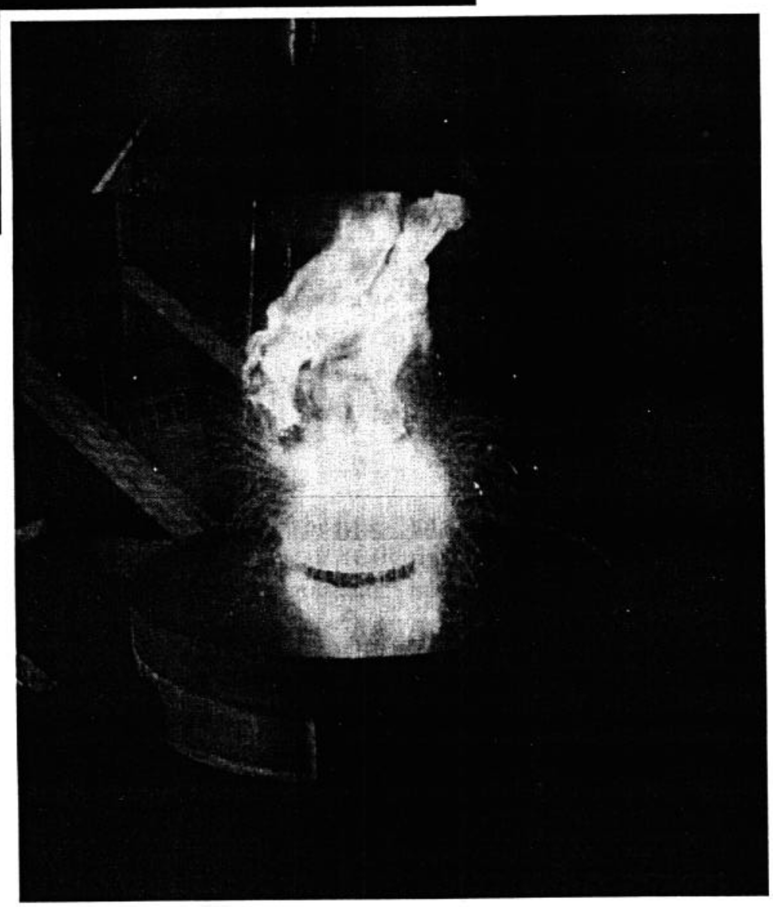


Figure 8 – Droplets being ejected during emulsion burn

Figure 9 – Oil and emulsion ejected during in–situ burn of 50% water emulsion

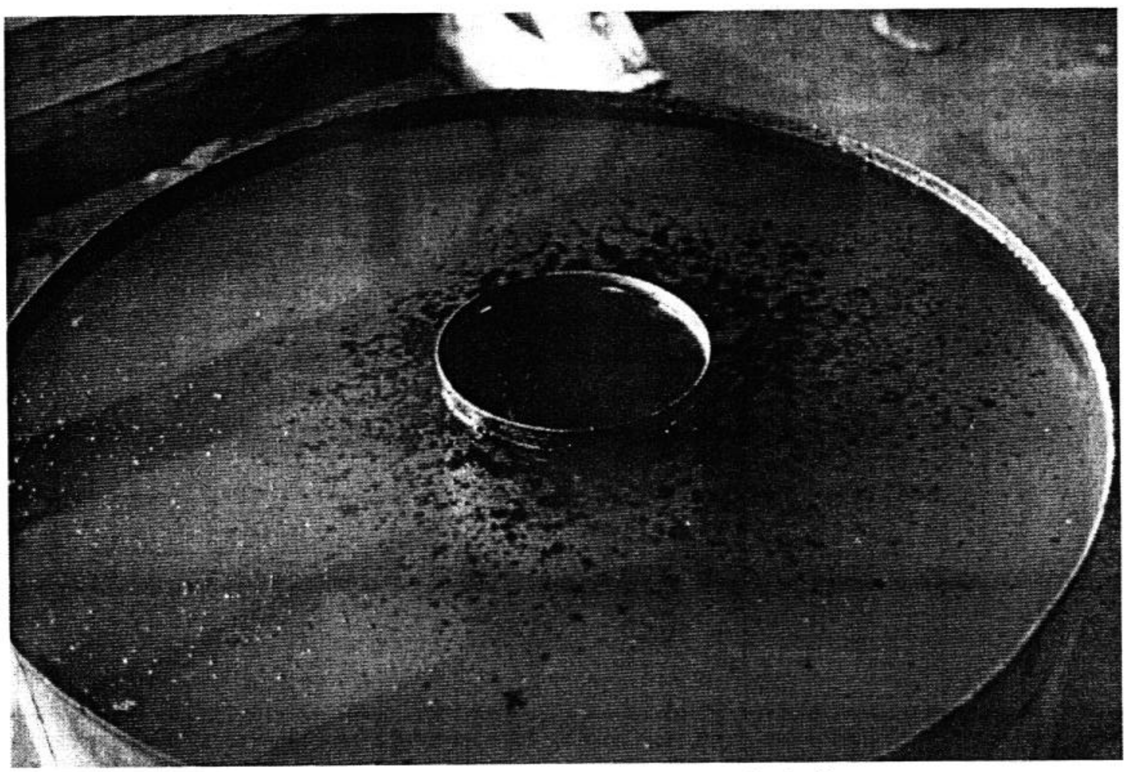


Figure 10 – Oil ejected during in–situ burn of unemulsified oil

FIGURE 11

OIL REMOVAL EFFICIENCY – COMPARISON OF CALCULATION METHODS

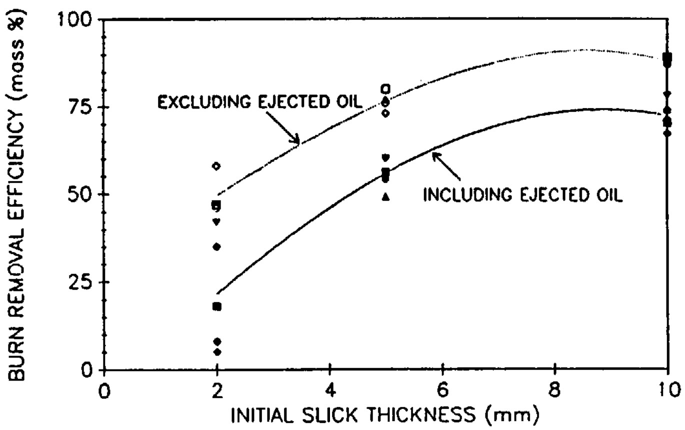


FIGURE 13

EFFECT OF WEATHERING AND EMULSIFICATION ON BURN EFFICIENCY

HIBERNIA B-27

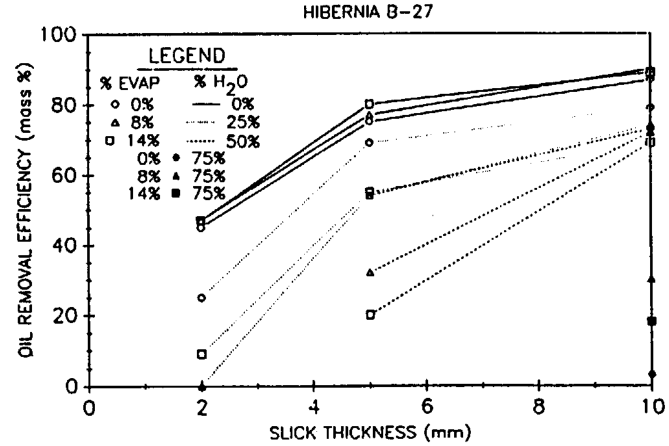


FIGURE 12

OIL REGRESSION RATE – COMPARISON OF CALCULATION METHODS

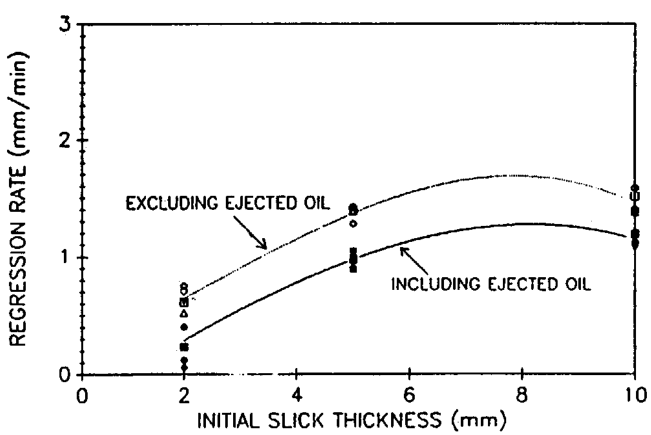
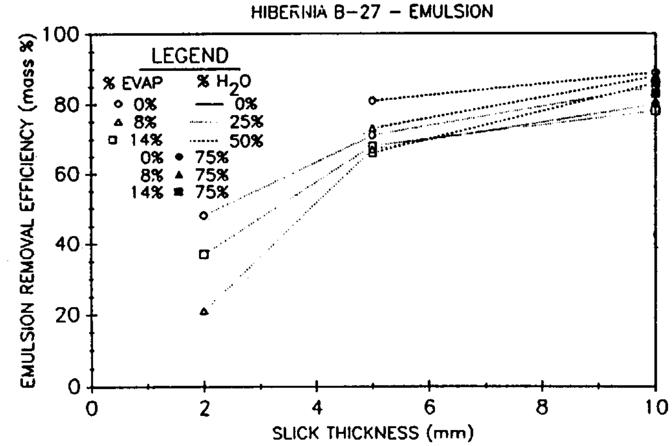


FIGURE 14

EFFECT OF WEATHERING AND EMULSIFICATION ON BURN EFFICIENCY

HIBERNIA B-27 – EMULSION



symbols joined by a dotted line) reduced oil removal efficiencies for the fresh oil by some 10% for the thicker slicks (20% for the 2 mm thick slick) and caused the effect of weathering to become more apparent. The weathered 25% water B–27 emulsions 5 and 10 mm thick showed a 15–25% decrease in oil removal efficiency compared with the unemulsified case. The 2 mm thick weathered 25% water B–27 emulsions had very low (0–10%) oil removal efficiencies. Increasing the water content to 50% further decreased the oil removal efficiency to about 50, 30 and 20% for 5 mm thick slicks of fresh, 8% and 14% weathered B–27 oil respectively but had little effect on the oil removal efficiencies for 10 mm thick slicks. The oil removal efficiencies for the 10 mm thick 75% water emulsions (solid symbols) were about: 5% for the fresh oil, 30% for the 8% weathered oil, and 20% for the 14% weathered oil.

Figure 14 shows the results for the emulsified slicks where the removal efficiency was calculated by: efficiency = 100% x (1 – mass of oil remaining in ring/mass of emulsion placed in ring). This represents the emulsion removal efficiency and includes emulsified water vaporized as well as oil burned from the test slick. In this case, emulsion water content had little effect on removal efficiency except for the 2 mm thick slicks. Emulsion removal efficiencies were in the 65–80% range for 5 mm thick slicks and in the 75–90% range for 10 mm thick slicks, even with 75% water emulsions.

Figure 15 compares the removal efficiency (either oil or emulsion) for 10 mm thick slicks of fresh and weathered B–27 crude as a function of emulsion water content. This shows more clearly the effects of burning emulsions. Regardless of water content up to 75% the emulsion removal efficiency is reasonably constant at 85–90%; however, the oil removal efficiency drops steadily up to 50% water then drops dramatically at 75% water. There are two reasons for this; first, although each slick is initially 10 mm thick, as the water content increases the equivalent thickness of oil decreases (i.e., a 75% water slick has only 2.5 mm of oil initially and thus the best possible efficiency would be 1 – 1 mm remaining/2.5 mm initially = 60%); and second, more of the heat required to vaporize oil to sustain combustion is spent vaporizing water.

Figure 16 shows the effect of weathering and emulsification on the oil removal efficiency for C–96 crude as a function of slick thickness. As with the B–27 crude (see Figure 13) the addition of 25% water to the C–96 crude reduced the removal efficiency by about 10% for the thicker slicks; unlike the B–27 crude, the 2 mm thick slick was unignitable for the weathered oils. As well, the 50% water slicks burned very poorly, resulting in combustion only in the case of the 10 mm slicks with removal efficiencies of 30% for the 5% weathered C–96 emulsion and 5% for the 10% C–96 emulsion. The 10 mm thick, 5% weathered, 75% water slick had an oil removal efficiency of just greater than 0.

Figure 17 shows the emulsion removal efficiencies calculated for the same runs. The 2 mm thick slicks showed poor combustion efficiencies. Increasing the emulsion water content from 25 to 50% results in a decrease in emulsion removal efficiency of about 20% for the 5% weathered slicks with 5 and 10 mm thickness. None of the more weathered or more emulsified slicks could be ignited.

Figure 18 compares the removal efficiencies (oil or emulsion) for the 10 mm thick slicks of C–96 crude as a function of water content. In the case of this oil both the emulsion and oil removal efficiencies declined steadily as water contents approached and exceeded 50%. The emulsion removal efficiency also seemed to be a function of weathering for the C–96 oil, unlike that of the B–27 crude (see Figure 15).

FIGURE 15

EFFECT OF EMULSIFICATION ON BURN EFFICIENCY

HIBERNIA B-27 – 10mm SLICKS

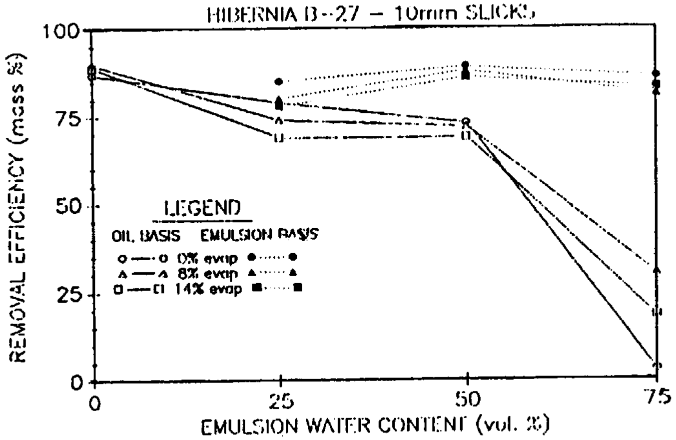


FIGURE 16

EFFECT OF WEATHERING AND EMULSIFICATION ON BURN EFFICIENCY

HIBERNIA C-96

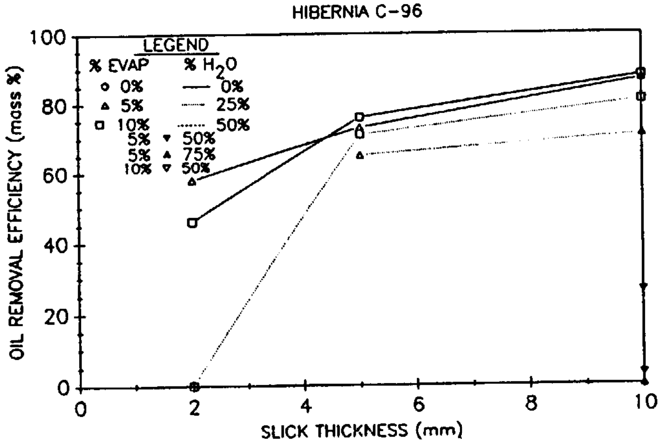


FIGURE 17

EFFECT OF WEATHERING AND EMULSIFICATION ON BURN EFFICIENCY

HIBERNIA C-96 – EMULSION

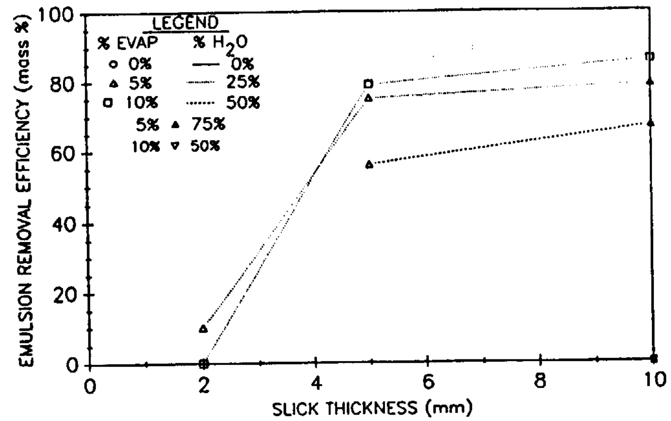
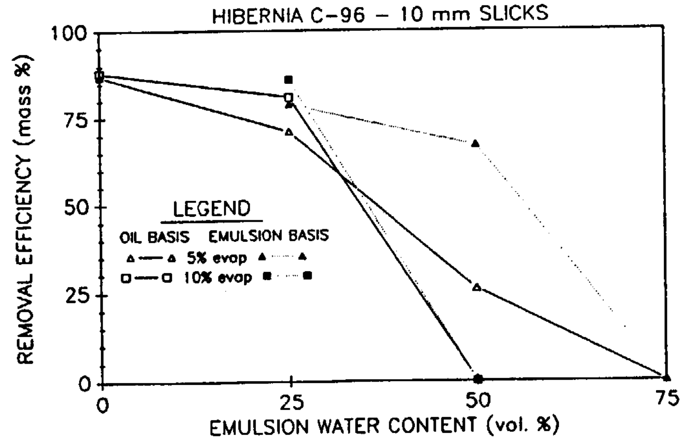


FIGURE 18

EFFECT OF EMULSIFICATION ON BURN EFFICIENCY

HIBERNIA C-96 – 10 mm SLICKS



This may be related to the higher pour point ("waxiness") of the C–96 oil in some unknown way.

Burn Rate

Figure 19 shows the effect of weathering and emulsification on oil burning rate (rate = oil burning efficiency x oil content of emulsion x initial thickness/burn time) as a function of slick thickness. The data for the unemulsified oils shows that burn rates increased from about 0.5 mm/min for 2 mm slicks to about 1.5 mm for 5 and 10 mm slicks; weathering had little effect on the burn rate.

The slicks of 25% water emulsion burned oil at a slower rate, between 0 and 0.24 mm/min for the 2 mm thick slicks, between 0.5 and 0.75 mm/min for the 5 mm thick slicks and between 1 and 1.25 mm/min for the 10 mm thick slicks. The higher values in each range were associated with fresh oil emulsions; weathering reduced burn rates slightly. In the case of emulsions of the B–27 oil containing 50% water oil burn rates were reduced further to 0.25 – 0.5 mm/min for 5 mm thick slicks and 0.5–0.75 mm/min for 10 mm thick slicks. At 75% water only two of the three 10 mm thick slicks tested could be ignited (fresh and 8% weathered oil) and had oil burn rates of only 0.02 and 0.1 mm/min respectively.

Figure 20 shows the emulsion removal rates (rate = emulsion burn efficiency x initial thickness/burn time) calculated for the same tests. In this case emulsion removal rates increased from 0.25 – 0.5 mm/min for 2 mm slicks to 1–1.25 mm/min for 5 mm slicks to 1.5–2.25 mm/min for 10 mm slicks. There was little discernible effect of weathering or water content on emulsion removal rate; if anything, increasing water content slightly increased emulsion removal rate.

Figure 21 compares the removal rates (oil and emulsion) for 10 mm thick slicks of B–27 crude as a function of emulsion water content. It is clear that as water contents increased oil removal rates decreased steadily and emulsion removal rates increased. With less oil per millimetre of slick, and more water to vaporize, the oil burned more slowly and gave up more of its energy to evaporating water.

Figure 22 shows the effects of weathering and emulsification on oil burning rates for the C–96 oil as a function of slick thickness. The burn rate of unemulsified C–96 crude was almost identical to that of unemulsified B–27 crude (see Figure 19). The addition of 25% water rendered the 2 mm thick slicks virtually unburnable and reduced the 5 mm and 10 mm burning rates to 0.5–0.75 mm/min. Of the more weathered, more emulsified slicks only the 5 mm thick slick with 50% water could be ignited and had an oil burning rate of about 0.2 mm/min.

Figure 23 shows the emulsion removal rates calculated for the same runs. The data for the C–96 crude exhibits the same trends as that for the B–27 crude. Increasing slick thickness increased emulsion removal rates and increasing water content increased emulsion removal rates.

Figure 24 better illustrates the effect of water content on removal rate (oil or emulsion) for 10 mm slicks of C–96 crude; as water contents increased, oil burning rates steadily decreased and, as water contents increased emulsion burning rates increased until the maximum burnable water content was reached (between 50 and 75% for 5% evaporated C–96 and between 25 and 50% for 10% evaporated C–96).

FIGURE 19

EFFECT OF WEATHERING AND EMULSIFICATION ON BURN RATE

HIBERNIA B-27

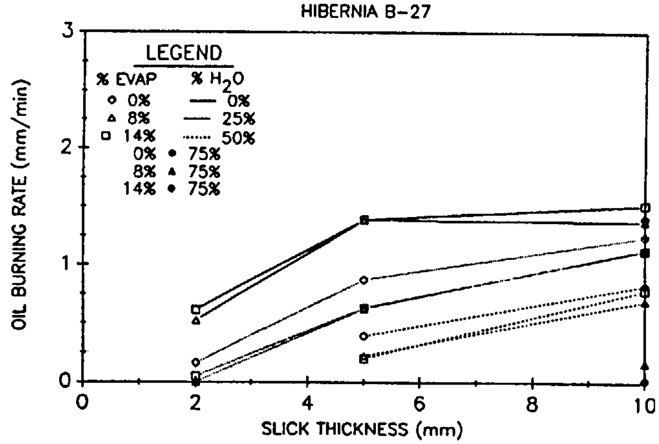


FIGURE 21

EFFECT OF EMULSIFICATION ON REMOVAL RATE

HIBERNIA B-27 – 10mm SLICKS

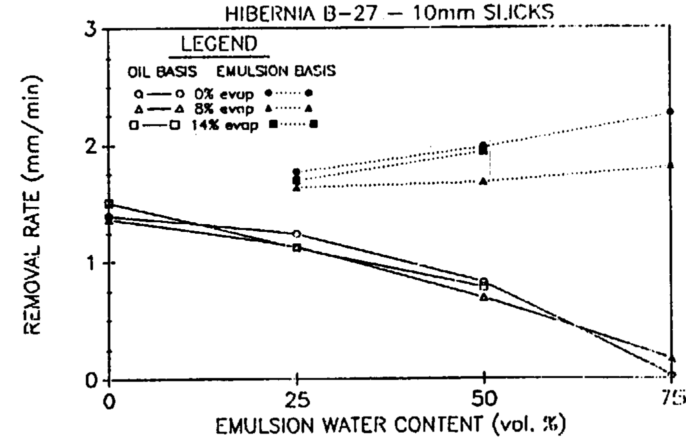


FIGURE 20

EFFECT OF WEATHERING AND EMULSIFICATION ON REMOVAL RATE

HIBERNIA B-27 – EMULSION

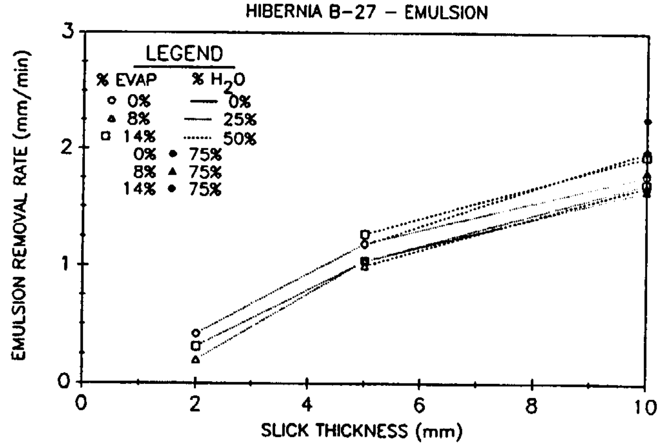


FIGURE 22

EFFECT OF WEATHERING AND EMULSIFICATION ON BURN RATE

HIBERNIA C-96

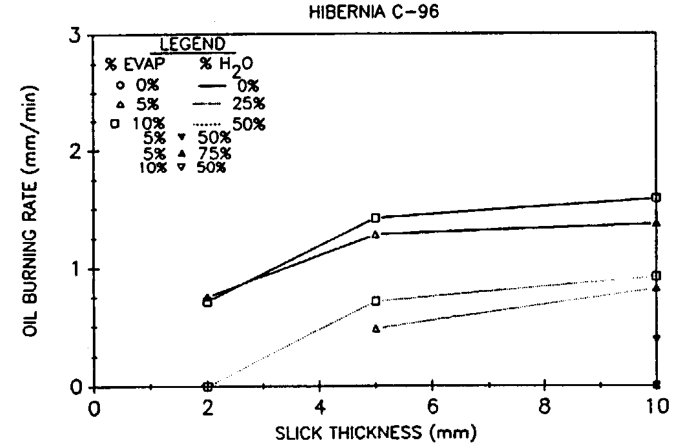


FIGURE 23

EFFECT OF WEATHERING AND EMULSIFICATION ON REMOVAL RATE

HIBERNIA C–96 – EMULSION

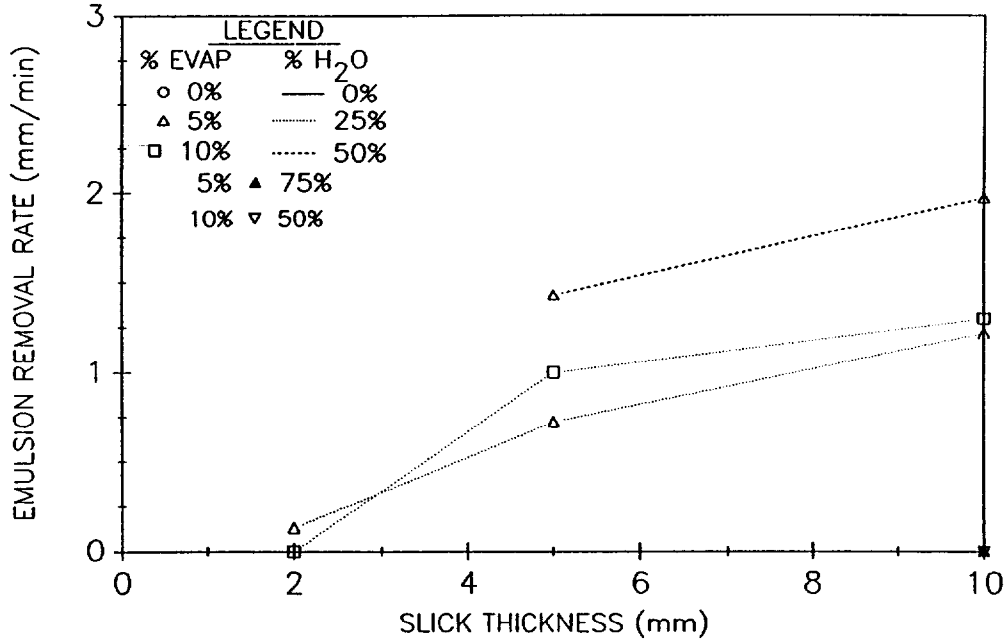
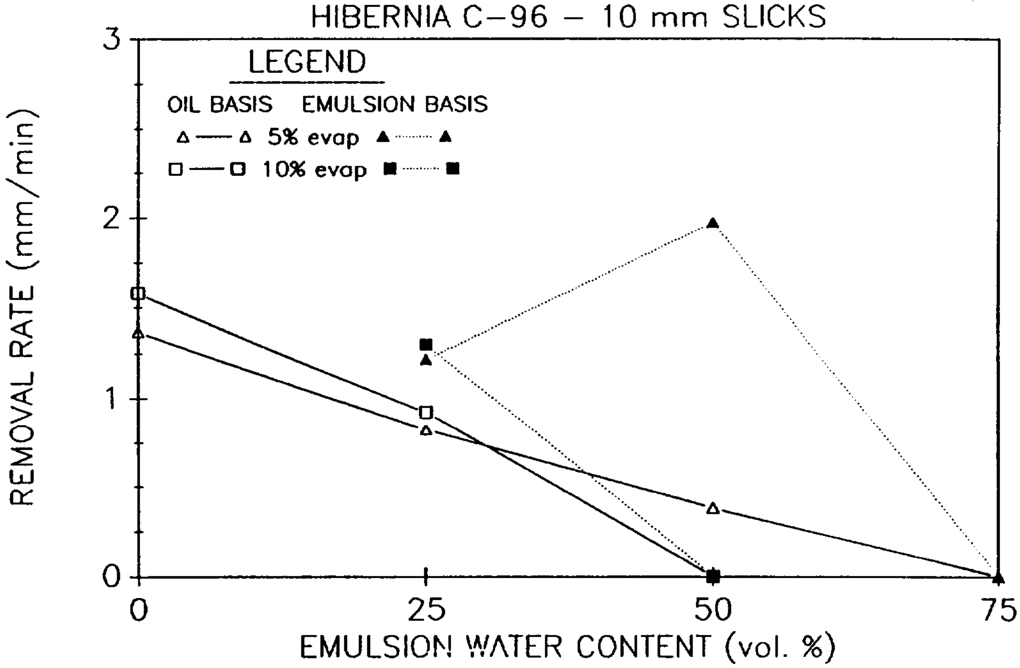


FIGURE 24

EFFECT OF EMULSIFICATION ON REMOVAL RATE

HIBERNIA C–96 – 10 mm SLICKS



DESIGN, FABRICATION AND TESTING OF THE "SWIRLFIRE" BURNER

EQUIPMENT AND METHODS

The "Swirlfire" Burner

A prototype "Swirlfire" burner was designed and constructed for this portion of the study. The device (Figures 25 and 26) is based on a design originally developed by Mr. Ed Twardus of Energetex Engineering and consists of a single unit incorporating a diesel engine, fan, rotary cup atomizer and combustion head. The prototype, designed to be heli–portable, incorporates pad–eyes for stable lifting and weighs about 400 kg dry.

The unique features of this burner, compared with other portable oil–spill disposal burners such as the Saacke system (Buist and Vanderkooy 1982) are: first, the "Swirlfire" delivers about 40–50% excess air (i.e., 140–150% of the stoichiometric air required for combustion); second, the "Swirlfire" burner utilizes two fuel atomization processes, the primary system being a rotary cup and the secondary system being impingement of oil on a hot steel plate inside the combustion chamber; and third, the combustion chamber itself incorporates a unique recirculation system and swirling motion to extend retention times and encourage complete, smokeless combustion.

A full parts list, operating instructions and maintenance instructions may be found in the report (S.L. Ross 1989).

Test Oils

Five oil types were used to test the capabilities of the burner, including: two crudes with various emulsion water contents, Bunker "C", diesel and waste engine oil. The properties of the fresh, unemulsified oils are given in Table 3. Emulsions for the tests were prepared by mixing appropriate volumes of crude oil and tap water in a 22.7 L pail with a high–speed mixer. Properties of the emulsions of the crudes were not measured.

TABLE 3

Physical Properties of Fresh Oils for the "Swirlfire" Tests

Oil	Density (kg/m^3) @ 10°C	Viscosity (mPas) @ 10°C	Pour Point	Flash Point
HIBERNIA B–27	878	240	9	11
UVILUK P–66	900	15	N.M.*	N.M.
DIESEL	831	2.9	–20⁺	55⁺
BUNKER "C"	1018	111,000	5⁺	>110⁺
WASTE ENGINE OIL	880⁺	200⁺	–36⁺	190⁺

* not measured
\+ from Bobra 1989

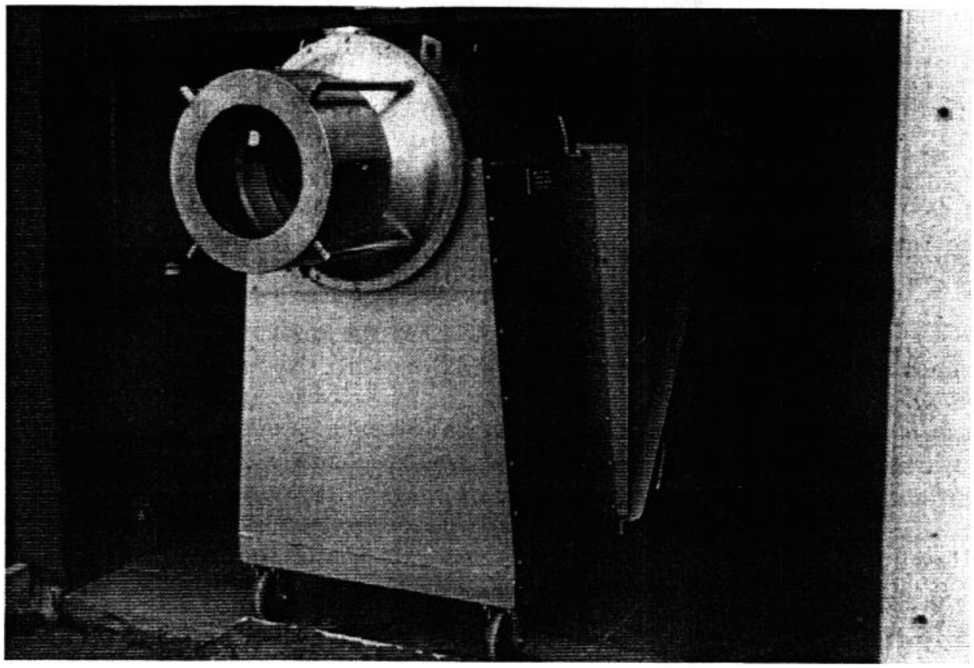
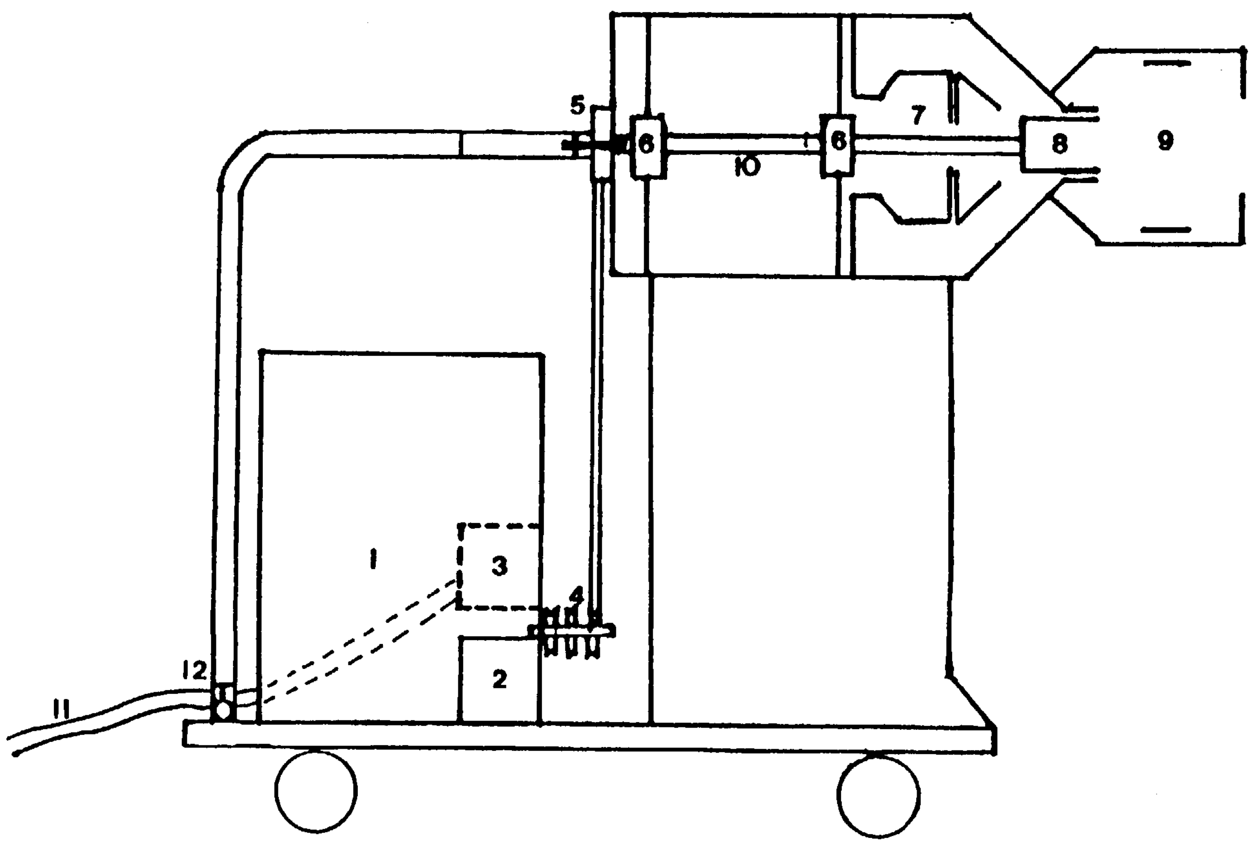


Figure 25 – The prototype "Swirlfire" burner showing the combustion chamber, rotary cup and ignition port

FIGURE 26

Schematic of the "Swirlfire" Burner



1 Engine
2 Generator
3 Pump
4 Pullies
5 Rotating seal
6 Bearings
7 Blower
8 Atomizing cup
9 Combustion head
10 Shaft
11 Hose
12 Valves

Test Measurements

The following were recorded during each test:

* oil or emulsion flowrate (by timing the decrease in height of oil in a 22.7 L pail from which the oil or emulsion was pumped)
* engine speed (rpm from a tachometer; fan and cup rpm = 1.54 x engine rpm; pump rpm = 0.5 x engine rpm)
* pump discharge pressure
* flame emissions (soot and fallout visually)

Following the test series, the burner was connected to a section of ducting and the airflow generated by the fan at various speeds was determined by measuring air velocity profiles in the duct (see the report).

Test Procedures

The following procedures were followed for each test:

1. the engine was started and run up to 700–800 rpm;
2. the pump suction hose was placed in a jerrycan of diesel fuel;
3. the shutoff valve was opened and the flow control valve opened one turn;
4. when diesel began to be atomized by the rotary cup, a burning, diesel–coated rag secured around the end of a steel bar was inserted into the ignition port and placed at the bottom of the combustion chamber; the diesel ignited in about 1 minute;
5. the burner was allowed to warm up for 3–5 minutes burning diesel;
6. the suction hose was moved into a 22.7 L pail of the test oil or emulsion and the oil or emulsion level recorded;
7. the height of oil or emulsion was recorded periodically, after each measurement the flow control valve was opened further;
8. once the combustion chamber began to produce smoke, the flow control valve was reduced ½ turn and the suction hose replaced in diesel fuel;
9. the burner was run until diesel reached the rotary cup, then the shutoff valve was closed the burner allowed to extinguish and cool down.

RESULTS AND DISCUSSION

Table 4 shows the highest flowrates of oil or emulsion recorded for the various test oils that resulted in a smokeless burn. Complete data for each test may be found in the report (S.L. Ross 1989). The results for unemulsified oil ranged from 0.76 L/min (6.9 bbl/day) for Bunker "C" to 1.88 L/min (17 bbl/day) for diesel oil; the crude oils were burned cleanly at rates in the 1.32–1.46 L/min range (12–13 bbl/day) and the waste engine oil was burned at 1.19 L/min (10.8 bbl/day). On the basis of the combustion rates for the unemulsified crudes and the diesel fuel and accounting for the different operating speeds, the nominal capacity of the prototype, for clean combustion, is in the 1.6 L/min (14 bbl/day = 21 gal/hr) range.

TABLE 4

Maximum Clean Combustion Rate Results

Oil	% Water (Volume)	Engine RPM	Pump Pressure (kPa)	Max. Combustion Rate (L/min)	Max. Combustion Rate (bbl/day)	Comments
Hibernia B–27	0	1400	165	1.32	12.0	clean burn
	25	1500	165	2.08	18.8	clean burn; some droplet fallout
	50	1600	165	2.71	24.5	clean burn; some droplet fallout
	66	1600	150	4.19	37.9	very clean burn; droplet fallout; max. pump rate
Weathered UVILUK P–66	0	1600	150	1.46	13.2	clean burn
	25	1600	150	2.96	26.8	clean burn
Bunker "C" (preheated to 49°C)	0	1600	170	0.76	6.9	some light smoke
waste engine oil	0	1600	150	1.19	10.8	clean burn
diesel	0	1700	150	1.88	17.0	very light smoke

When burning unemulsified crude oil the combustion process was very clean (Figures 27 and 28) with the flame at the maximum rate extending only some 30–40 cm out of the combustion chamber. If the flowrate was increased above the maximum clean burn rate the flames extended farther and some smoke was generated (Figure 29). Burning diesel fuel produced a very clean flame (Figure 30) at rates below the maximum as did the combustion of the waste engine oil (Figure 31). Burning Bunker "C" produced some light smoke regardless of flowrate (Figure 32) and some carbon residue was found inside the combustion chamber after the test (Figure 33).

As the water content of the crude oil emulsions increased the maximum clean burn rate increased. As shown in Figure 34, the increase in maximum clean burn rate was inversely proportional to the fraction of water in the fuel up to 66% water (the highest tested). As the water content increased, the characteristics of the flame changed as well. With 25% water in the crude oil the flame was slightly less luminous (Figure 35) than the water–free oil test (Figure 27) and slightly longer (about 50 cm vs. 30–40 cm). Some small water drops were ejected from the burner at the maximum combustion rate with the 25% water–in–oil emulsion.

At 50% water content, the flame was considerably less luminous than at 25% water (Figure 36) and slightly longer again (70 cm vs. 50 cm). Some small water drops were ejected from the combustion chamber during this test and, after the test, it was noted that some water had pooled in the bottom of the chamber (a drain plug is provided for its removal).

At 66% water content, the flame was almost invisible (Figure 37) and droplets of water, containing a small amount of oil, were observed to be ejected from the lower lip of the combustion chamber. After the test a considerable volume of water with a small amount of oil floating on top was discovered in the bottom of the chamber. Consideration should be given to providing a tube running from the drain in the chamber to allow continuous draining of this accumulated water. This tube could perhaps run back to a container where the oil could be separated and recycled into the burner.

During the tests with emulsions the efficacy of the secondary atomization system (the hot steel plate mounted inside the circumference of the chamber) became clear. It was obvious that a considerable fraction of the atomization was taking place at this plate; without it it seems unlikely that the high–water–content emulsions could have been successfully burned.

It should be noted that in one test (50% water content emulsion of weathered Uviluk P–66 crude oil) the emulsion separated and the pump sucked water which instantly extinguished the flames. Reignition required purging the lines with diesel and relighting the burner – a process that took about 5 minutes.

RECOMMENDED MODIFICATIONS TO THE PROTOTYPE

Although the prototype "Swirlfire" burner performed admirably during the tests, several modifications are required for more efficient use of such a device in field situations; many of these are very minor. They are listed in the report (S.L. Ross 1989).

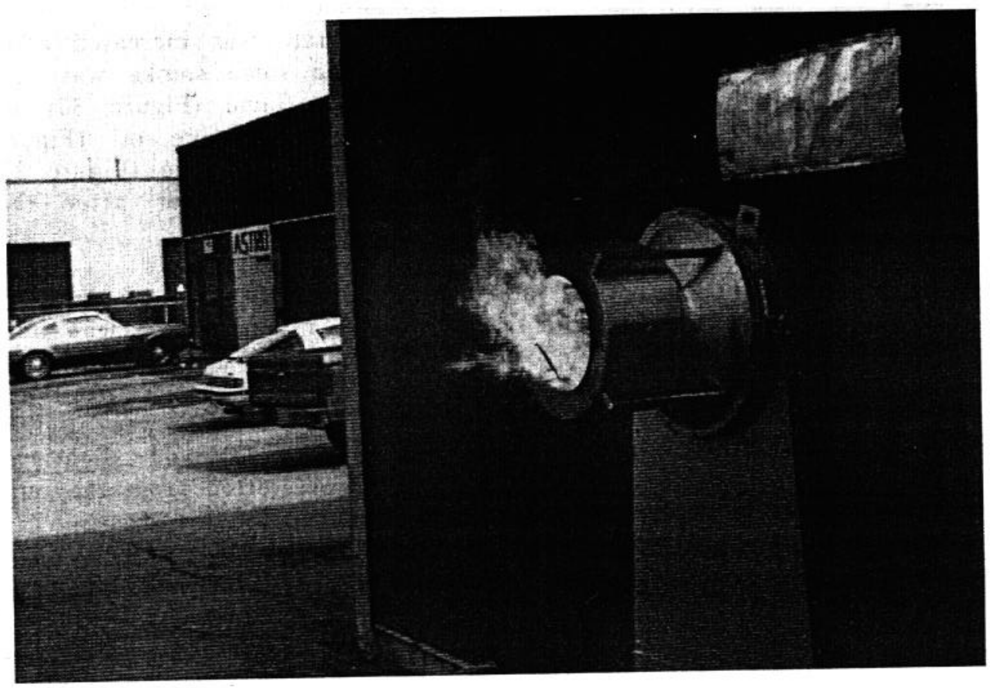


Figure 27 – Burning unemulsified Hibernia B–27 crude oil

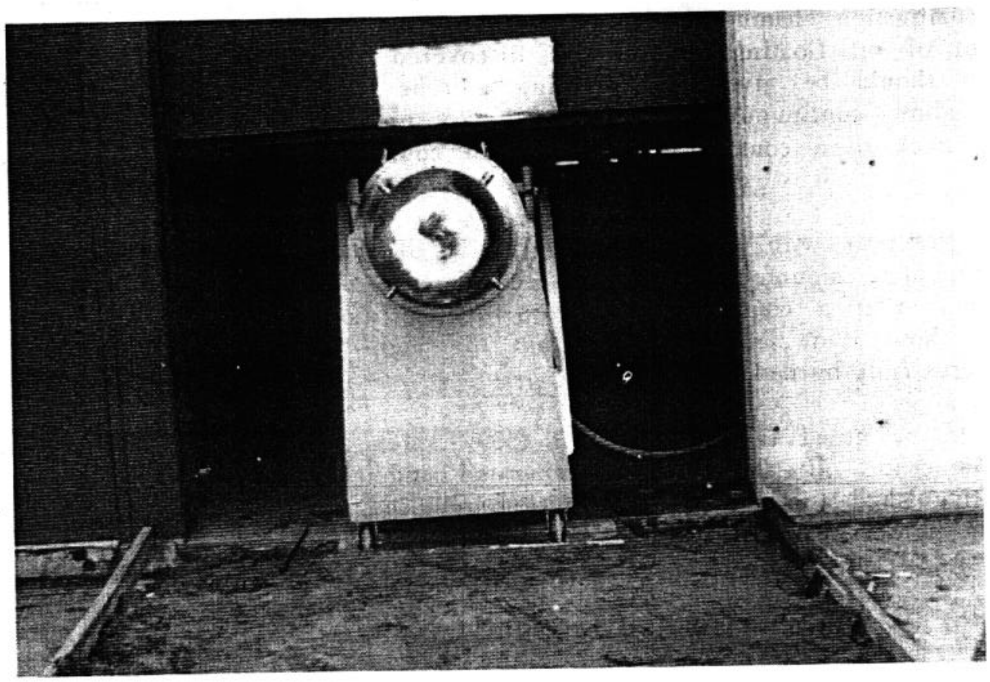


Figure 28 – As above; note swirling action of flame in combustion chamber

Figure 29 – Smoke generated when burning crude oil at rate above maximum clean rate

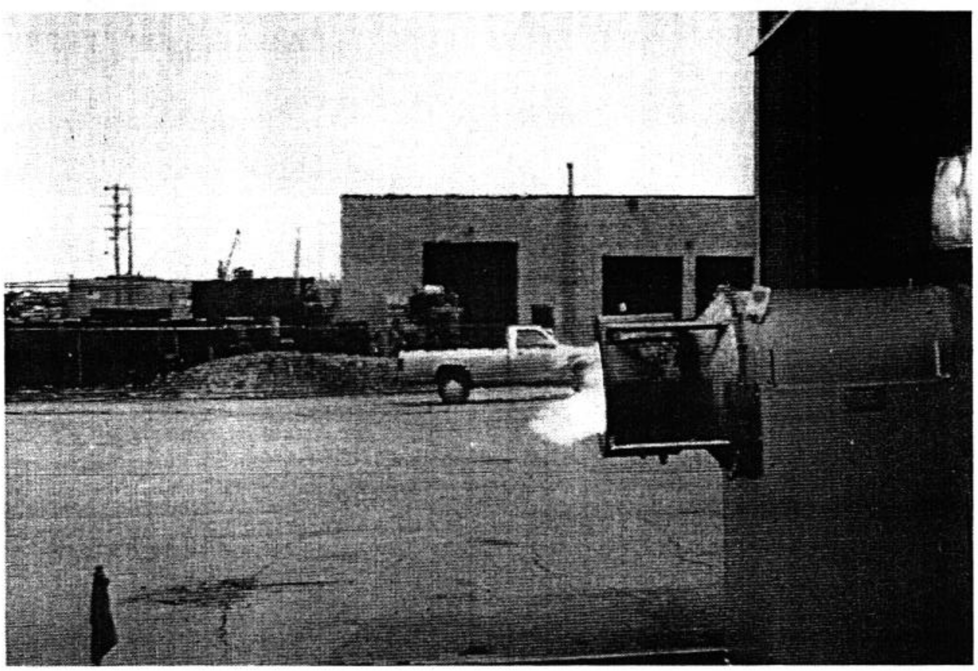


Figure 30 – Clean burn of diesel fuel

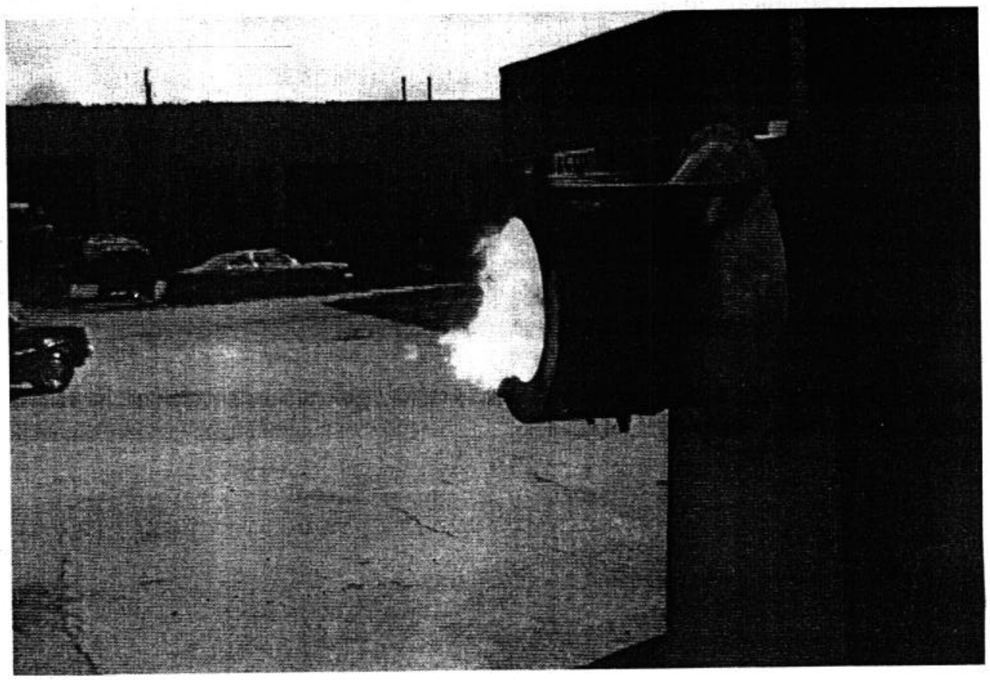


Figure 31 – Clean burn of waste engine oil

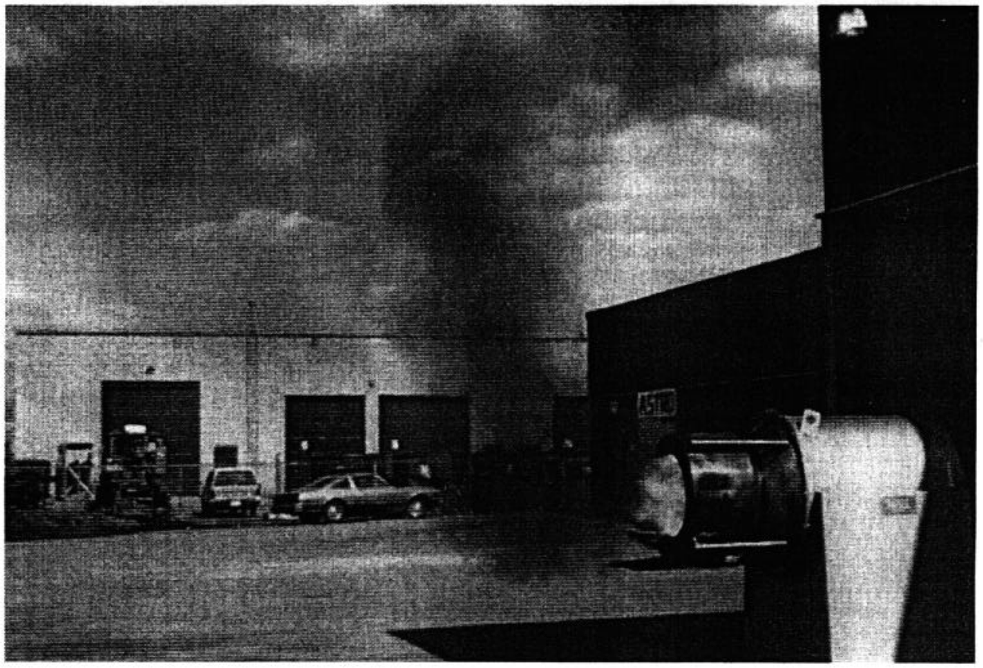


Figure 32 – Smoke generated when burning Bunker "C"

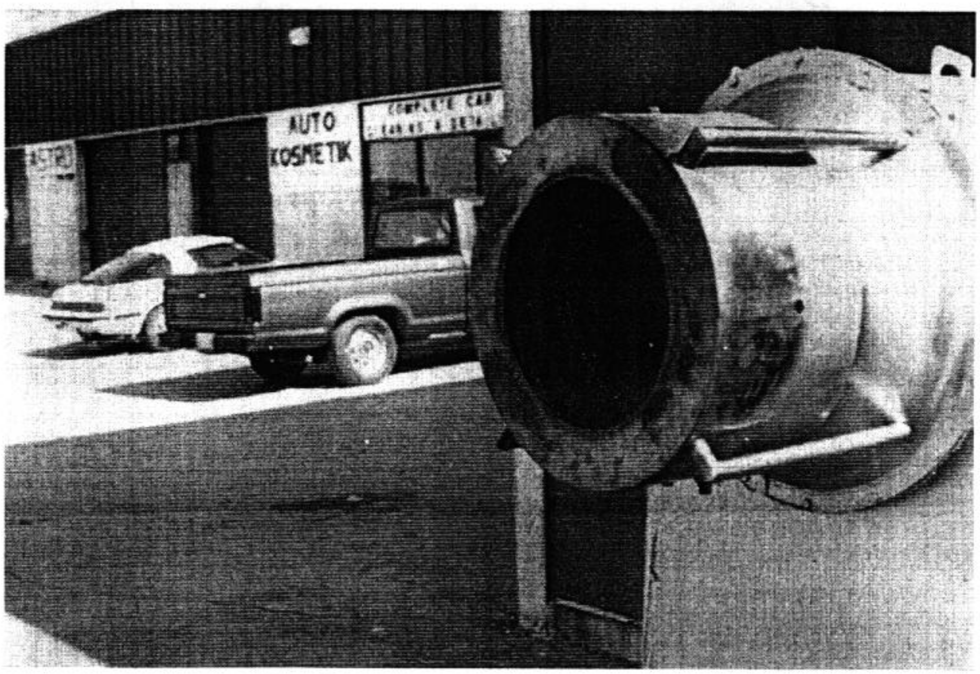
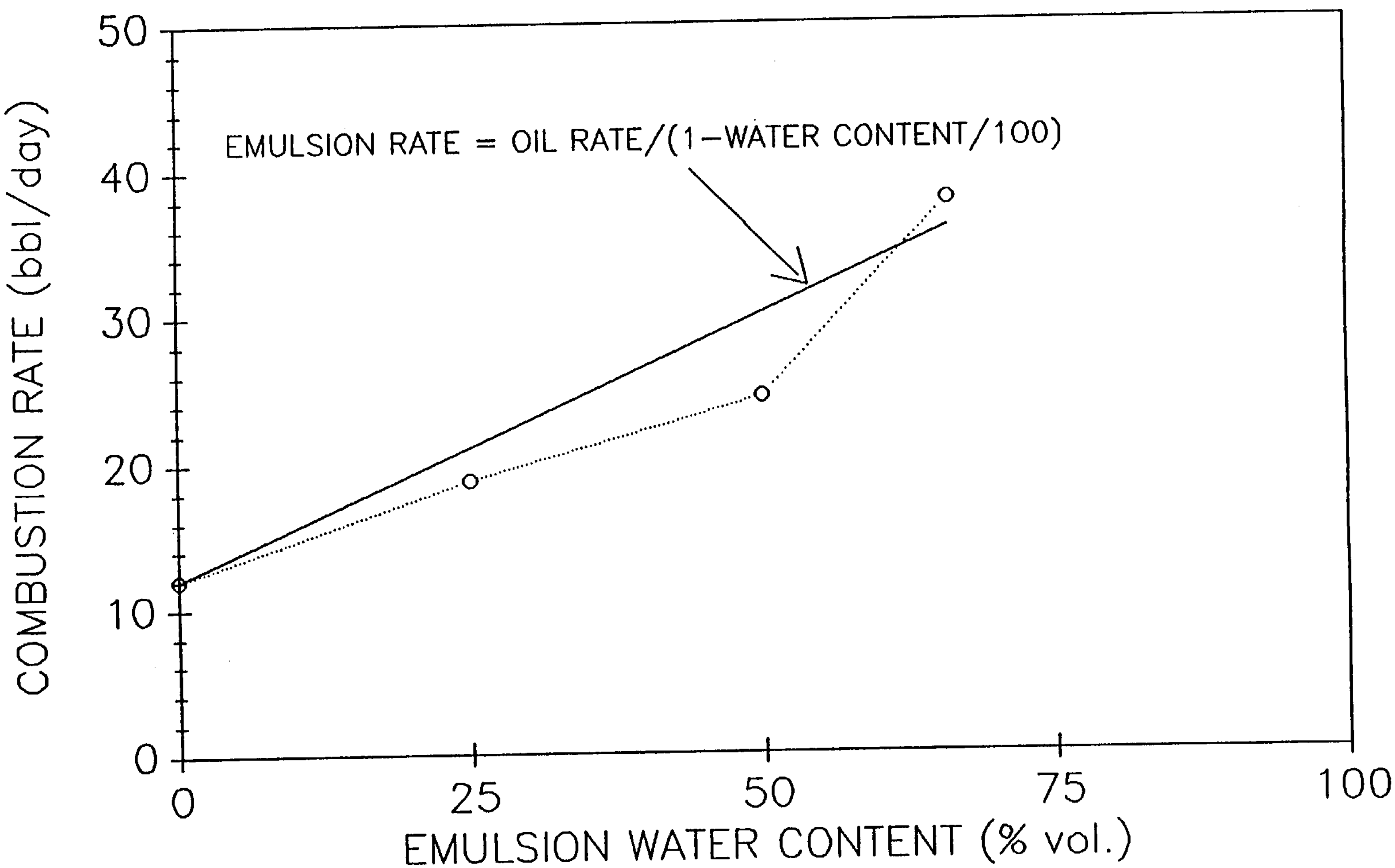


Figure 33 – Residue remaining inside combustion chamber after Bunker "C burn

FIGURE 34

EFFECT OF EMULSION WATER CONTENT ON
MAXIMUM CLEAN COMBUSTION RATE OF THE "SWIRLFIRE"



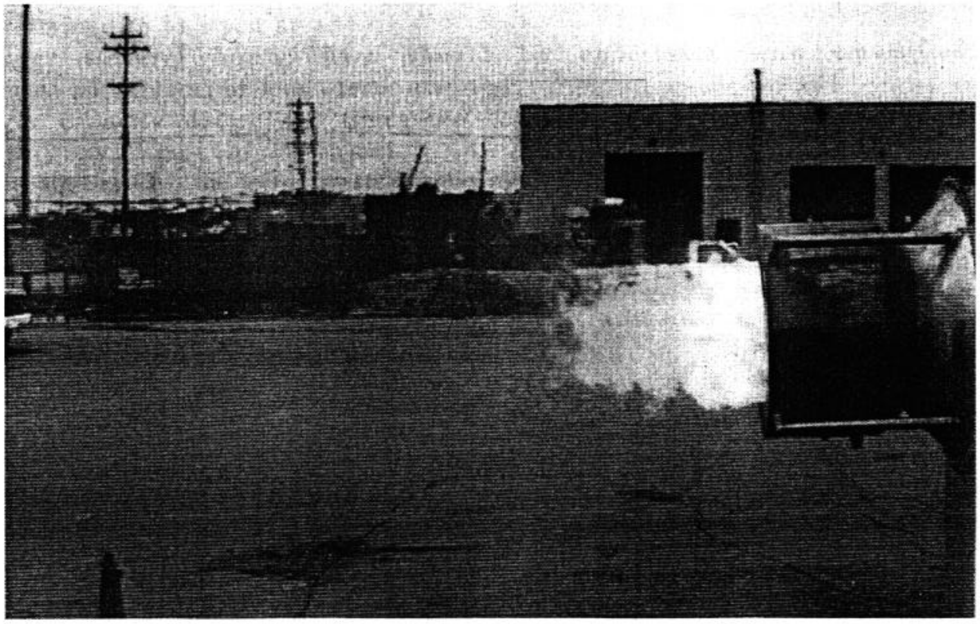


Figure 35 – Appearance of flame when burning 25% water–in–Hibernia B–27 emulsion

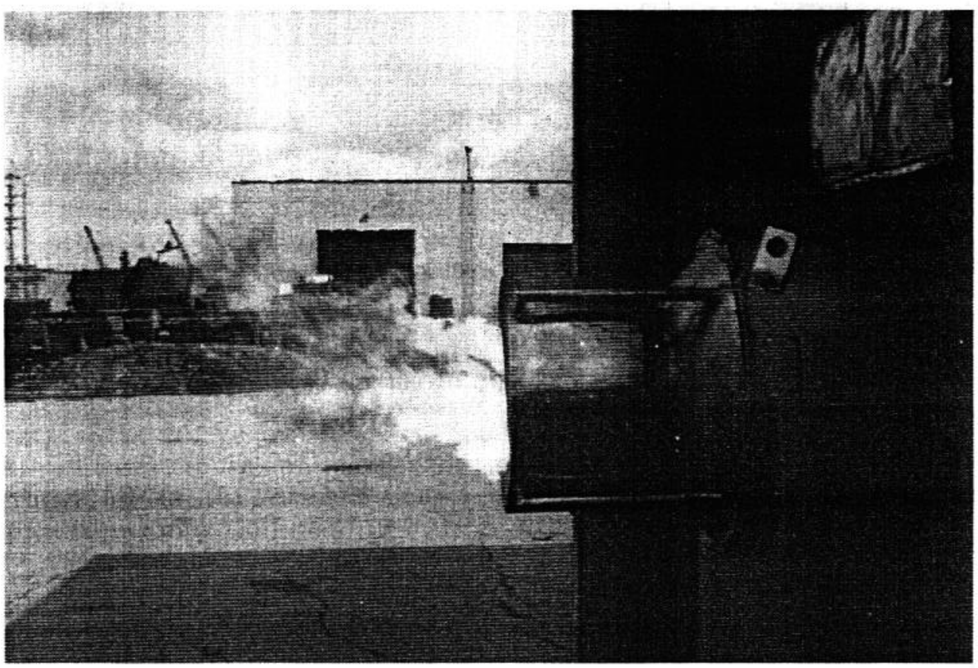


Figure 36 Appearance of flame when burning 50% water–in–oil Hibernia B–27

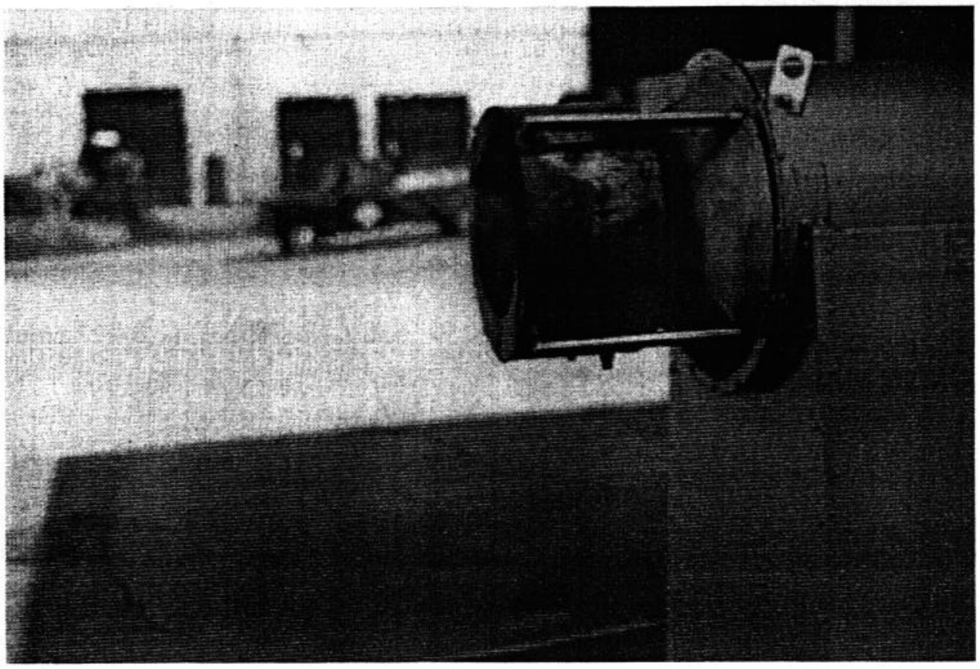


Figure 37 – Appearance of flame when burning 66% water–in–Hibernia B–27 emulsion; note droplets coming from lower lip of combustion chamber

As well as these minor modifications, based on experience with the prototype, the following are recommended:

* the maximum capacity of the prototype (i.e., ignoring smoke generation) should be determined in an open area;
* a longer (several hours) burn should be undertaken with emulsified oil to determine any effects of long–term use; and
* a larger capacity device (10 times the capacity of the prototype would provide a capability to dispose of 16 L/min = 145 bbl/day = 210 gal/hr as recommended in a previous study on oily waste disposal (S.L. Ross 1988)) should be designed, constructed and tested. Rough calculations indicate that this may be possible with less than a doubling of the weight of the unit.

CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

In–Situ Burning of Hibernia Crude Oil Spills

1. emulsions of the Hibernia C–96 crude proved to be more difficult to ignite and burn than those of the Hibernia B–27 crude;
2. the ignition times of slicks increased slightly with increasing weathering and increased dramatically with emulsification; flames would not spread over most slicks with water contents in excess of 50%;
3. the results of ignition tests with oil–soaked sorbent pad squares indicate that thick (>2 mm) slicks of oil should be easily ignitable with a "Helitorch" well beyond 12 hrs after a spill occurs; thick (>2–5 mm) slicks of emulsion should be ignitable by a Helitorch for up to about 12 hours after a spill occurs providing the emulsion water content is in or below the 25–50% range for Hibernia C–96 crude and in or below the 50% range for Hibernia B–27 crude;
4. slicks of emulsion with water contents in excess of these maximums can be ignited using a layer of fresh oil to initiate combustion over a larger slick area than can be achieved with the "Helitorch"; the maximum ignitable water content for thick (10 mm) slicks of emulsion using this technique was 50% for the Hibernia C–96 crude and 75% for the Hibernia B–27 crude;
5. oil burning efficiency increases with increased slick thickness, is not a strong function of oil weathering and decreases with increasing emulsification. Thick (10 mm) slicks of unemulsified oil had burn efficiencies in the 85–90% range. Thick (10 mm) slicks of emulsified oil containing 25% water had oil burn efficiencies of in the 70–80% range. Thick (10 mm) slicks of Hibernia B–27 emulsions containing 50% and 75% water had burn efficiencies in the 70–75% and 5–35% range respectively. Thick (10 mm) slicks of Hibernia C–96 emulsion with water contents of 50% and greater were generally unignitable;
6. emulsion removal efficiency (including both oil burned and water evaporated) increased with increasing water content up to the point where the slick was no longer ignitable. This, combined with the dramatic reduction in oil burning efficiency with increasing water content over 50% implies that, in the event of a real spill, two ignitions may be required: the first would be used to vaporize most of the water from the slick; after herding the residue to thicken it, the second would be used to burn off the oil; and

7. increasing water content of an emulsion from zero to the maximum ignitable, reduces the oil burning rate but increases the emulsion removal rate.

Testing of the "Swirlfire" Burner

1. The "Swirlfire" burner successfully combusted water-free crude oil at rates of 1.32–1.46 L/min (12–13 bbl/day) with no smoke;
2. Water-in-crude oil emulsions were burned cleanly up to a maximum 66% water content (the highest tested);
3. The rate at which the device could burn water-in-oil emulsions cleanly was inversely proportional to the fraction of oil in the emulsion (i.e., a 66% water content emulsion burned at a rate about 3 times that of the clean burn rate of the parent oil);
4. Diesel fuel and waste engine oil were burned cleanly at rates of 1.88 and 1.19 L/min (17 and 10.8 bbl/day) respectively;
5. Bunker "C" preheated to 50°C, was burned at a rate of 0.76 L/min (6.9 bbl/day); some smoke was generated regardless of flowrate.

RECOMMENDATIONS

In-Situ Burning of Hibernia Crude Oil Spills

1. The potential for rapid, efficient removal of oil spills by in-situ burning warrants that field trials of the technique be carried out offshore to assess "real world" ignitability, removal rates and removal efficiencies in wave conditions for slicks both contained by fireproof booms and uncontained.
2. The purchase, for field testing, of a "Helitorch" aerial ignition system is recommended.

Testing of the "Swirlfire" Burner

1. A number of minor modifications to the prototype are suggested to improve its operational use. These are listed in the report.
2. Further testing of the prototype is recommended to evaluate its capability for long-term operation and determine its maximum achievable combustion rate, regardless of smoke generation.
3. A model of the "Swirlfire" with 10 times the nominal capacity of the existing prototype (i.e., 16 L/min = 145 bbl/day = 210 gal/hr) should be constructed and tested as an operational unit, providing the testing recommended above is satisfactory.

ACKNOWLEDGEMENTS

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