IN SITU BURNING OF OIL IN ICE LEADS

H.M.Brown and R.H.Goodman
Esso Resources Canada Limited

ABSTRACT

A series of experiments was carried out at the Esso Research ice basin in Calgary, Canada to evaluate the critical parameters of burning oil in ice leads. This may be a useful spill cleanup technique in the Arctic under certain conditions. Twenty-five test burns of Norman Wells crude were carried out to study the effect of wind herding, oil weathering, oil thickness, and lead geometry on burning efficiencies. Burning efficiencies of up to 90% were measured where moderate winds herded the oil into long narrow leads. Burning in other lead geometries was less efficient as was burning in the presence of brash ice. Weathering of the oil up to 20% did not significantly effect the burns.

INTRODUCTION

Oil spill cleanup in Arctic waters poses unique problems because of the total or partial coverage of ice for much of the year. If oil is lost beneath the ice surface, such as might occur with an underwater pipeline break or well blow out, the oil would collect in rough areas of the ice sheet lower surface. In regions where the Spring breakup occurs, it could then percolate through the ice to form in melt pools. Otherwise, it would reach the surface only when leads open up around pressure ridges, either in the multi-year ice or in transition zone ice. Because such leads may be short lived and occur in remote areas, oil clean-up would be very difficult under the best circumstances.

In remote areas such as the Arctic, the transport and disposal of collected oil and debris becomes a problem of similar scope to that of containment and pick up. Hence, the burning of spilled oil in-situ appears be a simple and straight forward solution. Several recent studies have addressed various aspects of in-situ burning, particularly with respect to oil in melt pools. Dickens and Buist (1981) reported on a field study of oil clean-up in ice infested waters conducted under the auspices of COOSRA, in which the burning of oil in melt pools was studied. The OHMSETT facility in New Jersey has been used to determine burning rates and burning efficiencies of oil in broken ice with varying ice coverages. Energetex (1981) studied spreading rates of oil on water and the effects of wind herding. Buist and Twardus (1984) conducted theoretical and laboratory studies on oil and flame spreading under differing wind conditions. To date, the one area of burning as a clean-up technique in ice infested waters that has not been addressed is that of the efficiency of burning of oil in ice leads.

In order to evaluate the parameters of burning which are likely to be critical in ice leads, a series of experiments was carried out in February 1986 at the Esso Resources ice test basin in Calgary. The tests were designed

Environment Canada. Arctic and Marine Oilspill Program (AMOP) Technical Seminar, 9th. Proceedings. June 10-12, 1986, Edmonton, Alberta, Canada, Environment Canada, Ottawa, Ontario, 245-256 pp, 1986.

to evaluate the effect of wind herding, oil weathering, oil thickness, lead geometry, and presence of brash ice on burning efficiency. The size of the facility allowed burning experiments to be carried out at essentially full scale.

TEST FACILITIES AND EQUIPMENT

The Esso ice test basin is a large outdoor concrete pool 30 meters wide by 56 meters long and varying in depth from 0.75 to 3 meters. Water capacity is approximately 2200 cubic meters. Two 200,000 BTU/hour refrigeration units are available for forming the ice sheet, although for the oil in ice leads burning experiment, the sheet was allowed to form naturally.

A device was designed and constructed to measure the thickness of oil on water. It consisted of a hollow aluminum bar 5cm. by 12cms. in cross section and 1.5 meters long, with leveling feet at each end. A sliding trolley, which runs along the beam but is electrically isolated from it by teflon bearings, holds a digital readout micrometer screw. One lead of a sensitive ohmmeter is attached to the micrometer screw while the other lead is grounded to a large paddle which extends from the aluminum bar into the water below the oil slick. The device detects the oil-water interface by measuring the change in resistivity as the micrometer screw is turned vertically through the oil to the water. In laboratory tests the reproducibility of oil thickness measurements with the device was ±0.03mm.. Under the best lighting conditions, the device always detected the oil-water interface before the screw tip was visible below the oil.

In order to determine heat fluxes into the water and ice from the burning process, an underwater rack was constructed which held 6 thermocouples and 6 thermistors. Each thermal device could be raised or lowered to a preset depth or imbedded in the ice at the side of the lead. All outputs were connected through a sheathed cable buried in the ice to a Sea Data Inc. Model 1250 logger. The signals were digitized at a one second rate and recorded on magnetic tape for later analysis.

Wind was provided by a 17ft. airboat. It used a 150hp. aluminum V6 engine to drive a 54 inch blade at 1000 to 3800 rpm.. The entire unit was light enough to be easily moved across the ice surface to any desired location. Generally, winds could be controlled to within ±0.5 m/sec. of the desired velocity provided that local winds were calm. This was insured by erecting fences consisting of 4 by 8ft. plywood sheets parallel to the ice leads 1.5m from each edge. To obtain very low winds it was necessary to erect a lattice baffle immediately behind the airboat so as to reduce the air flow. A hand held anemometer was used to measure the air flow 20cms above the water surface.

Each burn was recorded on colour video with a portable Hitachi camera mounted on a tripod. Some experiments were monitored with a Barr and Stroud Model IR18 infrared camera operating between 8 and 13 microns wavelength.

PROCEDURES

During November and December 1985, the ice sheet on the outdoor basin froze naturally to an average thickness of 45cms. Chain saws were used to cut several artificial leads in the sheet. For most experiments these were 1 by 10 meter leads, but a semicircular hole 5m in diameter, a square hole 5m by 5m ,and two triangles each with a 1m base and 4m perpendicular were also cut. Typically the water surface was 3 to 4cms. below the top ice surface.

Once the lead was clear of brash ice, the temperature sensing array was lowered into the lead and the sensing elements adjusted for correct heights. Aged Norman Wells crude (from 10 to 40 litres) was then poured carefully on the lead surface and allowed to spread under the experimental wind conditions selected. After approximately 15 minutes, equilibrium thicknesses were obtained and thickness measurements were then made using the device described previously. The wind was measured about 20cms. above the oil surface and adjusted by varying the airboat engine speed. Wind speed was always set at the front edge of the oil slick.

The Norman Wells crude was aged by parging the oil in barrels with a stream of compressed air. The degree of weathering was estimated both from the loss of oil from the barrels and from simulated distillation gas chromatography.

Oil was ignited with a small hand held torch, usually at the upwind edge of the slick but occasionally at the down wind edge. The progression of the flame front was then measured with a stopwatch as it passed meter marks at the edge of the lead. When burns took place in irregular leads, a sketch of the burning front at regular intervals was made and later checked for accuracy by viewing the video tapes.

After completion of a burn, the residue was removed from the lead, placed in plastic bags, and weighed. This could usually be done using sieve shovels which would lift the viscous residue and allow the water to drain off. Residue recovery was estimated to be better than 95%.

Samples of lead water were taken for hydrocarbon analysis both before and after the burn. Residue samples were saved for later analysis.

A total of 25 burns were carried out during January and February 1986 in which the parameters studied were wind herding, oil weathering, slick thickness, and lead geometry. Two experiments were conducted in the presence of brash ice.

RESULTS AND DISCUSSION

General

The processes which occur during the burning of a combustible liquid are very complex but depend on the rate at which heat is transferred to the fuel, the rate at which fuel is carried to the flame, and the rate at which oxygen can be supplied to the flame and combustion products removed. These various processes could be observed during the experimental burns carried out in the ice leads. A typical burn sequence began with the ignition of one end of the oil slick. Initially the fire spread slowly often with small visible blue flames at the base of slightly larger (10 to 15cm.) yellow flames. At this point whatever light ends were available (depending on the oil type) were burning. As sufficient heat was transferred to the slick to vaporize heavier components the flames increased in size and began to spread more rapidly. Within about one minute after ignition, the fire had usually reached one square meter in area with flames a meter high. At this point rapid boiling of the lead water would commence accompanied by popping noises and a marked increase both in flame size and spreading rate. It appeared that the violent agitation of the water caused by the boiling served to increase the rate at which fuel was supplied to the fire. Voluminous black smoke accompanied this phase. There was no evidence that the initial fuel type had any effect on the fire by the time it had matured to this stage. Depending on wind speed, air would often be entrained to the extent that a firestorm would develop and the flame would take on the characteristics of a miniature tornado. This stage of the fire continued as long as there was fuel available. Finally, as fuel was exhausted, the fire would very rapidly die down to a few scattered small blue flames which might persist for a minute or more before extinguishing. Rapid cooling of the residue followed.

Wind, oil weathering, amount of oil, and lead geometry have been varied and the effect of these on oil burning in ice leads measured by calculating the flame spreading rate, the burning regression rate, and the burning efficiency. In addition, the viscosity and specific gravity of the residues have been measured and gas chromatographic analyses made. The lead waters have been measured for hydrocarbon content. Many of these analyses and measurements are summarized in Table I and will be discussed in detail below.

Wind Herding:

Wind may be very advantageous for burning oil in leads by herding thin sheens of oil to thicknesses which will support combustion. In an early study of burning in melt pools, Energetex Engineering (1977) showed that low winds would herd oil, which was otherwise to thin to burn, to sufficient thicknesses for burning. They determined that without wind, fresh slicks had to be thicker than 0.6mm to burn and heavily weathered oil had to be at least 3mm thick to burn. We studied slicks from 1.0 to 4.0mm thick. In the Beaufort, winds average 3 to 5 meters/sec. Studies by Dome (1981) show that the ground wind shear over level ice causes the 10 meter height wind speeds to be approximately halved at ground level. Thus to mimic realistic Beaufort winds, experiments should be carried out with ground winds of about 2.5 meters/second.

The average wind herded oil thicknesses calculated on the basis of the amount of oil spilled and the observed oil coverage are shown in the table. These calculated values agree well with the average of the thicknesses measured with the device described previously. The herded thicknesses are in general agreement with those reported by Energetex(1977). Buist and Twardus (1984) find that 1 hour weathered oil 2mm in depth will be herded to about 3mm with a 1 meter/sec. wind, which agrees well with the measured value in experiment #13.

TABLE I RESULTS OF BURNING EXPERIMENTS

Oil Weathering %	Test #/Conditions	Volume Spilled ℓ	Wind Speed m/sec	Burn Time After(sec) Ignition	Residue Volume ℓ	Burn Efficiency %	Herded Slick Area m^2	Regression Burning Rate mm/min.	Flame Velocity m/sec.
5	10	30	--	271	3.2	89	9.6	0.6	0.05
	13	20	1	189	4.7	77	7.3	0.6	0.12
	15	30	2.5	290	4.1	86	7.8	0.7	0.15
10	4	30	1.5	158	3.8	87	5.7	1.7	0.05
	5	30	--	358	4.5	85	8.1	0.5	0.04
	6	20	--	199	5.8	71	9.0	0.4	0.07
	7	40	--	375	6.5	84	10.0	0.5	0.03
	8	10	--	356	3.3	67	3.7	0.3	0.03
	9	30	2.5	226	3.1	90	3.2	2.2	0.07
15	16	30	--	303	4.4	85	9.5	0.5	0.05
	20	30	0.5	346	2.5	92	4.0	1.2	0.03
	17	30	2.5	195	3.0	90	3.0	2.7	0.08
20	23	30	--	277	5.7	81	7.4	0.7	0.04
	21	30	1.4	201	4.9	84	4.5	1.6	0.03
	25	30	5.8	225	4.7	84	1.6	4.1	0.07
~ 10	2 Brash	27	--	885	8.2	70	9.0	0.1	0.01
~ 10	3 Ice	27	4.5	565	5.4	80	5.0	0.4	0.03
5	24 Circle	30	3	189	5.4	73	3.5	2.1	--
	22 Crosswind	20	4	305	6.6	78	9.8	0.2	--
	11 Square-Centre	30	--	161	9.1	70	12.6	0.5	--
	12 Square-Side	30	3	414	7.5	75	5.5	0.6	--
	14 Square-Corner	30	3.5	467	7.9	74	5.5	0.5	--
15	18 Triangle-Downwind	20	2	174	2.3	89	2.7	2.2	0.11
	19 Traingle-Upwind	20	2	574	2.6	87	2.7	0.7	0.01

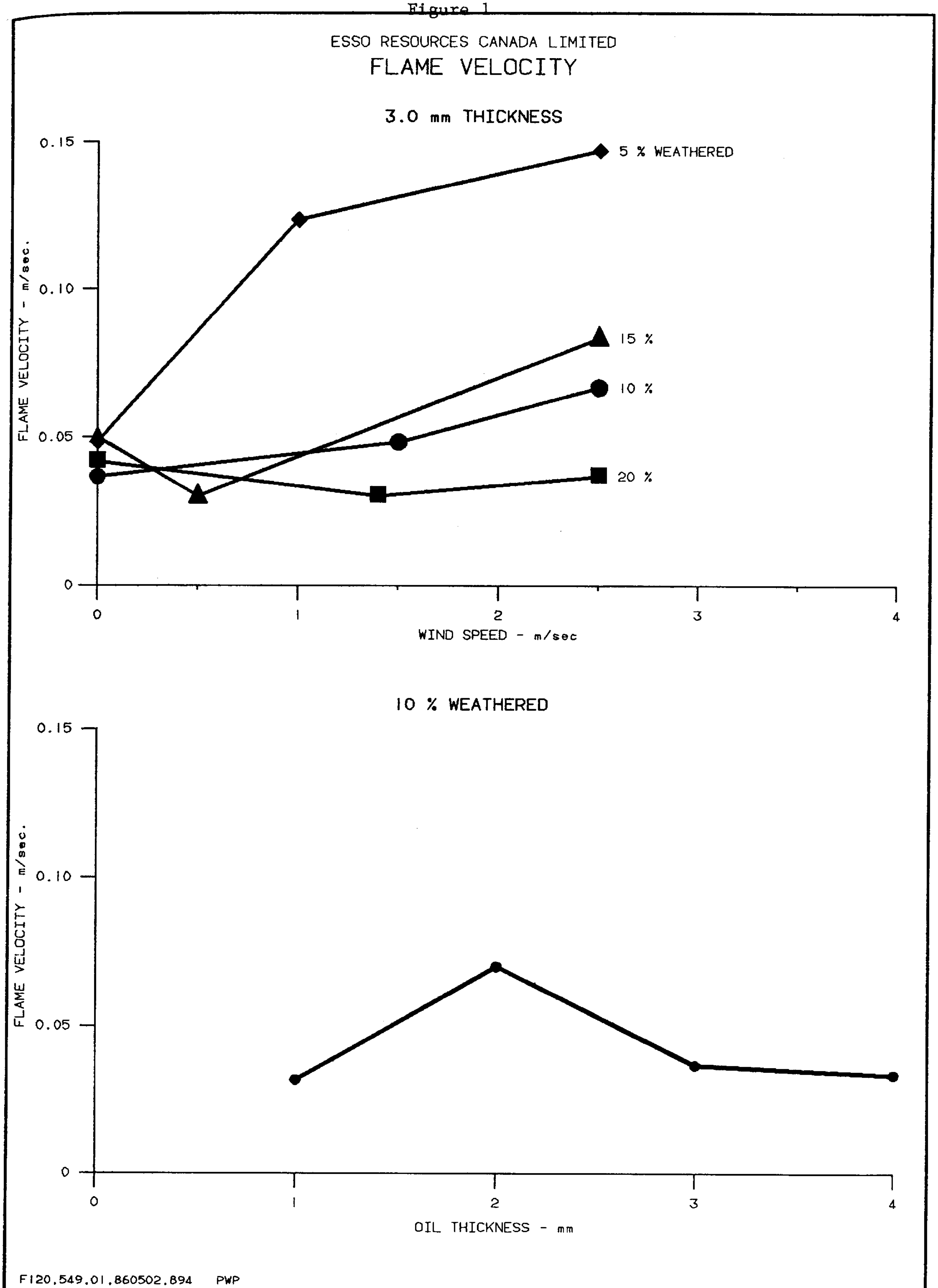
Flame Spreading Rate:

One would anticipate that the rate at which the flame front spreads along an oil slick would depend primarily on the wind speed and degree of oil weathering. The rates shown in Table I are averages measured between the time the flames covered the first square meter of the slick and the time the flame front reached the end of the lead. No values are calculated for the square or circular leads. All results for oil thicknesses of 3mm in rectangular leads are plotted in Figure 1(a). As expected there is a general increase in flame spreading rate with increasing wind speed and a dependence on degree of oil weathering. However, the latter is not marked once the weathering exceeds 10%. Presumably the flame spreading rate depends on the amount of light ends in the oil available to preheat and vaporize the remaining material, and most of these have been lost after 10% weathering. The presence of brash ice significantly slows the flame front as can be seen by comparing the values in Table I Trial #3 (with ice) to Trial #9. Finally, from Figure 1(b) it is clear that the amount of oil spilled, once it is thicker than 3mm (in this work, 30 l spilled), does not affect the flame speed. The graph suggests that a 2mm thickness is optimum but more tests are needed to confirm this finding.

These results are in general agreement with the work of Buist and Twardus (1984). Their results from wind tunnel experiments using Alberta Sweet Mixed Blend crude show a linear relationship of flame velocity with wind speed and a dependence on oil aging. For approximately 10% (8 hour) aged crude they measured the flame speed to be 3m/min. at a wind speed of 1.5m/sec. and about 4m/min. for a wind speed of 2.5m/sec. Considering that our experiments were conducted outdoors at real scale where it is very difficult to control the wind, the results are remarkably similar. The two oils have similar viscosities and normal alkane distribution. In both sets of experiments the thickness of the spilled oil was 3mm.

Temperature measurements of the water, ice and air as the flame spread down the lead were also taken, usually at the 8 meter mark of the lead. An example of these temperature profiles is shown in Figure 2(a) Probe numbers 4 and 6 were located in the oil and number 5 was one centimeter higher in the flame. Other probes were placed from 3 to 8cm. below the water level and show a temperature rise of up to 5 degrees C. as the flame front passes over. Usually this maximum occurs about one minute after the front arrives. From a number of similar profiles some preliminary measurements have been made. These indicate that the flame duration is shorter when a wind is present and the water returns to its original temperature more quickly. It appears that the maximum flame temperature may be higher however. When the oil thickness was 2mm. rather than 3mm. the flame duration was shorter and, as might be expected, the water temperature rose less. In a light wind the temperature rise of the water from burning 15% weathered oil was greater than from burning 20% weathered oil. Further analyses of these profiles and video image analysis of the flames is continuing.

Figure 1


ESSO RESOURCES CANADA LIMITED
FLAME VELOCITY
3.0 mm THICKNESS
FLAME VELOCITY - m/sec.
0.15
0.10
0.05
0
5 % WEATHERED
15 %
10 %
20 %
0
1
2
3
4
WIND SPEED - m/sec
10 % WEATHERED
FLAME VELOCITY - m/sec.
0.15
0.10
0.05
0
0
1
2
3
4
OIL THICKNESS - mm
F120.549.01.860502.894 PWP

Regression Burning Rates:

Average regression burning rates have been calculated as a measure of the speed with which a given oil slick can be burned under different wind conditions. These were calculated from the wind herded areas of the oil before ignition and the total burning times after the fire had become established. Rates are listed in Table I, and for 3mm oil thicknesses in the rectangular leads, are graphed in Figure 2(b) It can be seen that for a given oil type there is a linear relationship between the wind velocity and the regression burning rate. This may be due to the herding which thickens the oil and promotes more efficient transfer of heat from the flame to volatilize the remaining fuel. In addition the wind insures that the fire is not oxygen limited. Curiously, the graph shows that the more weathered oil burns at a faster rate. This phenomenon may be related to the mechanics of heat transfer to the remaining fuel as well. It is clear from experiments #2 and #3 (Table I) that the effect of brash ice, which would be expected to impede the heat transfer, dramatically decreases the burning rate.

The effect of lead geometry is not quite as apparent. Where wind herding can confine the oil such as in the apex of a triangle (test #18) or along the circumference of a small circle (test #24), the burning rates are similar to those in the long rectangular leads. Unconfined slicks such as along the side of a large square lead (test #12) or in the centre of an open area (test #11) have lower burning rates.

There are no exactly comparable measurements in the literature but Buist and Twardus (1984) have measured the regression rates of fresh Alberta Sweet Mixed Blend crude under calm confined conditions and find that the rates vary from about 1.0 to 2.0mm/min. These are for oil thicknesses of 4 to 40mm, that is, much thicker than reported here. Nevertheless, the rates are similar to our thinner weathered oils. We observe a similar trend of regression rates with oil thickness for calm conditions as they report but with lower absolute values. Likewise, in small scale laboratory tests, Smith and Diaz (1984) report burn rates of 0.2 to 0.4mm/min. for 2.5 to 10.5mm deep fresh Prudhoe Bay crude.

Burning Efficiencies:

In Figure 3(a) the calculated burn efficiencies as a function of wind speed and oil type are summarized for 3mm depth oil in rectangular leads. These are based on the weight of the burn residues and their specific gravities. While all of the efficiencies are high, there is a slight overall increase with wind speed. There does not appear to be a consistent dependence on oil weathering, except under calm conditions where there is a slow decrease with increased weathering (Figure 3(b)). Figure 3(c) shows that the efficiency increases with the amount of oil burned, at least to a depth of 4mm.

The efficiencies for other tests listed in the table show that the lead geometry is important for good burning. Where the oil can be confined by herding (such as at the apex of a triangle - test #18 and #19) the efficiencies are comparable to those in straight leads. For more open leads where the oil is herded along a straight edge, the efficiencies are 10 to 20% lower (tests 11, 12, 14, and 24). In test #22 the wind was directed across a l

Figure 2

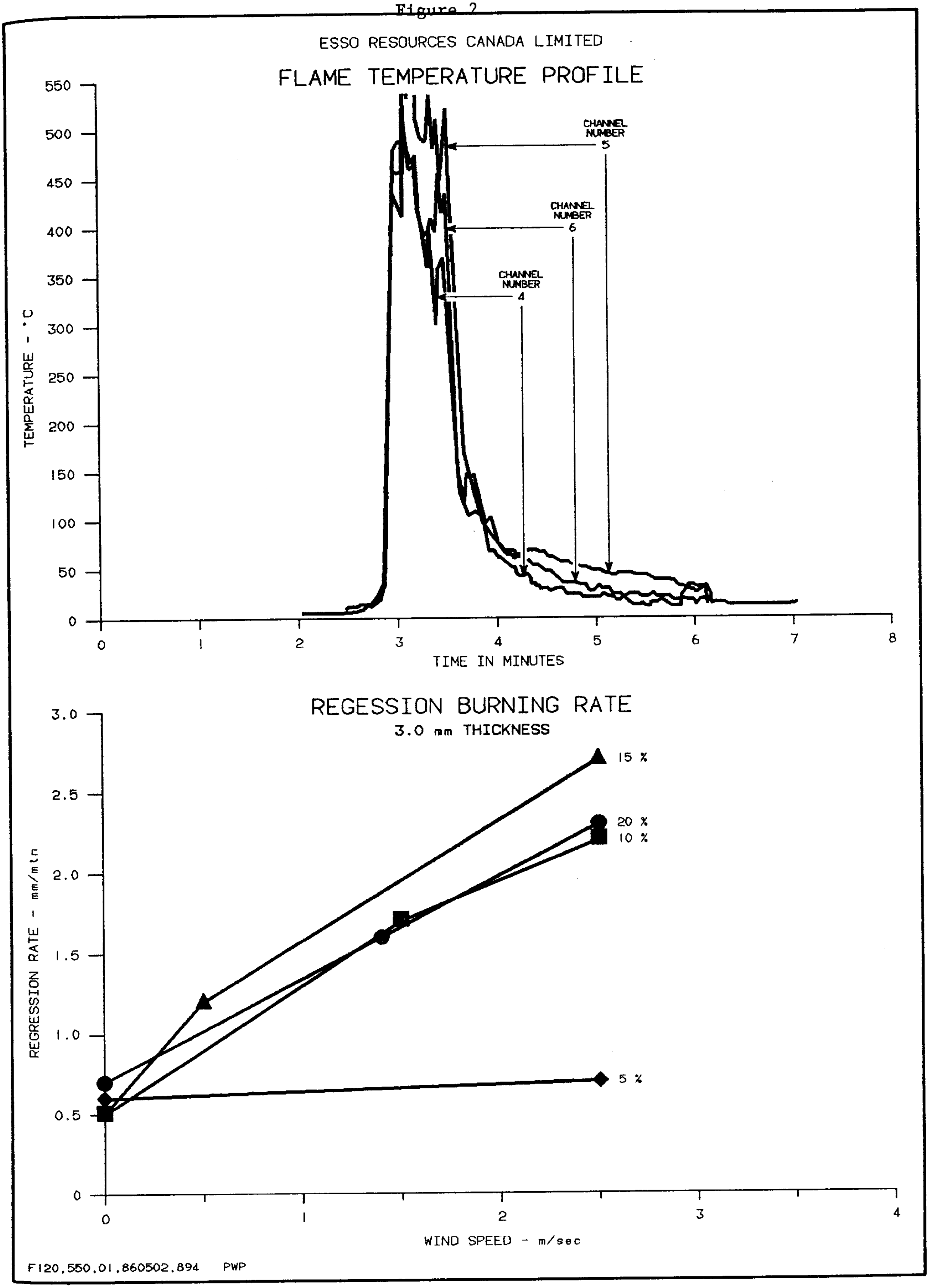
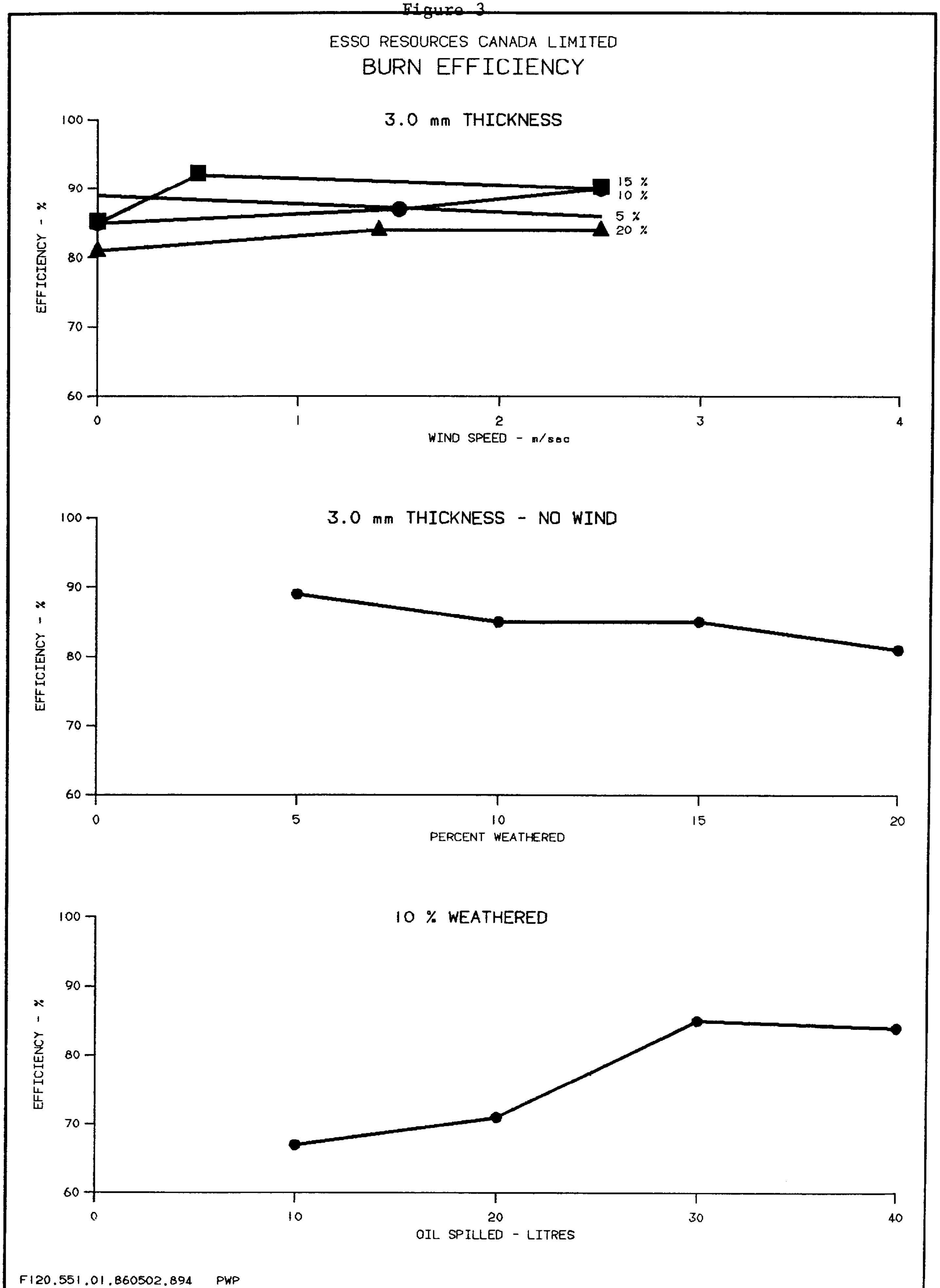

ESSO RESOURCES CANADA LIMITED
FLAME TEMPERATURE PROFILE
TEMPERATURE - °C
550
500
450
400
350
300
250
200
150
100
50
0
CHANNEL NUMBER 5
CHANNEL NUMBER 6
CHANNEL NUMBER 4
0
1
2
3
4
5
6
7
8
TIME IN MINUTES
REGESSION BURNING RATE
3.0 mm THICKNESS
REGRESSION RATE - mm/min
3.0
2.5
2.0
1.5
1.0
0.5
0
15 %
20 %
10 %
5 %
0
1
2
3
4
WIND SPEED - m/sec
F120,550,01,860502,894 PWP

Figure 3


ESSO RESOURCES CANADA LIMITED
BURN EFFICIENCY
3.0 mm THICKNESS
EFFICIENCY - %
100
90
80
70
60
0
1
2
3
4
WIND SPEED - m/sec
15 %
10 %
5 %
20 %
3.0 mm THICKNESS - NO WIND
EFFICIENCY - %
100
90
80
70
60
0
5
10
15
20
PERCENT WEATHERED
10 % WEATHERED
EFFICIENCY - %
100
90
80
70
60
0
10
20
30
40
OIL SPILLED - LITRES
F120.551.01.860502.894 PWP

x 10m lead where the ice height above the water was 3cm. In this case, despite a 4m/sec. wind, no herding was observed and consequently, the efficiency was similar to test #13 where the wind was very low. Apparently the 3cm ice height above the water was sufficient to shield the oil from the wind.

Brash ice also decreases the burning efficiency by retarding herding. Smith and Diaz (1985) report 79% efficiency for weathered Prudhoe Bay crude in 4m/sec. winds and 75 to 84% ice cover. These conditions would be similar to our test #3. Buist and Twardus (1985) report an 88% efficiency for a large scale confined burn of fresh Prudhoe Bay oil with a 0 to 2m/sec. wind, again a value similar to a number of the runs reported here. The field trials conducted in the Beaufort by Dome (1981) in which oil percolated from below the ice into melt pools resulted in burning efficiencies of 18% to 77 %. In some instances wind herding was an important factor and oil thicknesses up to 5cm. were reported.

SUMMARY

Oil spill cleanup in Arctic waters poses unique problems because of the presence of ice and the remoteness of potential spill sites. This work investigates the removal by burning of spilled oil in leads. Twenty-five burns of weathered Norman Wells crude were carried out under varying wind conditions in leads cut in an ice sheet. It was found that burning efficiencies of up to 90% were possible if moderate winds (similar to average Beaufort winds) herded the oil into long narrow leads. For leads of other geometries with similar winds, efficiencies might be as low as 70%. Winds of up to 4m/sec. across a narrow lead caused no oil herding and resulted in low efficiency burns. Brash ice impeded wind herding of the oil and resulted in lower burning efficiencies. Wind herded oil could be ignited at either the upwind or downwind edge with similar burning results. Weathering of oil of up to 20% did not significantly affect the burn efficiency in moderate winds.

Further analysis of water, ice, and flame temperature data, as well as residue composition and viscosities is continuing.

ACKNOWLEDGMENTS

This work was carried out under a grant from the Environmental Studies Revolving Funds. We wish to acknowledge the help of R.A.Paterson who was responsible for the operation of the ice test basin.

REFERENCES

Buist, I.A. and Twardus, E.M., 1985. Burning Uncontained Oil Slicks: Large Scale Tests and Modelling, Proc. of Eighth AMOP Technical Seminar, Edmonton, Canada, pp. 103-129.

Buist, I.A., and Twardus, E.M., 1984. In-Situ Burning of uncontained Oil Slicks, Proc. of Seventh AMOP Technical Seminar, Edmonton, Canada, pp. 128-154.

Energetex Engineering (1977). Ignition and Burning of Crude Oil on Water Pools Under Arctic Springtime Conditions, Report to Canmar Drilling Ltd., Calgary.

Oil and Gas Under Sea Ice Study, Vol. 1, 1981, Report prepared for Dome Petroleum Ltd., Calgary, Canada.

Smith, N.K. and Diaz, A., 1985. In Place Burning of Prudhoe Bay Oil in Broken Ice, Proc. 1985, Oil Spill Conference, API, pp. 405-409.