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January 1986

The Environmental Studies Revolving Funds are financed from special levies on the oil and gas industry and administered by the Canada Oil and Gas Lands Administration for the Minister of Energy, Mines and Resources, and by the Northern Affairs Program for the Minister of Indian Affairs and Northern Development.

Environmental Studies Revolving Funds
Report No. 013

January 1986

LABORATORY TESTING OF AN OIL-SKIMMING BOW IN BROKEN ICE

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The correct citation for this report is:

Abdelnour, R., T. Johnstone, D. Howard, and V. Nisbett. 1986. Laboratory testing of an oil-skimming bow in broken ice. Environmental Studies Revolving Funds Report, No. 013. Ottawa. 60 p.

Published under the auspices of
the Environmental Studies Revolving
Funds ISBN 0-920783-12-0

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SUMMARY

This report summarizes the results of laboratory experiments carried out on a model (small prototype) of an oil-skimming bow (OSB). The OSB is a device designed to recover oil from waters obstructed by broken ice. The system could be fitted to most ice-reinforced ships or ice-breakers servicing the offshore industry in a particular area, enabling them to assist in the recovery of oil after a major oil spill.

A series of 69 tests was carried out to evaluate the efficiency of the OSB model at Arctec Canada's environmental ice tank in Kanata, Ontario. The tank is 30 m long, 5 m wide, and 1.5 m deep. The temperature of the room can be set between 0 and -20°C.

For this experiment, an ice sheet 15 cm thick was grown and was later broken into small cakes. Four simulated broken ice fields were prepared for the tests at concentrations of 0, 30, 50, and 70% respectively; two oil types having viscosities of 22 and 460 cSt were used; the oil was spilled to form slicks 5 and 10 mm thick. The model was towed at velocities of 0.08, 0.15, 0.20, and 0.30 m/sec.

Other important parameters that could effect the OSB efficiency were not investigated, but were kept constant during the test. These parameters include the length of the spray boom, its orientation, its location, its height above water, the angle of incidence of the jets, and the OSB shape.

The tests resulted in a maximum overall efficiency (oil recovered/oil presented) of 21% that was achieved with the model operating at a velocity of 0.1 m/sec, in an ice concentration of 70%, with an oil slick thickness of 6.4 mm, a viscosity of 460 cSt, and a boom 5.6 times wider than the ship beam. However, the average efficiency of the entire system, operating in broken ice was only 10.2%. Because of the ineffectiveness of the boom to move the oil at the far end, the equivalent swath width for 100% oil removal was about 1.2 times the ship's beam.

RÉSUMÉ

Ce rapport résume les résultats des expériences en laboratoire effectuées sur un prototype (modèle réduit) dune proue récupératrice de pétrole (PRP). La PRP constitue un dispositif conçu pour ramasser le pétrole dans des eaux obstruées de glace brisée. Ce système pourrait être installé sur la plupart des navires renforcés contre la glace ou des brise-glaces desservant l'industrie de l'off-shore dans une zone déterminée, leur permettant ainsi de participer au travail de récupération du pétrole à la suite d'un important déversement.

Une série de 69 essais a été exécutée afin d'évaluer l'efficacité du modèle PRP au bassin de glace naturelle d'Arctec Canada, à Kanata, Ontario. Ce bassin est d'une longueur de 30 m, d'une largeur de 5 m et d'une profondeur de 1,5 m. La température ambiante peut varier entre 0 et -20°C.

En vue de cette expérience, une couche de glace d'une épaisseur de 15 cm a été formée, puis brisée en petits morceaux. Quatre champs simulés de glace fragmentée ont été préparés pour les essais, à une concentration respectivement de 0, 30, 50 et 70%; deux types de pétrole ayant une viscosité de 22 et 460 cSt ont été employés; le pétrole a été déversé de façon à constituer deux nappes de 5 et de 10 mm d'épaisseur. Le modèle a été tracté à une vitesse de 0,08, 0,15, 0,20 et 0,30 m/sec.

D'autres paramètres importants susceptibles d'avoir un effet sur l'efficacité de la PRP n'ont pas été examinés en détail, mais ont été conservés invariables pendant la durée des essais. Il s'agit entre autres de la longueur du rideau de pulvérisation, de son orientation, de son emplacement, de sa hauteur au-dessus de l'eau, de l'angle d'incidence des jets et de la forme de la PRP.

Dans l'ensemble, ces essais ont abouti à un maximum d'efficacité, à un résultat de 21% (pétrole récupéré/pétrole présenté), lequel a été obtenu en déplaçant le modèle à une vitesse de 0,1 m/sec, dans une concentration de glace de 70%, avec une nappe de pétrole d'une épaisseur de 6,4 mm, d'une viscosité de 460 cSt et un barrage flottant 5,6 fois plus large que le barrot du navire. Toutefois, le rendement du système entier fonctionnant dans la glace brisée a été seulement de 10,2%. Compte tenu de l'incapacité du barrage flottant à repousser le pétrole vers les extrémités, la largeur du balayage pour 100% de pétrole repoussé n'a été que d'environ 1,2 fois celle produite par le barrot du navire.

INTRODUCTION

Increased frontier explorations and development for hydrocarbons in the Canadian Arctic have increased the chances of an accident, possibly resulting in a major oil spill in this region. This has prompted environmentalists, scientists, and engineers to design and develop systems that will be capable of recovering the majority of the oil spilled in these areas (Oil Industry Task Group 1984).

In October 1982, the Canadian Offshore Oil Spill Research Association (COOSRA) held a brain-storming workshop, to develop ideas for oil recovery from ice environments (COOSRA 1982). The report included 95 ideas of which 12 were considered economically and technically feasible. Four were related to recovery of oil from broken ice environments and among those considered were:

- use of an ice floe as a skimmer
- use of a porous inclined plane bow as a skimmer
- use of broken ice pieces to form a boom.

The system conceived and used for this experiment was based on two ideas. First, the use of a spray boom to herd the oil, and secondly, the addition of a recovery system to a vessel of opportunity to collect the herded oil. It consisted of a detachable oil-skimming bow (OSB) equipped with floating weirs, in combination with spray booms to sweep the oil slick toward the oil collection portion of the skimmer (Figure 1). This concept is a combination of ideas presented at the COOSRA brain-storming workshop (COOSRA 1982).

The OSB would be designed to fit vessels readily available in the Arctic region. Typically, they would be icebreakers or ice-reinforced supply ships. It is anticipated that minor modifications would be necessary to fit the OSB to other assigned vessels. The OSB would be designed and constructed to keep the cutting and welding to a minimum.

The OSB would consist of many linked segments, allowing the complete assembly to follow the contour of the vessel's bow. Each segment would be open-ended and about 2 m long and 1 m deep. Segments would be of welded steel construction, and designed to be capable of withstanding forces developed as the ship travels slowly through broken ice. It was assumed that the maximum vessel speed during oil recovery would not exceed one to two knots. In addition, each segment of the OSB would have ice deflection and blocking

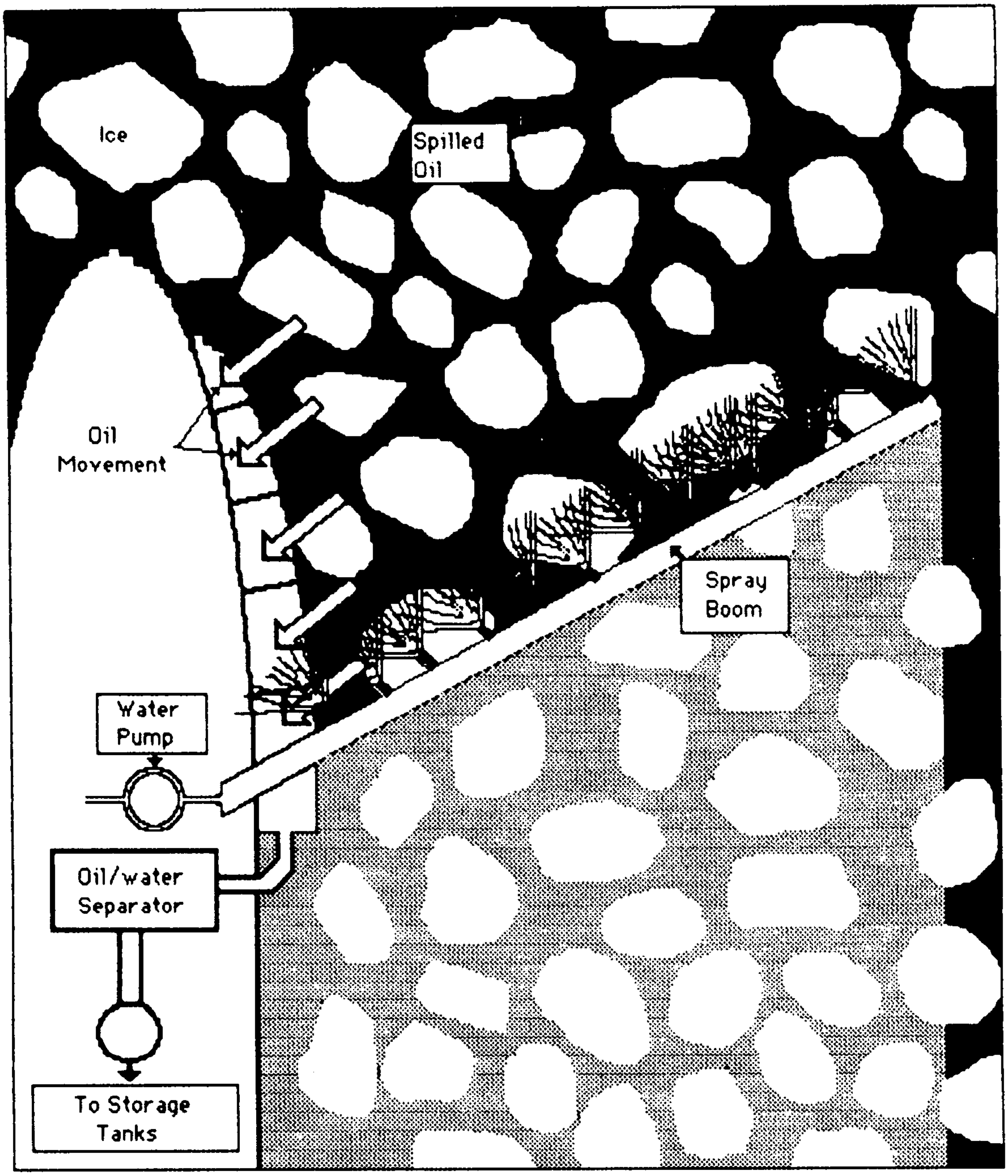

Figure 1. Principle of operation of the oil-skimming bow.

grids to prevent clogging or damage to the weir by ice (Figure 2).

The final segment of the OSB would incorporate an adjustable floating weir, which would minimize water collection and improve the oil-to-water ratio of the recovered liquid. Collected liquid would be pumped from the weir to a primary oil and water separation tank. The separated oil could then be pumped to storage tanks on board the vessel or to additional separation tanks (Figure 3).

To test this concept, a small prototype model was fabricated and tested in various ice concentrations in a refrigerated basin 30 m x 5 m x 1.5 m located at Arctec Canada Limited in Kanata.

In this report the authors describe the model and the tests conducted, and present their results and conclusions. Finally, they outline briefly areas in which additional studies are thought to be necessary, to establish the maximum effectiveness of the envisaged system in broken ice fields of the Arctic.

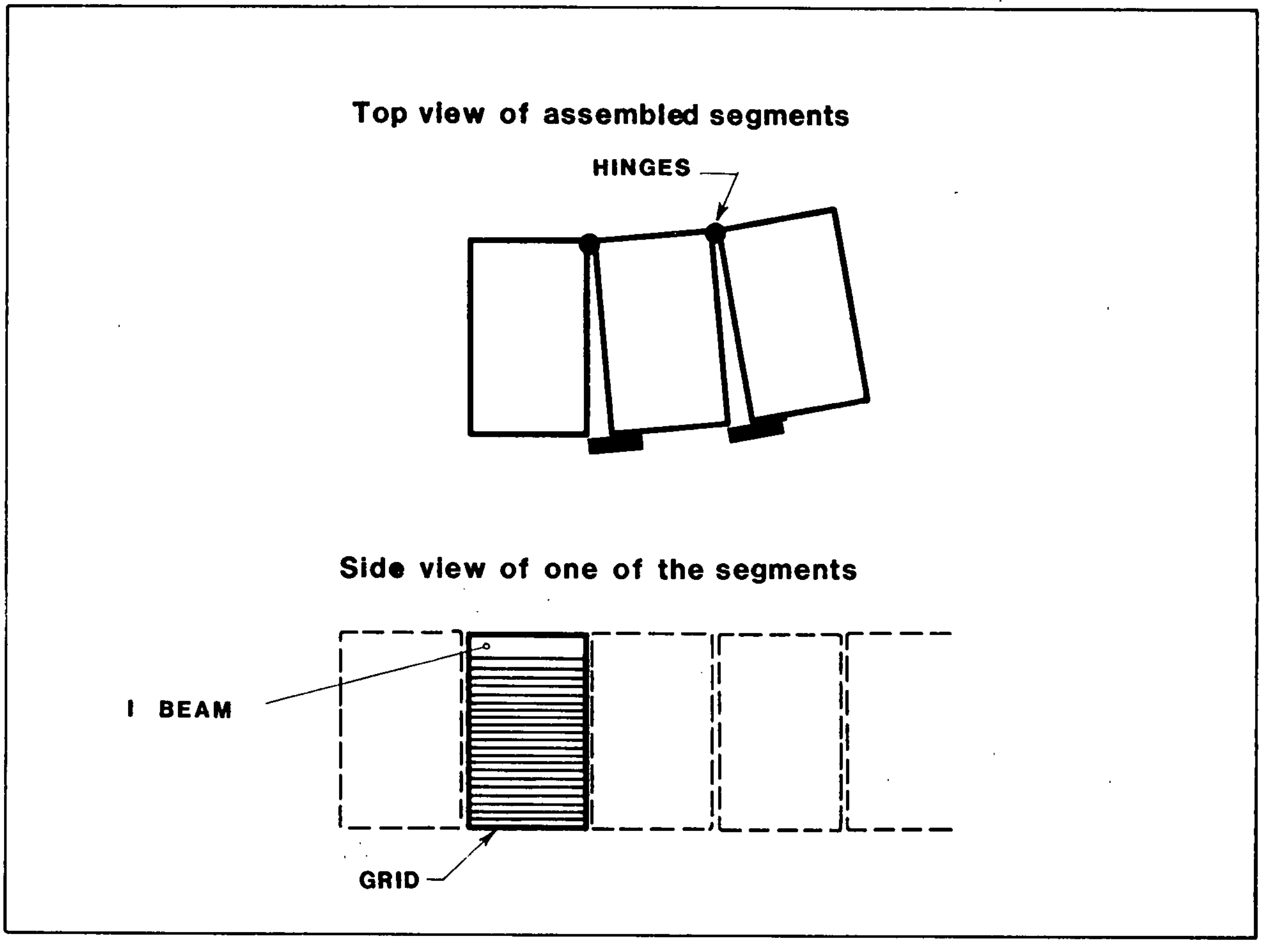

Figure 2. Oil-skimming bow segments.

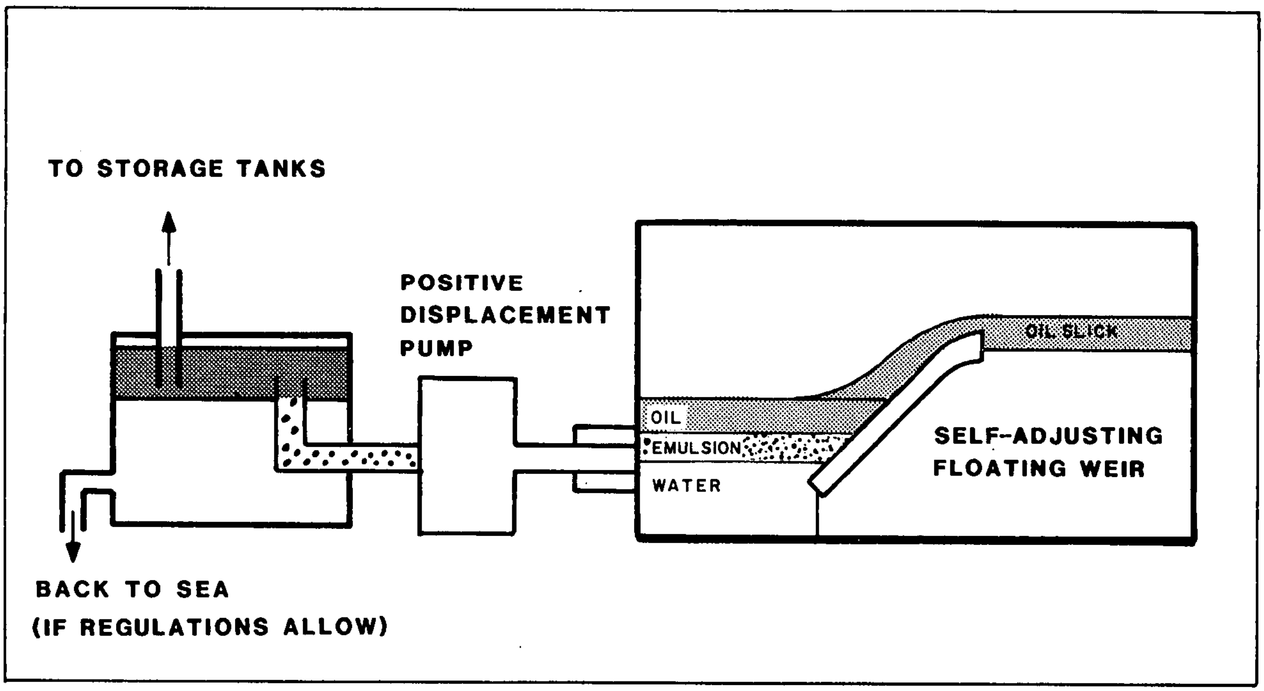

Figure 3. Oil collection concept.

EXPERIMENTAL APPROACH

MODEL DESCRIPTION

The mock hull fabricated for these tests was 2.25 m long and 0.9 m wide, consisting of a curved plate that resembled the front section of a ship, cut along its centre line. In addition, the hull was fabricated in such a way as to form the oil storage reservoir for the collected oil. The hull was also designed to incorporate an ice deflector and an oil collection weir (see Appendix A). As the model travelled through the oil slick, oil and ice were separated by the ice deflector. The oil then flowed over the weir and was collected in the reservoir. The entire model was constructed from aluminum except for the weir which was made of wood.

The operation of a weir depends on a fluid level differential between fluids on either side of the weir. To maintain this difference in level, a 2.5 l/s (40 gpm US) pump was used, withdrawing fluid from the bottom of the model. Only water was removed from the reservoir. To prevent a cyclone effect withdrawing oil from the surface of the reservoir, a large, sloped plate was positioned just above the reservoir's outlet. On the actual OSB, a floating weir would probably be used to compensate for the ship's motion and to maintain a high oil-to-water ratio for the recovered oil. For the small prototype test, an adjustable level, fixed weir was used, because motion compensation was not necessary during testing. Through experimentation prior to testing, it was determined that the weir should be submerged 20 mm below the water surface. In this position, clogging of the weir with small pieces of ice was minimized, while still maintaining a reasonable fluid level differential over the weir.

To ensure that oil collection began only after steady state conditions were achieved, oil was not collected in the reservoir until the model had travelled a specific distance. Steady state conditions were assumed to be reached when oil particles initially at the extreme end of the spray boom began to flow over the weir. Based on test operations, it was decided that the model must travel between 2 and 5 m in the oil slick prior to the commencement of oil collection. To facilitate this, a spring-loaded door was attached to the back plate of the model, as in Figure 4. Prior to achieving steady state conditions, this door was kept open and was closed once steady state conditions were assumed to be reached. To simplify the experimental procedure, oil collection was initiated after the model had travelled 5 m.

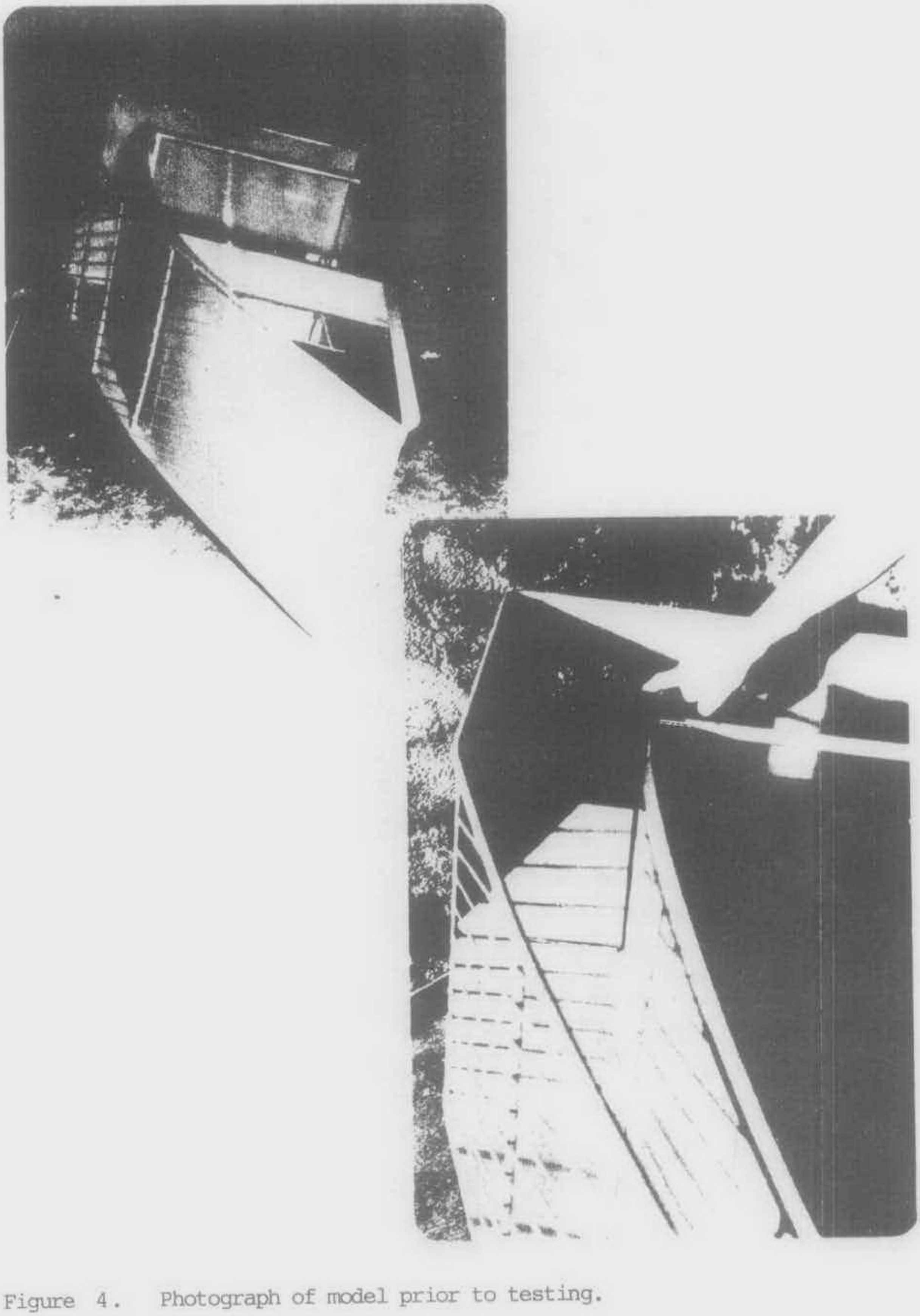

Figure 4. Photograph of model prior to testing.

The spray boom used was 5 m long and had a diameter of 6.4 cm. Ten spray nozzles were spaced 0.5 m apart and each was adjusted to give an angle of contact at the water surface at about 23°. The orientation of the spray boom is shown in Figure 5. At the beginning of the tests the angles of individual spray jets were adjusted to give optimum performance. Water from the basin was supplied to the spray boom at a rate of 1.9 l/s (30 gpm US) at a pressure of 276 kPa. These parameters were selected based on the previous work done by Comfort et al. 1980.

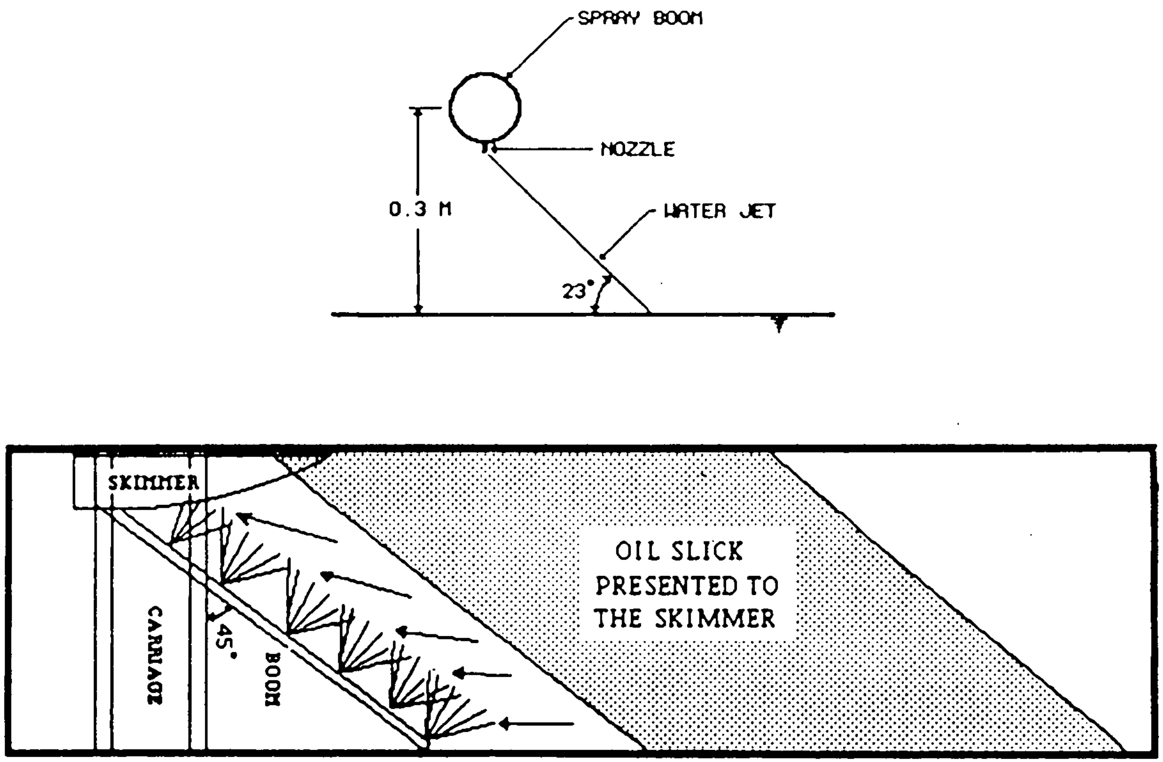

Figure 5. Illustration of test set-up.

ICE PREPARATION

The ice sheet was prepared by lowering the air temperature of the basin to -20°C, for about 96 hours. By this time, the ice sheet was about 160 mm thick and the air temperature of the basin was then raised to approximately 0°C and was kept at this temperature for the majority of the tests. During weekends, the air temperature was lowered to -3°C to slow down ice melting.

The ice sheet was then broken into random-shaped pieces with diameters of 0.2 to 0.4 m. At the mid-point and at the conclusion of the tests, 14 randomly selected pieces of ice were measured to ensure there had not been excessive deterioration of the ice during testing (Table 1). The surface area increased by 15% whereas the ice thickness decreased by 9%. It should also be noted that the edges of the ice became smooth and rounded.

TABLE 1

Ice dimensions

	August 20th (Test #22)				September 14th (Test #60)			
Sample (#)	Length (cm)	Width (cm)	Area (cm^2)	Thick. (cm)	Length (cm)	Width (cm)	Area (cm^2)	Thick. (cm)
1	33	27	891	19	67	32	2144	11
2	25	24	600	12	30	27	810	17
3	55	30	1650	13	30	23	690	13
4	40	40	1600	16	31	29	899	22
5	30	22	660	15	29	23	667	15
6	40	26	1040	14	46	26	1196	15
7	25	25	625	20	48	33	1584	17
8	70	29	2030	20	70	21	1470	16
9	30	25	750	19	39	27	1053	13
10	60	26	1560	18	70	33	2310	19
11	30	20	600	17	37	31	1147	10
12	35	28	980	17	34	22	748	16
13	60	30	1800	20	57	34	1938	17
14	20	20	400	17	36	24	864	16
Average	40	27	1085	17	45	28	1251	16
Std. dev.	16	5	534	3	15	5	553	3

OILS USED FOR TESTING

Oils of two different viscosities were used during the test program. They were Circo 4X Light and Circo Light. These particular oils were chosen because, unlike crude oil, their properties do not vary significantly with time.

The viscosity of each oil was measured at several different temperatures using Zahn viscosimeters (see Appendix B). The results are presented in Figure 6, in which oils from the Hibernia oil field in offshore Newfoundland and from Tarsiut fields in the Beaufort Sea are also presented. Additional information on each oil provided by Sunoco is listed in Table 2.

TABLE 2

Physical properties of oils used

Physical properties	Circo 4X Light	Circo Light
Density at 15°C, kg/dm^3	0.8883	0.9243
Flash point °C	110	174
Pour point °C	-45	-32

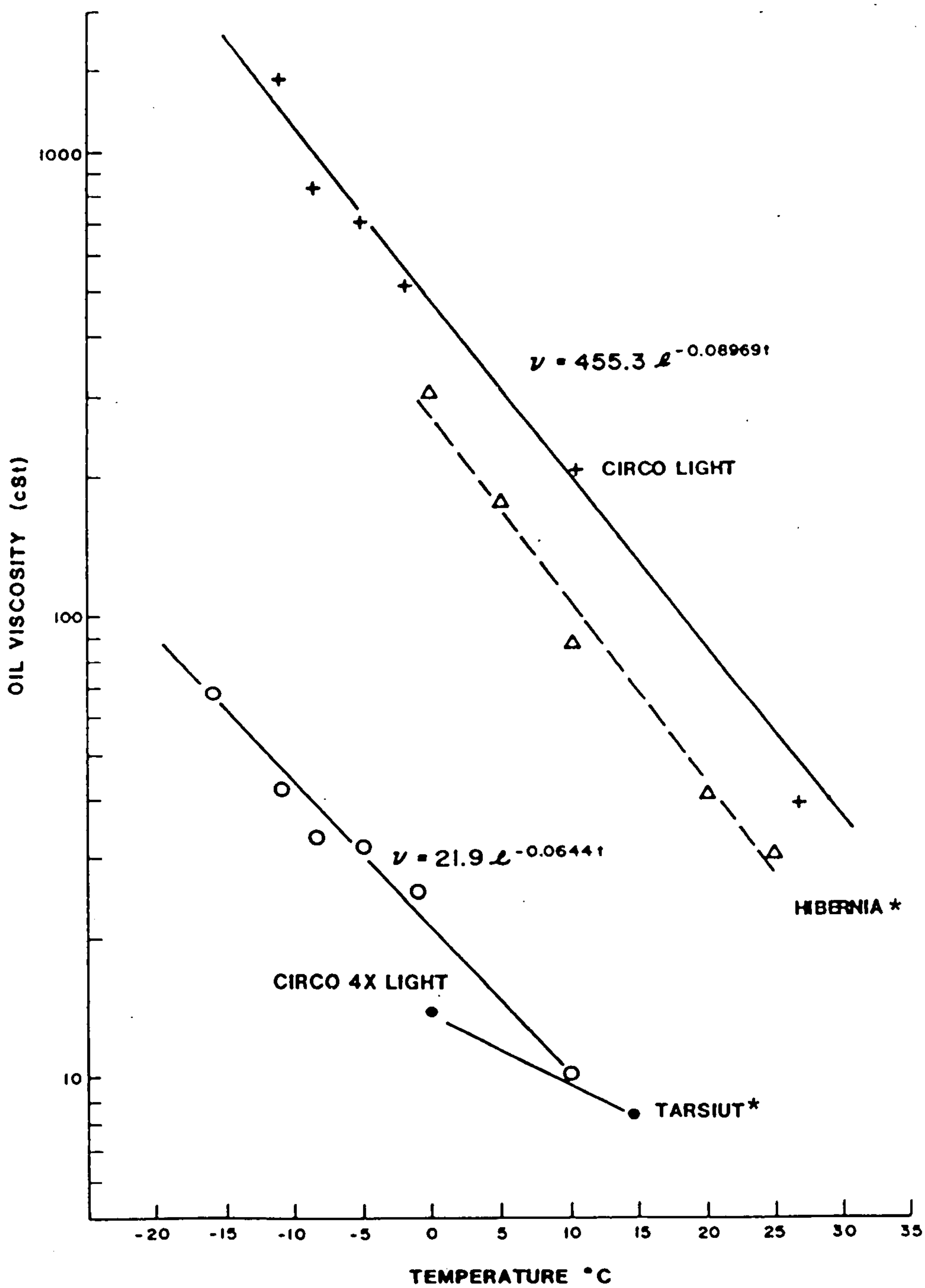

Figure 6. Viscosity versus temperature of oils used during test.
(experimental)
(*Information provided by Environment Canada)

TEST VARIABLES

In developing the test plan to evaluate the model, there were many variables to consider. Of prime importance was the actual shape of the model and the velocity at which it should travel through the test area. Variables related to the spray boom were nozzle design, nozzle spacing, height from the water surface, water pressure, and water flow rate. Ice concentration, ice thickness, and sea state would also affect the model's performance. Parameters directly related to the oil such as oil slick thickness and viscosity were also considered.

Because of the large number of variables, it was decided to limit the number considered to the following four:

- ice concentration
- oil slick thickness
- oil slick viscosity
- skimmer velocity.

Initially, it was decided to test the model in ice concentrations of 50, 70, and 90%, with target velocities of 0.15, 0.25, 0.50, and 0.75 m/s. However, after conducting the first run with ice at 90% concentration, the forces on the model were high and the oil collection efficiency was low. With the concurrence of the ESRF's Technical Project Officer, the ice concentrations were revised to 30, 50, and 70%, and the target velocities to 0.08, 0.15, 0.20, and 0.30 m/s. Figure 7 illustrates various ice concentrations.

To investigate the effects of oil viscosity on the skimmer's operation, two oils having different viscosities were used; Circo Light and Circo 4X Light.

In addition, oil slick thicknesses of 5 and 10 mm were used during this test program.

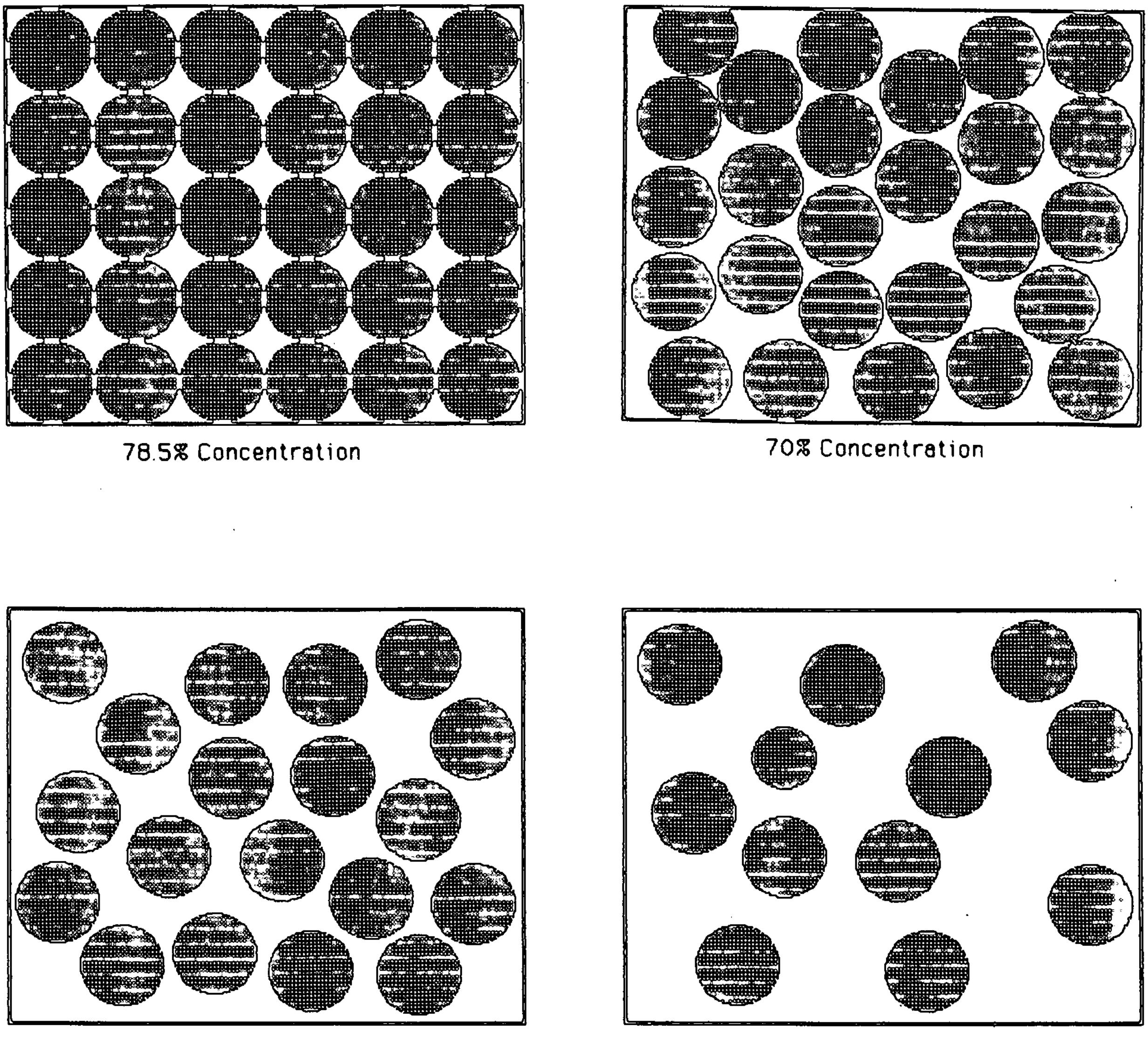

Figure 7 Visual comparison of ice concentrations.

TEST PROCEDURE

Of the 69 tests conducted, 48 were conducted at the velocities, ice concentrations, slick thicknesses, and oil viscosities indicated in Table 3. Nine were conducted without the spray boom operating and generally at the lowest target velocity to evaluate the boom's effect on oil collection. Five were conducted in open water, and for these tests the spray boom pressure had to be reduced to 138 kPa, because the oil was swept in front of the OSB. Only one velocity was used during these tests. The balance were tests that were repeated for various reasons.

The procedure followed during each test was as follows: 20 measurements of the oil slick thickness were taken first, followed by air, water, and oil temperatures. Oil slick thickness measurements were made using an open-ended, 38 mm diameter glass tube that was pushed downward normal to the slick. The bottom of the tube was sealed, and the tube was removed from the slick. The slick thickness was then measured directly with a measuring tape. Next, photographs of the test area were taken for later verification that ice concentrations during a particular set of tests had not changed (Figure 8). At this point the spray boom and reservoir pumps were started, and the rear door of the model was opened. The test was initiated by adjusting the carriage controls to give the desired target velocity. After the model had travelled a predetermined distance, the rear door was closed, and the model began collecting oil. Throughout most of the tests, video recordings were made. However, during test #49, technical problems with the video camera were experienced. Consequently, video recordings of the last 19 tests were not possible. For each test, 35 mm photographs were taken of items of interest, and handwritten notes were made concerning points of interest during the preceding test.

At the conclusion of each test, the quantity of oil collected by the OSB was calculated based on the average thickness of the oil floating in the reservoir. Typically, four thickness measurements were taken, were then averaged, and were found to have a maximum variation of 3 mm. The volume collected was then determined from the product of the reservoir area and oil thickness. Samples of the recovered oil were removed and were allowed to stand for 24 hours, during which time any water mixed in the oil would separate. It was found that there was an average of 1% water in these samples. Also, at this time, the final position of the model was recorded, so that, by knowing the surface area that the prototype travelled, the ice concentration, and the slick thickness, the quantity of oil presented during the test could later be calculated. Data obtained during the tests were recorded on standard data sheets (see Appendix C).

TABLE 3

Test matrix

Test #	Ice concentration[a] (%)	Oil type[b]	Slick thickness (mm)	Skimmer velocity (m/s)
1	70	Circo 4X	5	0.08
2	70	"	"	0.15
3	70	"	"	0.20
4	70	"	"	0.30
5	70	"	10	0.08
6	70	"	"	0.15
7	70	"	"	0.20
8	70	"	"	0.30

a) Additional 8 tests with ice concentration of 50%:
additional 8 tests with ice concentration of 30%.

b) Additional 24 tests with Circo Light.

Figure 8. Test #58 showing a 5 mm oil slick, at 30% ice concentration.

TEST RESULTS

The results of the tests are summarized in Table 4. The oil presented was that contained in the swath of the OSB and the boom over the total length of the run (see the calculation in Appendix D).

The oil recovered in the model reservoir was measured after each run and later these measurements were used to calculate the efficiency of the OSB:

$$n = \frac{\text{volume of recovered oil.}}{\text{volume of presented oil}}$$

Forty-four tests were conducted with the system fully operational; nine tests were performed with the spray boom off; and five tests were conducted in open water conditions with the spray boom operating at reduced pressure.

Figure 9 shows the model at 70% ice concentration during test #6 and Figure 10 shows the oil flowing over the weir during test #63.

TABLE 4. Test Results

TEST #	DATE	OIL TYPE	OIL VISCOS (cSt)	SLICK THICK (mm)	ICE CONCE. (%)	OSB VELOCITY (cm/sec)	TEST LENGTH (m)	OIL PRES. (l)	OIL COLLECT. (l)	EFFI-CIENCY (-)	COMMENTS
1	16/08/84	C-4X	22	7.30	70	17	15.8	169	(-)	(-)	PUMPS FAILED
2	16/08/84	C-4X	22	7.00	70	17	12.5	129	12.9	10.0	
3	17/08/84	C-4X	22	5.90	70	15	10.0	87	13.4	15.5	MODEL LOWERED 3 cm
4	22/08/84	C-4X	22	5.10	70	10	16.0	120	25.3	21.1	
5	22/08/84	C-4X	22	5.20	70	10	16.0	122	20.2	16.5	ICE BLOCKED WEIR
6	22/08/84	C-4X	22	5.80	70	16	15.0	128	23.4	18.3	
7	22/08/84	C-4X	22	5.80	70	22	15.0	128	20.2	15.8	
8	23/08/84	C-4X	22	5.20	70	29	14.0	107	5.5	5.1	PUMPS FAILED
9	23/08/84	C-4X	22	5.60	70	30	13.5	111	6.7	6.0	NO SPEED RECORD
10	26/08/84	C-4X	22	10.10	70	11	14.0	208	45.1	21.7	
11	27/08/84	C-4X	22	10.80	70	17	13.5	214	24.8	11.6	
12	27/08/84	C-4X	22	10.00	70	23	14.0	206	23.0	11.2	
13	27/08/84	C-4X	22	10.40	70	30	12.5	191	14.6	7.6	
14	28/08/84	C-4X	22	5.80	50	10	14.0	199	17.3	8.7	
15	28/08/84	C-4X	22	5.90	50	16	14.0	202	13.5	6.7	
16	29/08/84	C-4X	22	6.30	50	22	14.0	216	7.4	3.4	
17	29/08/84	C-4X	22	6.60	50	28	14.0	226	6.4	2.8	
18	29/08/84	C-4X	22	10.30	50	10	15.0	379	38.5	10.2	
19	29/08/84	C-4X	22	12.20	50	17	14.0	418	13.6	3.3	NO SPRAY BOOM
20	29/08/84	C-4X	22	11.70	50	17	14.0	401	24.4	6.1	
21	29/08/84	C-4X	22	13.20	50	23	14.0	453	20.6	4.5	
22	30/08/84	C-4X	22	12.50	50	31	12.0	368	13.9	3.8	
23	30/08/84	C-4X	22	5.30	30	10	13.0	236	29.9	12.7	

TABLE 4(con't)

TEST #	DATE	OIL TYPE	OIL VISCOS (cSt)	SLICK THICK (mm)	ICE CONCE (%)	OSB VELOCITY (cm/sec)	TEST LENGTH (m)	OIL PRES. (l)	OIL COLLECT (l)	EFFI-CIENCY (-)	COMMENTS
24	30/08/84	C-4X	22	5.10	30	17	13.0	227	24.4	10.7	
25	30/08/84	C-4X	22	5.20	30	23	14.0	250	15.2	6.1	
26	31/08/84	C-4X	22	5.00	30	29	13.0	223	4.6	2.1	
27	31/08/84	C-4X	22	4.90	30	10	14.0	235	4.2	1.8	NO SPRAY BOOM
28	31/08/84	C-4X	22	10.40	30	11	15.0	535	39.1	7.3	
29	31/08/84	C-4X	22	10.40	30	17	13.5	482	42.3	8.8	
30	31/08/84	C-4X	22	11.40	30	22	13.5	528	27.8	5.3	
31	31/08/84	C-4X	22	11.20	30	30	13.0	499	19.9	4.0	
32	31/08/84	C-4X	22	11.70	30	10	15.0	602	14.8	2.5	NO SPRAY BOOM
33	06/09/84	C-L	460	6.40	70	10	15.0	141	25.9	18.4	
34	07/09/84	C-L	460	5.50	70	17	14.5	117	14.8	12.6	
35	07/09/84	C-L	460	5.50	70	21	13.5	109	11.5	10.5	
36	07/09/84	C-L	460	6.50	70	30	14.0	134	20.3	15.2	
37	07/09/84	C-L	460	7.30	70	17	14.0	150	19.9	13.2	REPEATED TEST
38	07/09/84	C-L	460	6.90	70	10	14.0	142	3.5	2.5	NO SPRAY BOOM
39	10/09/84	C-L	460	10.60	70	10	14.0	218	24.6	11.3	
40	10/09/84	C-L	460	11.50	70	17	14.0	237	21.8	9.2	
41	10/09/84	C-L	460	10.60	70	22	14.0	218	20.2	9.3	
42	10/09/84	C-L	460	10.50	70	29	13.0	201	15.4	7.7	
43	10/09/84	C-L	460	10.80	70	11	14.0	222	5.8	2.6	NO SPRAY BOOM
44	11/09/84	C-L	460	7.10	50	10	14.0	244	38.1	15.6	OIL SLICK TOO THICK
45	11/09/84	C-L	460	6.00	50	10	13.5	198	30.5	15.4	
46	11/09/84	C-L	460	6.20	50	17	14.0	213	27.8	13.1	

TABLE 4(con't)

TEST #	DATE	OIL TYPE	OIL VISCOS (cSt)	SLICK THICK (mm)	ICE CONCE (%)	OSB VELOCITY (cm/sec)	TEST LENGTH (m)	OIL PRES. (l)	OIL COLLECT (l)	EFFI- CIENCY (-)	COMMENTS
47	11/09/84	C-L	460	5.90	50	22	13.5	195	32.4	16.6	
48	11/09/84	C-L	460	6.30	50	30	13.0	201	17.3	8.6	
49	11/09/84	C-L	460	6.50	50	10	14.0	223	4.4	2.0	NO SPRAY BOOM
50	12/09/84	C-L	460	10.00	50	10	13.0	319	51.1	16.0	
51	12/09/84	C-L	460	10.60	50	16	13.0	338	36.3	10.8	
52	12/09/84	C-L	460	10.40	50	10	13.0	331	13.9	4.2	NO SPRAY BOOM
53	12/09/84	C-L	460	10.00	50	22	13.0	319	29.7	9.3	
54	12/09/84	C-L	460	9.90	50	30	13.0	315	23.4	7.4	
55	12/09/84	C-L	460	4.60	30	10	13.0	205	5.4	2.6	NO SPRAY BOOM
56	12/09/84	C-L	460	4.70	30	10	13.0	210	24.6	11.7	
57	12/09/84	C-L	460	4.50	30	16	13.0	201	14.2	7.1	
58	13/09/84	C-L	460	4.90	30	22	13.0	218	12.6	5.8	
59	13/09/84	C-L	460	5.00	30	30	13.0	223	7.6	3.4	
60	14/09/84	C-L	460	9.80	30	28	13.0	437	21.5	4.9	
61	14/09/84	C-L	460	10.30	30	16	13.0	459	44.5	9.7	
62	14/09/84	C-L	460	10.60	30	10	13.0	473	55.9	11.8	
63	14/09/84	C-L	460	10.20	30	16	13.0	455	46.7	10.3	
64	14/09/84	C-L	460	9.70	30	11	13.0	433	9.2	2.1	NO SPRAY BOOM
65	17/09/84	C-L	460	6.80	NO ICE	10	14.0	466	56.2	12.0	OPEN WATER TESTS
66	17/09/84	C-L	460	6.30	NO ICE	15	14.0	432	39.5	9.1	
67	17/09/84	C-L	460	6.00	NO ICE	15	14.0	412	26.1	6.3	
68	17/09/84	C-L	460	5.80	NO ICE	15	14.0	398	28.7	7.2	
69	17/09/84	C-L	460	5.50	NO ICE	15	14.0	377	25.5	6.8	

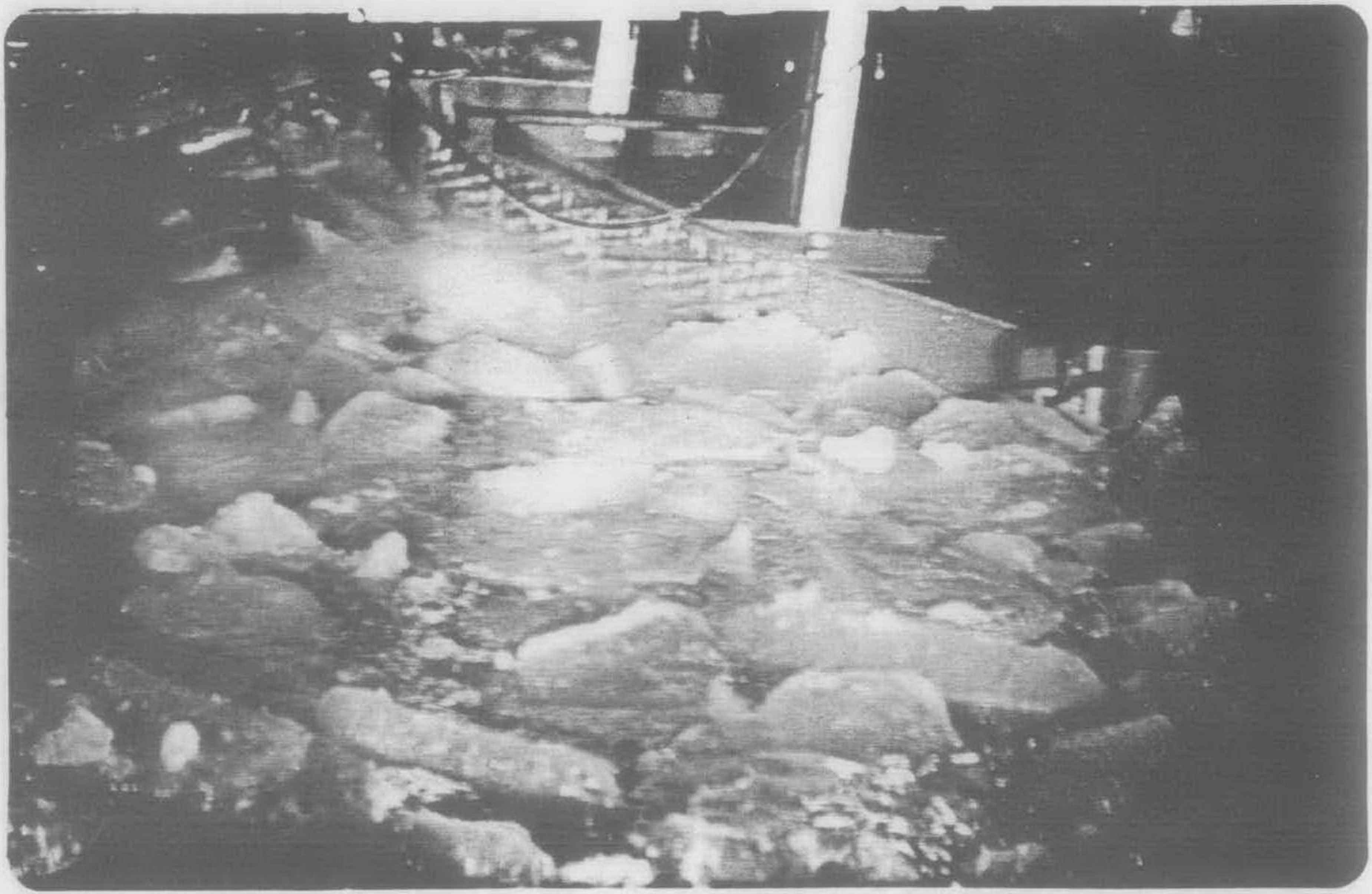

Figure 9. Test #6 in progress with a 5 mm oil slick, at 70% ice concentration.

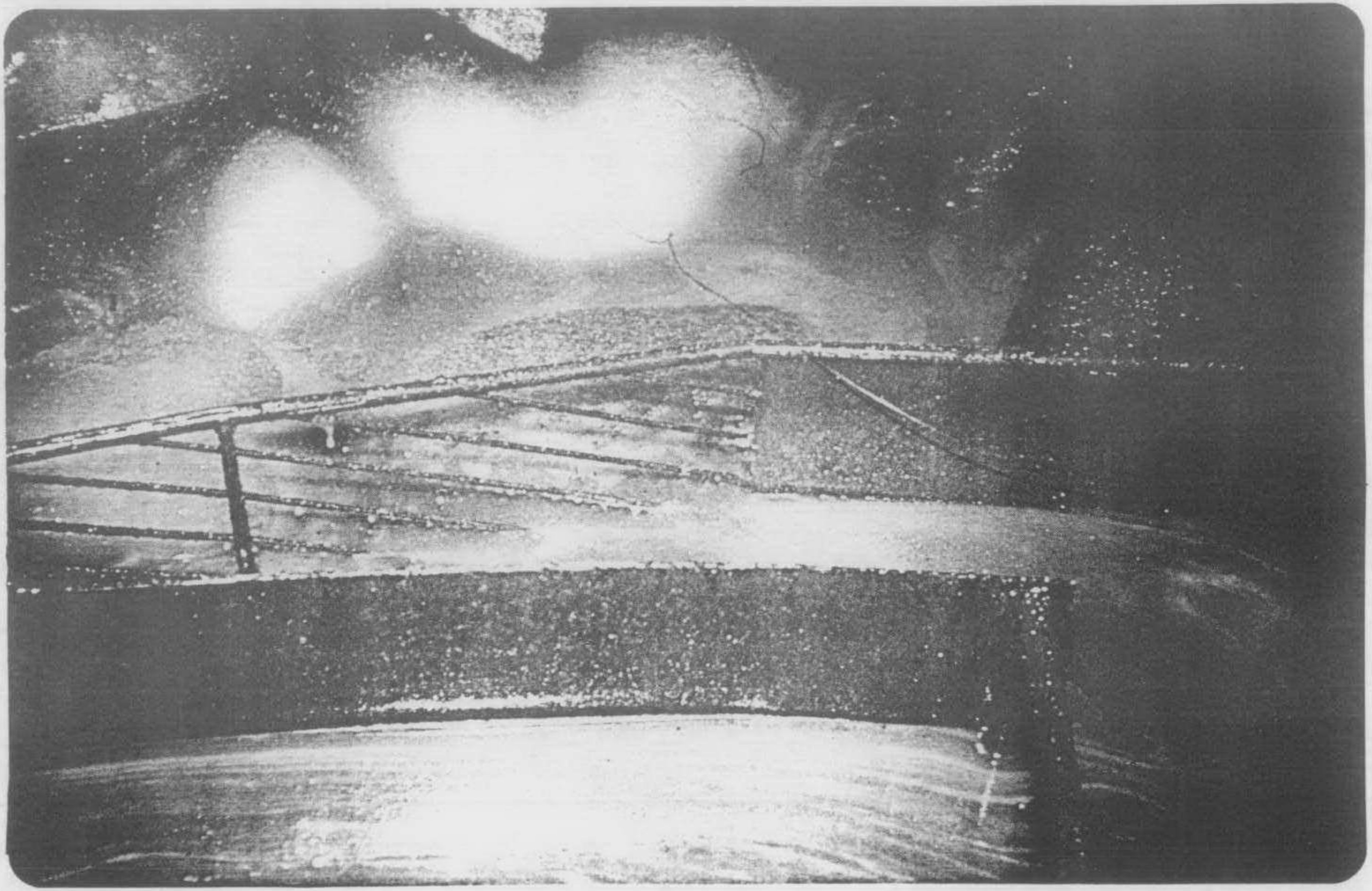

Figure 10. Oil flowing over the weir during test #63 with a 10 mm oil slick, at 30% ice concentration.

DISCUSSION

FACTORS INFLUENCING THE OSB EFFICIENCY

Only the most important factors influencing the efficiency of the OSB were considered in this experimental program. There follows a brief discussion of each of these parameters.

Velocity

The model efficiency versus velocity for each oil is presented in Figure 11. Based on these plots, it is clear that the efficiency of the OSB decreases as the velocity increases. Two factors caused this to happen.

a) At higher OSB velocities, there was insufficient energy transfer to allow the oil to accelerate to its maximum velocity. Consequently, the oil was not swept toward the floating weir quickly enough to be collected.

b) The oil slick broke down and oil passed under the spray jets. A possible mechanism for this failure is illustrated in Figure 12.

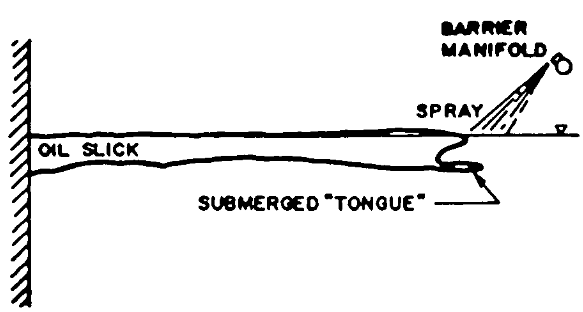

Figure 12. Slick profile generated by water spray (after Comfort and Menon 1980).

As the currents induced by a spray jet increase, a submerged tongue develops. Because oil cannot resist shear, the upper portion of the slick accelerates, whereas the lower portion remains stationary. Consequently, the oil escapes below the spray jet. This mechanism is clearly dependent on slick

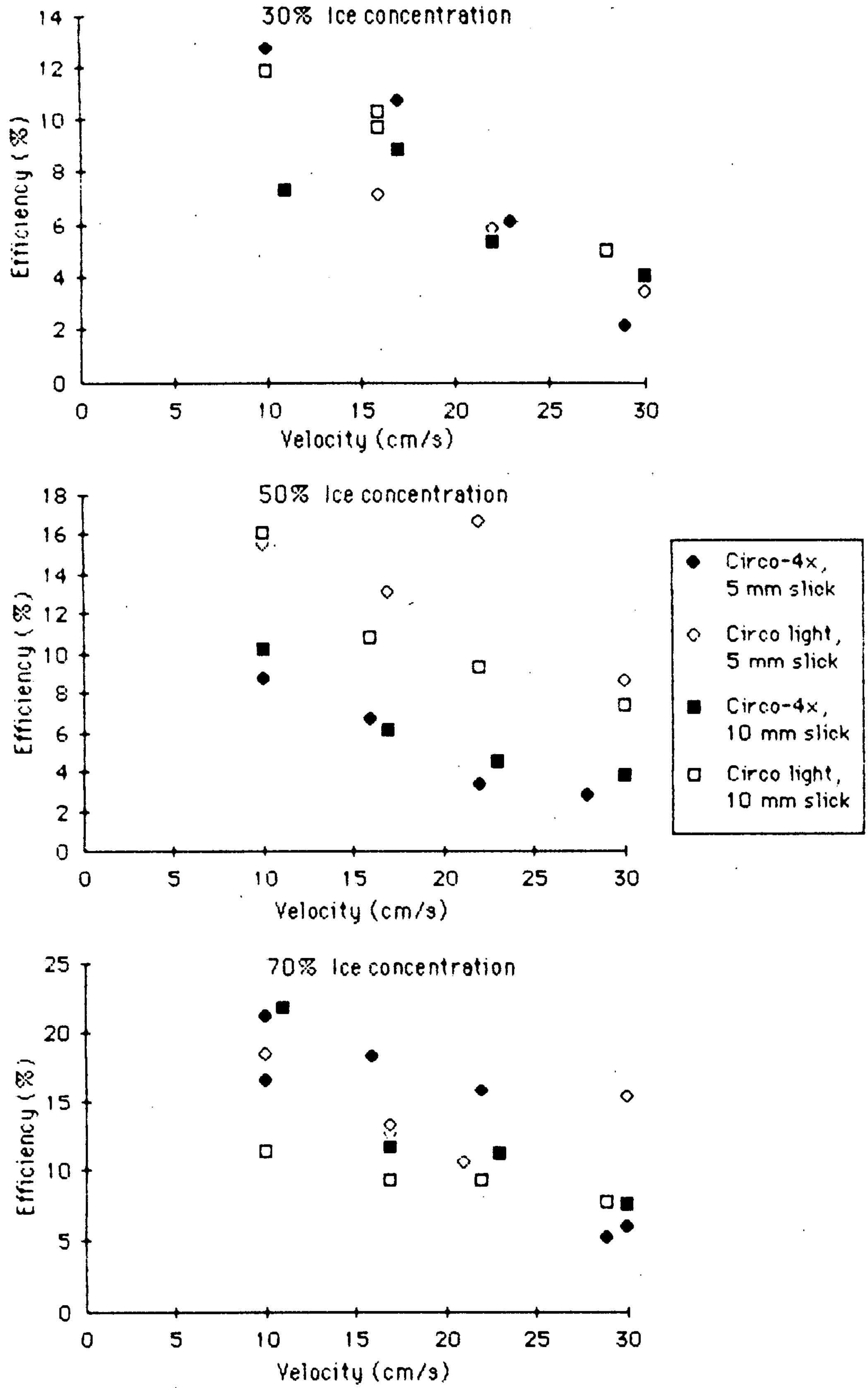

Figure 11: Efficiency versus model velocity.

thickness as well as the induced current flow. Locally, slick thickness is affected by ice obstructing the flow of oil, thus increasing the quantity of oil that may escape under the spray jets.

The water velocity profile caused by the spray jet has a marked effect on the effectiveness of the spray boom. Work done by Comfort et al. (1980) indicated that the current velocity diminishes drastically with depth. If the velocity component resulting from the forward motion of the OSB is superimposed on these profiles, it is immediately clear how the oil escaped below the spray jet (Figure 13).

To improve the efficiency of the spray boom, a detailed study of the induced current profile should be undertaken, so that the best spray boom design can be achieved.

Ice Concentration

During the test at 50 and 30% ice concentrations, it was observed that the ice pieces tended to move up the basin, as a result of the applied force of the spray boom. It was also observed that the quantity of oil flowing over the weir was negligible until the ice immediately ahead of the OSB became sufficiently compacted between 60 to 70% concentration (however, this movement was not observed for the tests with 70% concentration). This tendency resulted in a lesser recovery efficiency for the lower ice concentrations as suggested in Figure 14.

Slick Thickness

A slight trend in Figure 15 shows that the thicker the oil slick, the lower the oil recovery efficiency for tests conducted in the broken ice. This trend is particularly evident for tests conducted with 70% ice concentration and, to a lesser extent, for those done with 50% ice concentration. However, for the tests done at 30% ice concentration, the reverse trend is observed on average. Interestingly, for the test done in open water, it was found that efficiency increased as the slick thickness increased.

Oil Viscosity or Type

Figure 16 presents the model efficiency as a function of oil viscosity. Based on these figures, no clear trend was identified.

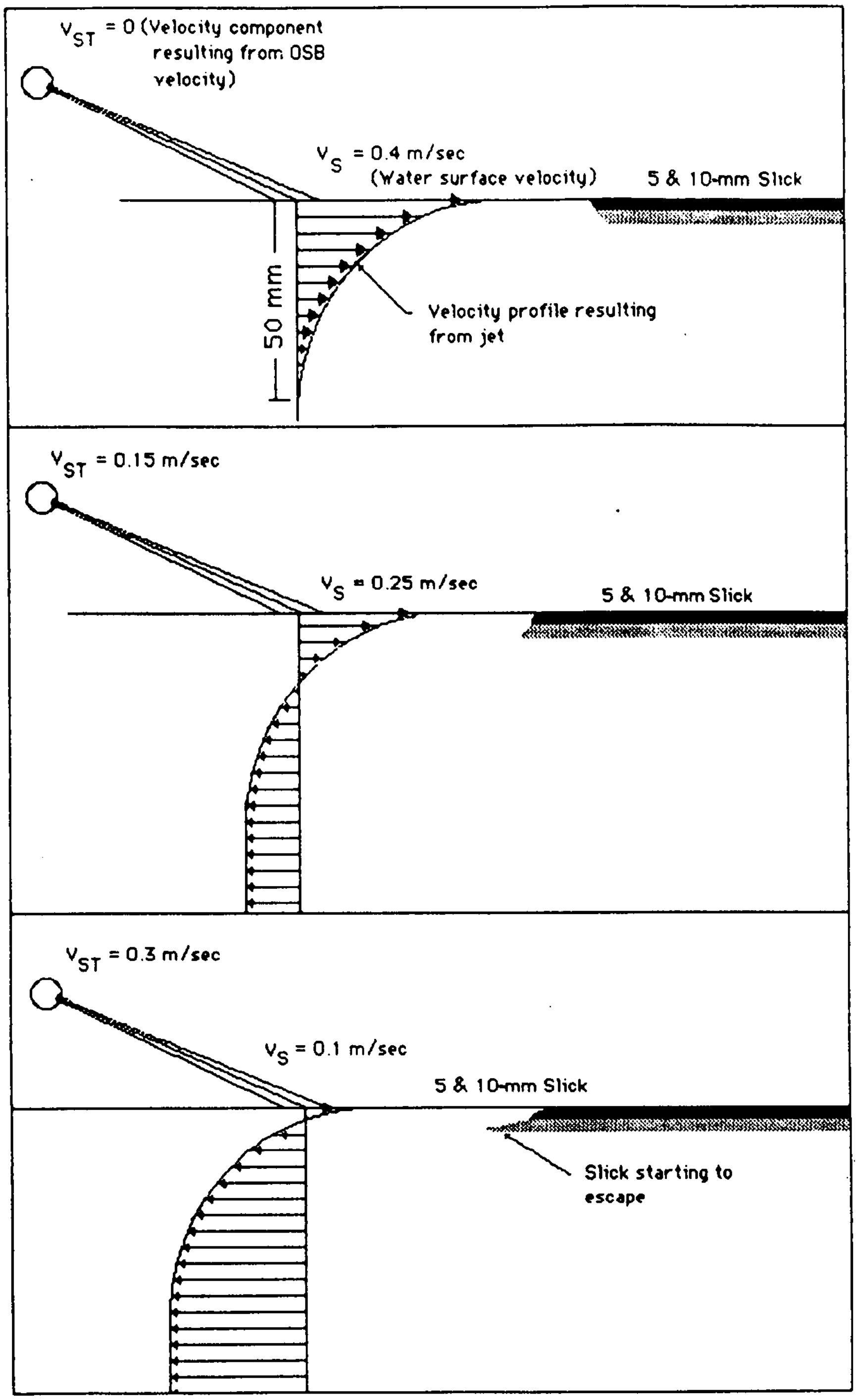

Figure 13. Spray jet velocity profile.

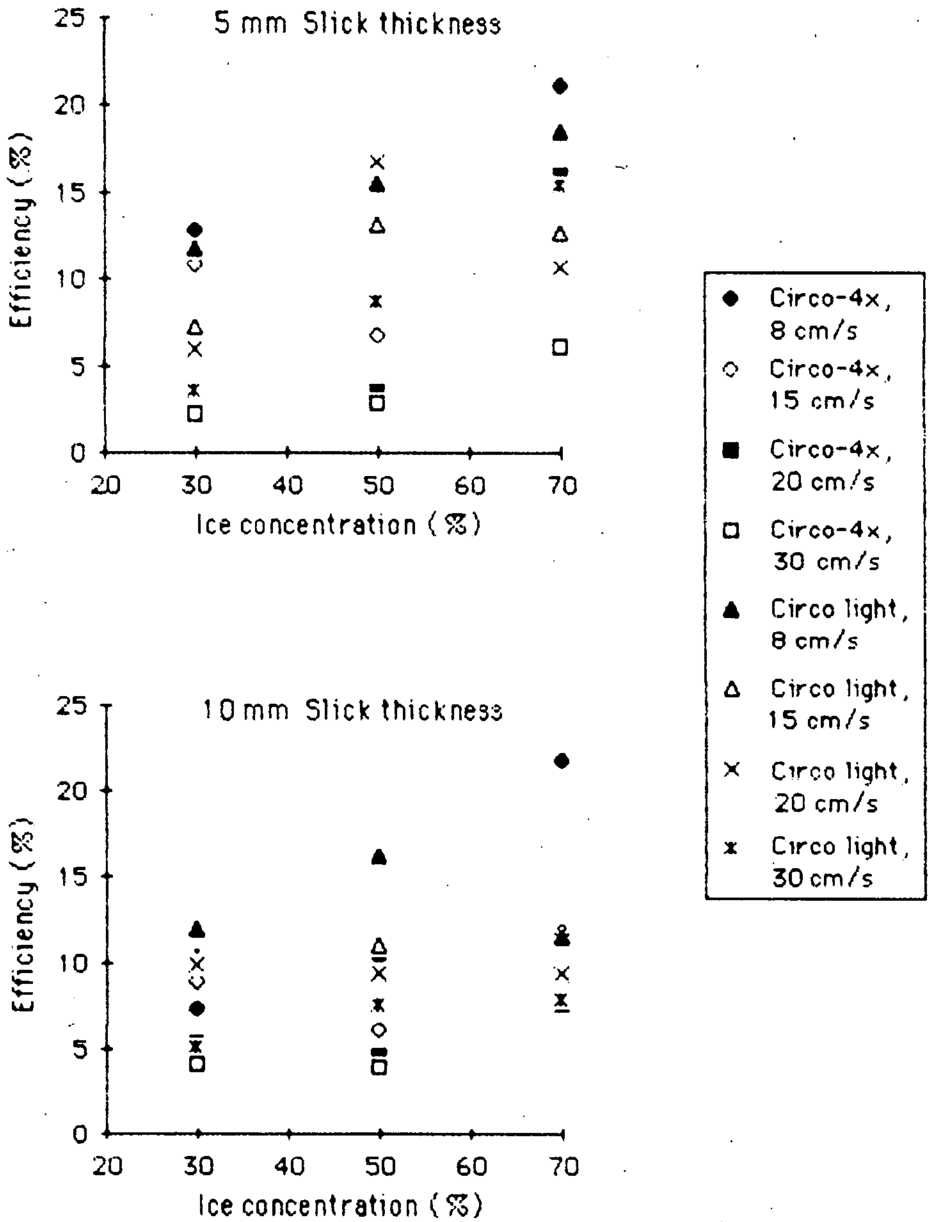

Figure 14: Efficiency versus ice concentration.

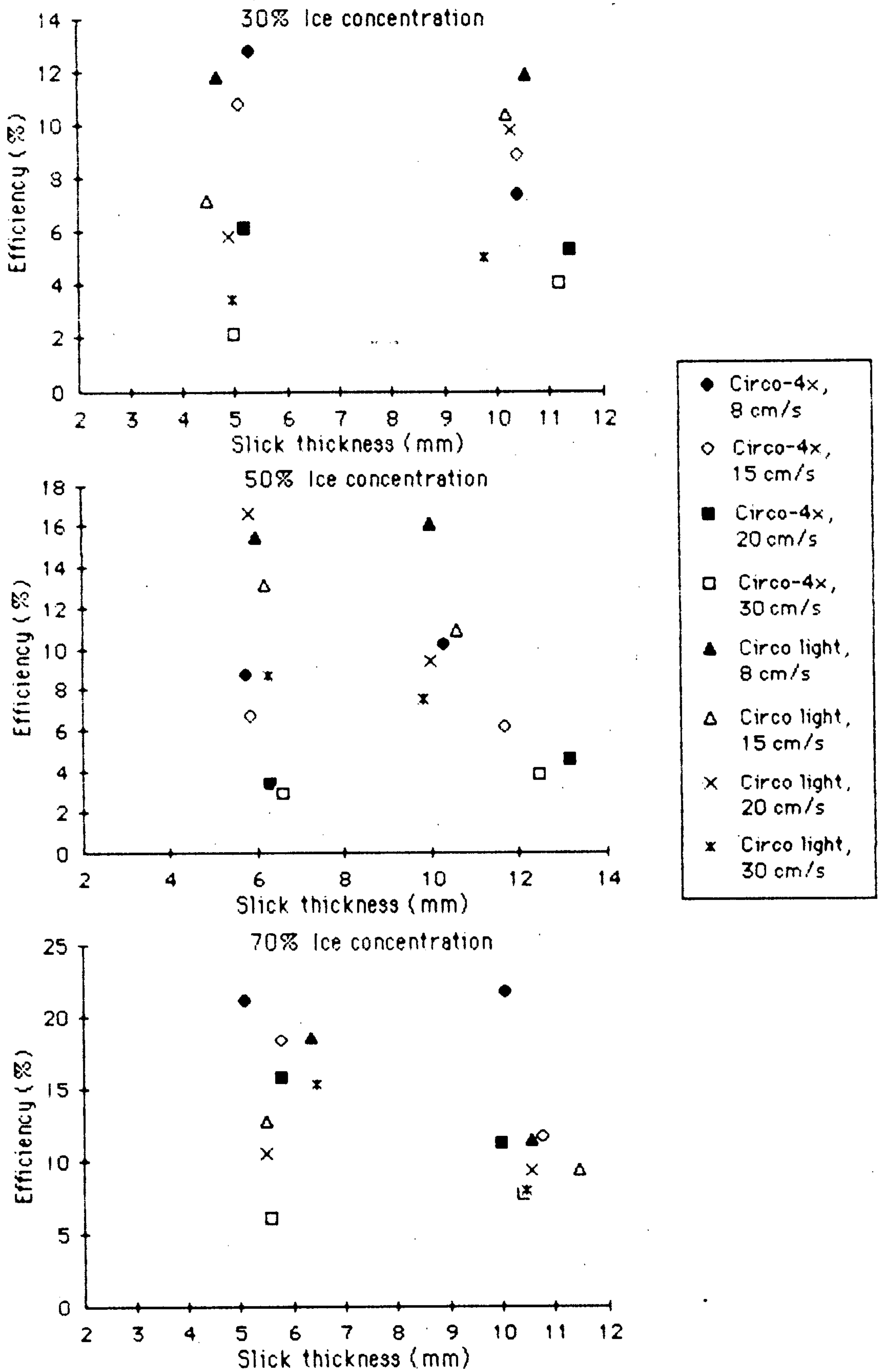

Figure 15: Efficiency versus slick thickness.

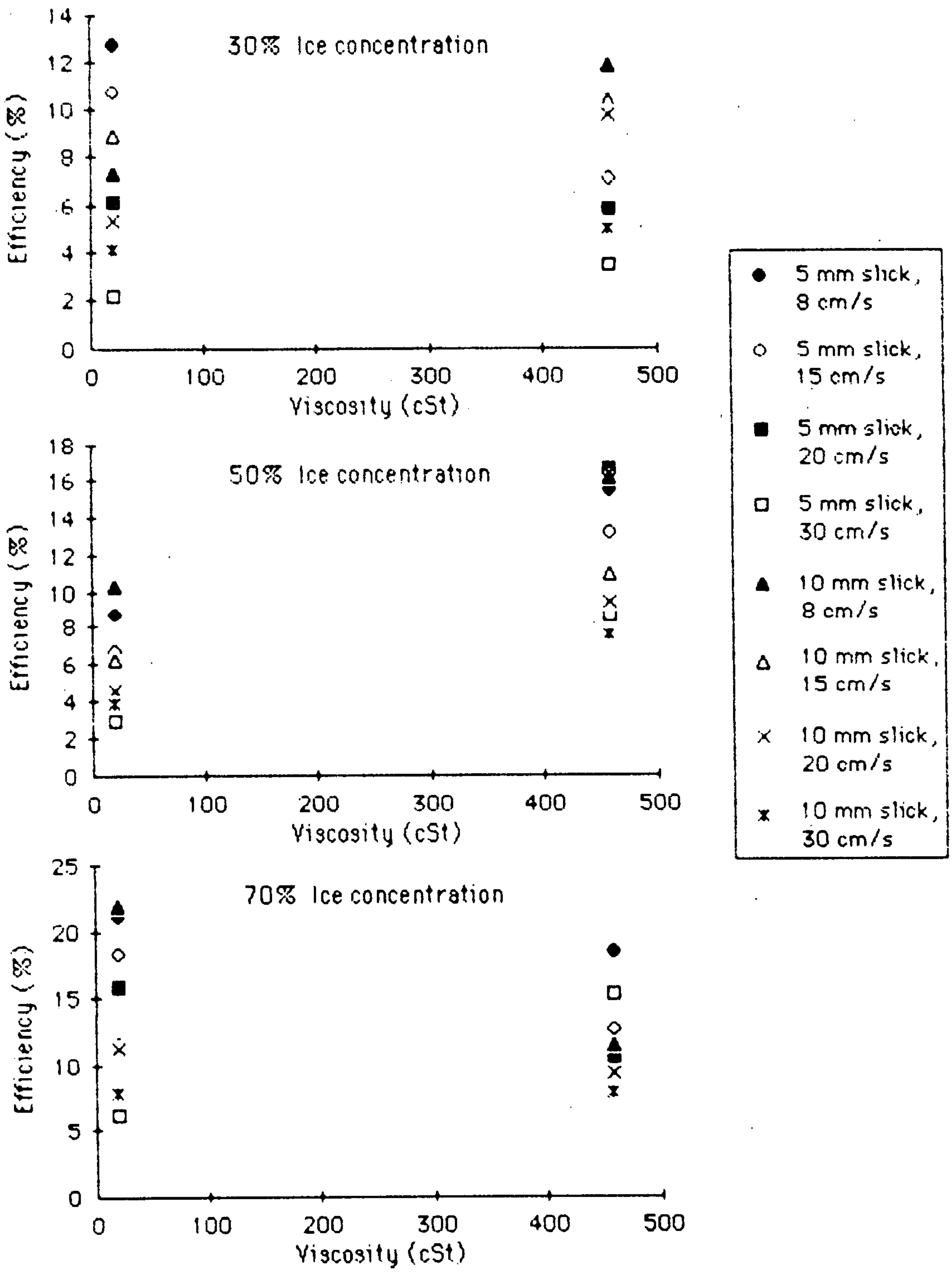

Figure 16: Efficiency versus oil viscosity.

Spray Boom Length and Orientation

This factor was not investigated during this experimental program. Based on the test observations, it was clear that the width of the boom was too long; little oil from the extreme far end of the boom was actually collected. A smaller boom length would have increased the efficiency significantly, but reduced, somewhat, the oil recovery rate.

Water Spray Velocity Discharge or Pressure

There are no data in the literature that permit the evaluation of the effects of the jet velocity and orientation on moving the oil between broken ice floes. However, this problem has been investigated for open water conditions by Comfort et al. (1979) who concluded that the slick will break up, if it is moved too rapidly.

Air and Water Temperature

The viscosity, (see Figure 6), is dependent on the temperature of the oil, which is in turn influenced primarily by the water temperature and also by the air temperature. Cold air temperature could result in the formation of frazil ice that may adhere to the opening of the OSB, and block the flow of the oil slick.

Presence of the Spray Boom

To evaluate its effect on the recovery efficiency of the OSB, six tests (Nos. #38, 43, 49, 52, 55, and 64), were carried out without the spray boom. As in previous tests, the pump in the reservoir was kept running continuously to ensure that the water level inside the reservoir remained at a low enough level for efficient operation of the weir skimmer.

For comparison, the efficiency with and without the spray boom was calculated in an identical manner. For all tests, the efficiency was calculated by considering the oil presented to be the trapezoid bounded by the length of the test and the sum of the model width and spray boom length. From this definition, the average efficiency without the spray boom was 2.3 and 3.0% for the 5 and 10 mm slick, respectively. However, for those tests without the spray boom, the oil presented is actually the trapezoid bounded by the length of the test and the width of the model. Using this definition for the oil presented, the efficiency would be 5.6 times higher, making the efficiency without the spray boom in the same range as the results with the spray boom (Figure 17).

It should also be noted, that during these tests, there was a significant reduction in the ice movement up the basin compared to the tests conducted with the spray boom operating.

Tests in Open Water

It was anticipated that the efficiency of the model in open water would be significantly higher than values obtained for the model operating in the ice fields. However, this was not the case as the results of tests 65 to 69 show. The maximum efficiency was 12.0%, about half of the maximum efficiency obtained while operating in ice. This resulted from the oil being swept up the length of the basin, rather than toward the model, even though the boom pressure was reduced to 138 kPa. Because only a few tests were conducted in open water, only one collection velocity (0.15 m/s) was used. During these tests the oil was not returned into the basin, thus the slick thickness dropped after each test. Figure 18 shows efficiency against slick thickness, using Circo Light oil. This plot shows that as the slick thickness increases so also does the efficiency, which was the reverse of the trend noted for tests conducted in ice.

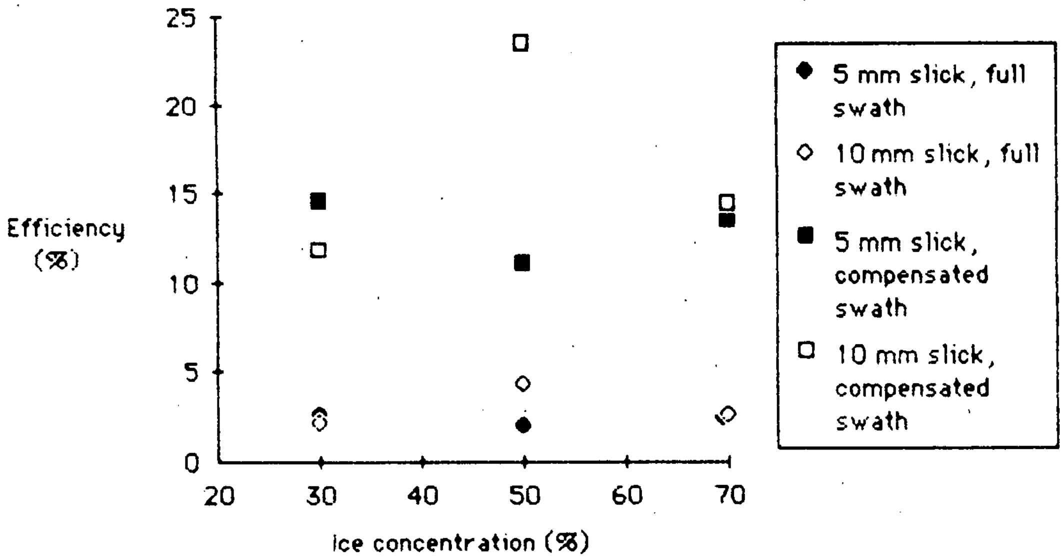

Figure 17: Efficiency versus ice concentration for tests conducted without spray boom.

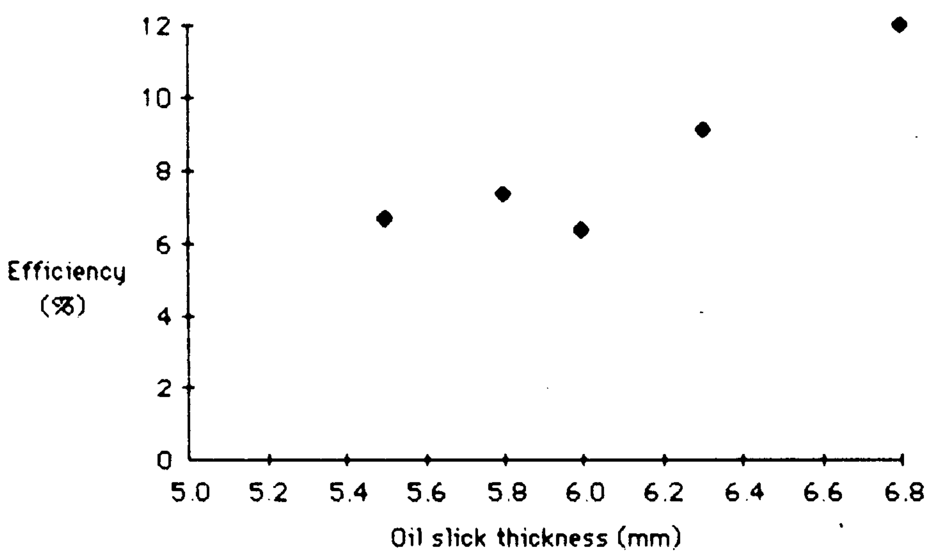

Figure 18: Efficiency versus slick thickness for tests in open water with Circo Light oil and velocity of 0.15 m/s.

PROTOTYPE DESIGN CONSIDERATIONS

The Spray Boom

The expected efficiency of a prototype OSB will depend significantly on the design of the spray boom. The spray boom has to be designed to ensure that the induced water velocity, from the water surface to the bottom of the oil slick, is higher than the velocity of the OSB so that it is always positive as shown in Figure 19.

The velocity profile of the induced water flow has to be optimized to move the oil on the surface without sweeping ice forward at the same time.

This could possibly be achieved by decreasing the angle (α) between the jet and water surface, resulting in an increase of the surface water velocity and a decrease in velocity of the water below the slick. This angle may become very sensitive to the motion of the ship and the associated waves, therefore, it has to be carefully evaluated.

The Skimmer Attachment to the Ship

The skimmer has to be designed to withstand the impact of ice floes. The structure will have a smooth shape to reduce the possibility of structural damage. A grid will have to be installed to prevent large pieces of ice from blocking the weir. The method of fixing the skimmer to the ship has to be designed to be simple, but secure.

The ship should be ice resistant, which is usually the case for most supply ships operating in seas covered with broken ice.

Ice Conditions

The ice conditions that are expected to be seen in the area are an important consideration. Smaller ice pieces, with their smaller mass, accelerate faster than larger, thicker floes. Therefore, the jet velocity of the spray boom has to be capable of producing variable surface current profiles necessary in various ice conditions. This problem may not be significant for high concentrations of ice because the ice pieces would be in contact and will remain in place during skimming operations. However, another problem may be experienced in high concentrations of broken ice where only small free channels are left for the oil to flow toward the skimmer.

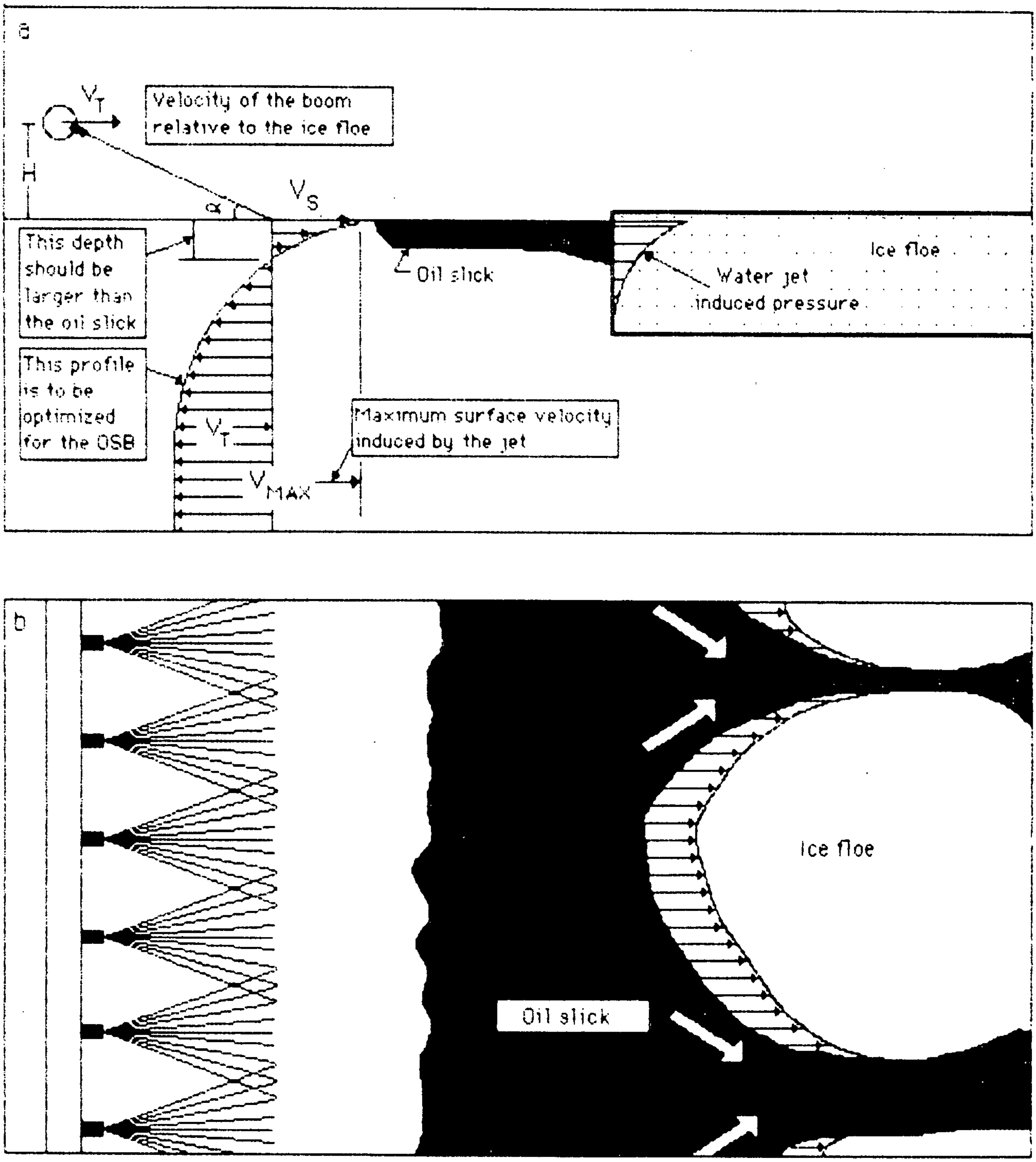

Figure 19. Prototype design considerations: a) spray jet velocity profile. b) oil moving around a piece of ice.

CONCLUSIONS

Based on the results of this experimental program, the model of the oil-skimming bow (OSB) could operate in broken ice prepared under laboratory conditions and could achieve an efficiency of oil recovered/oil presented of more than 20%. However, the average efficiency for the tests conducted was only 10.2%. Emulsification of the Circo oil collected in the skimmer reservoir was measured and was about 1% on average. This may not always be the case, because significant mixing was observed during the test and crude oil may be more susceptible to emulsification than Circo oil.

The results of the amount of oil recovered and the efficiency of the recovery for the tests at 30 and 50% ice concentrations were lower than expected. During the tests, a 5 m long run was used to allow steady conditions to be reached. This distance was calculated, assuming that the ice would not move with the model. This assumption was incorrect and steady oil recovery rate did not occur before 40 to 70% of the run was complete. To formulate a theoretical solution that may lead to improving the performance of the system, it is necessary to understand the mechanics of the floe movement under the transient forces resulting from the surface water current, induced by the spray boom.

Tests conducted in open water indicated that efficiency increased with slick thickness. However, the efficiencies were lower than those obtained while operating in ice, because more oil was swept in front of the model than toward the model.

RECOMMENDATIONS

Refinement of three important features of the spray boom is believed to be necessary if the efficiency of the OSB is to be improved significantly.

a) Length of boom

A shorter length would increase the efficiency of the system without reducing significantly the amount of oil recovered.

b) Orientation of boom

The angle of the spray boom with the normal to the model hull was 45°. This angle was decided after assuming that the oil would be capable of moving freely from the far end of the boom toward the model. Based on test observations, (Figure 20), the oil collected was primarily from the nearer end of the spray boom rather than from the entire area passing under the boom. An investigation of the effect of increasing this angle could improve the efficiency and possibly the rate of oil recovery.

c) Pressure of boom

A parametric study optimizing the water line pressure, water discharge, and angle of incidence with the horizontal plane of the water jet would improve the efficiency. This could result in the oil being herded at higher velocities while the ice remains stationary.

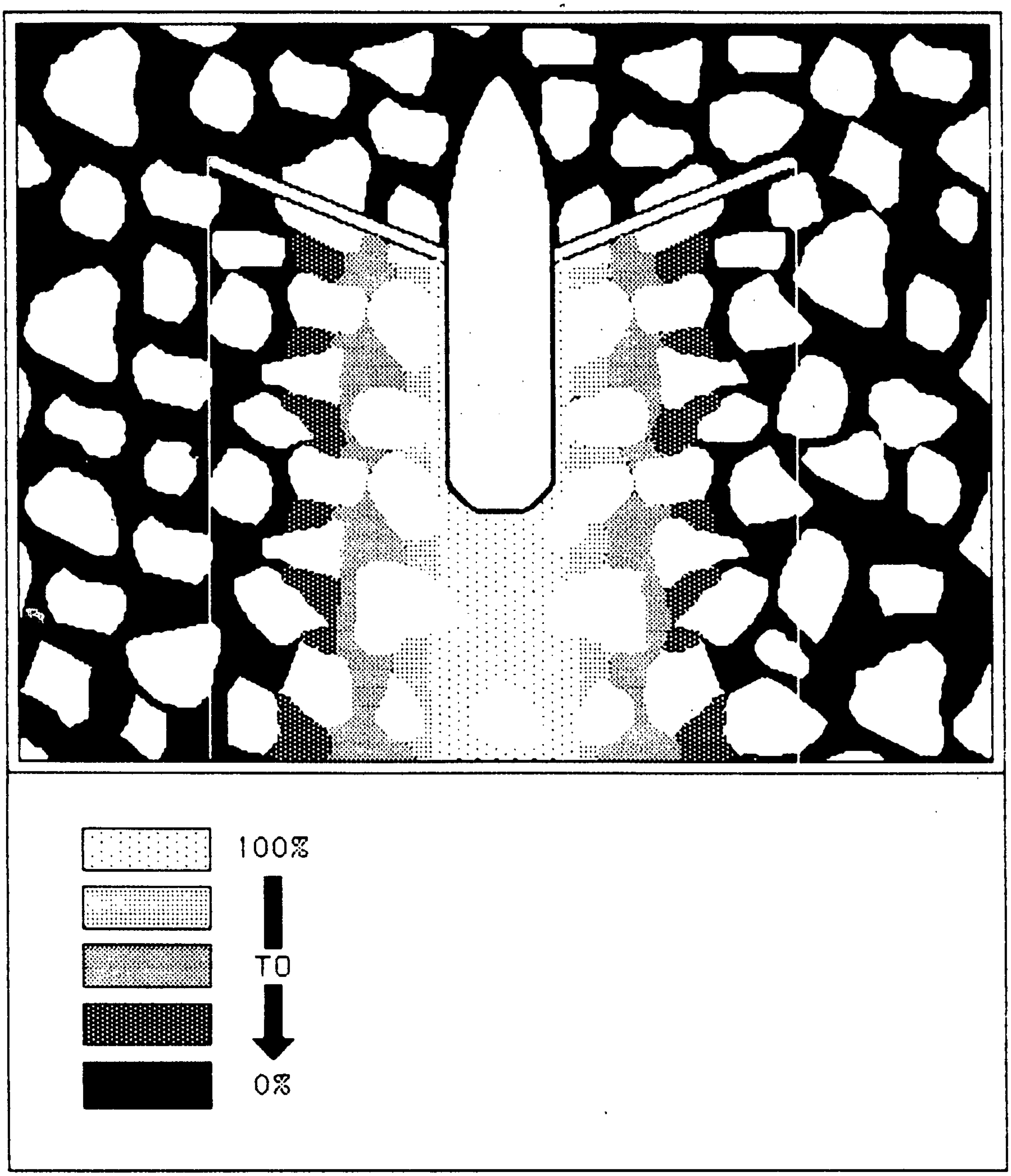

Figure 20. Efficiency of the oil-skimming bow based on observations.

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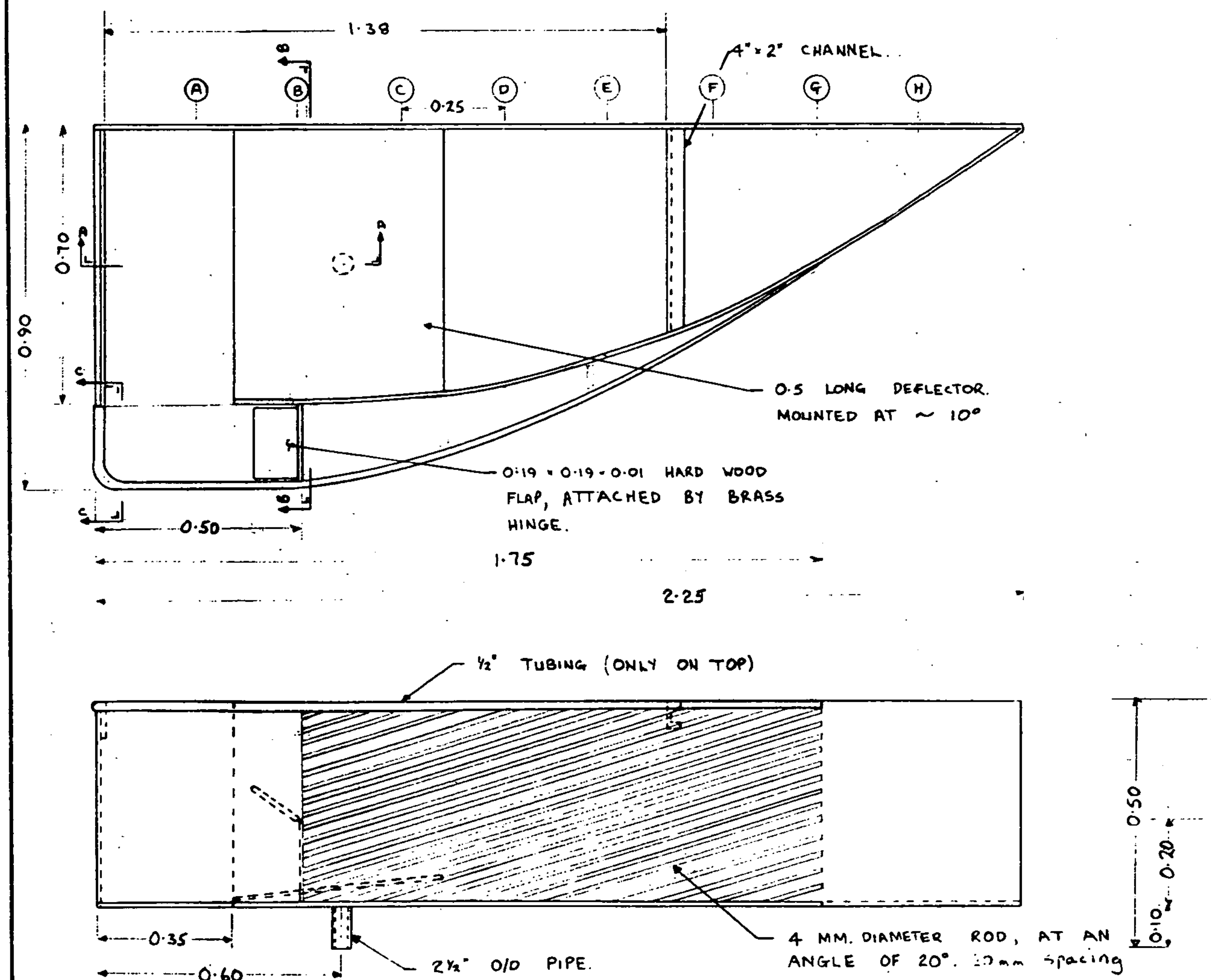
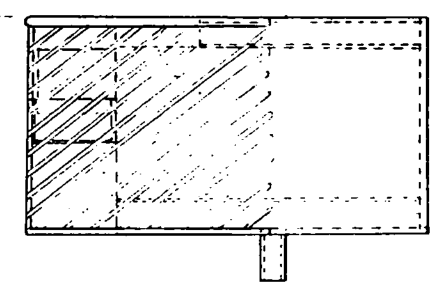
APPENDICES

APPENDIX A

DRAWINGS OF TEST MODEL





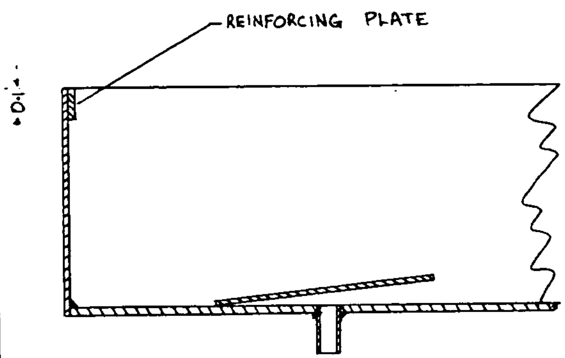
POSITION	WIDTH (M)
A	0·70
B	0·70
C	0·67
D	0·64
E	0·56
F	0·48
G	0·36
H	0·19

NOTES

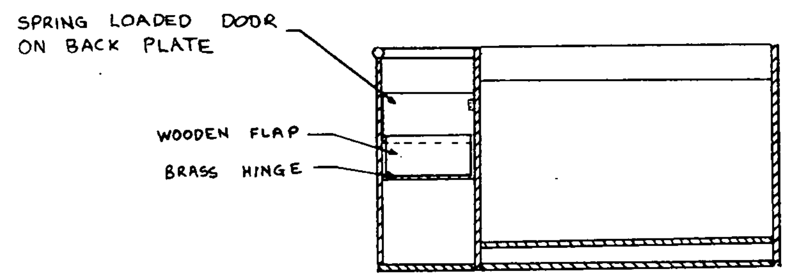
- MODEL TO BE FABRICATED FROM ALUMINIUM.
- ALL WELDED CONSTRUCTION
- ALL DIMENSIONS IN METERS, EXCEPT AS SPECIFICALLY NOTED.
- THE AREA INSIDE THE BOW AND WIER SHOULD BE WATER TIGHT.
- ALL PLATE ⅛" THICK.

BOW SKIMMER NTS.

June 28/84



SECTION "A-A"



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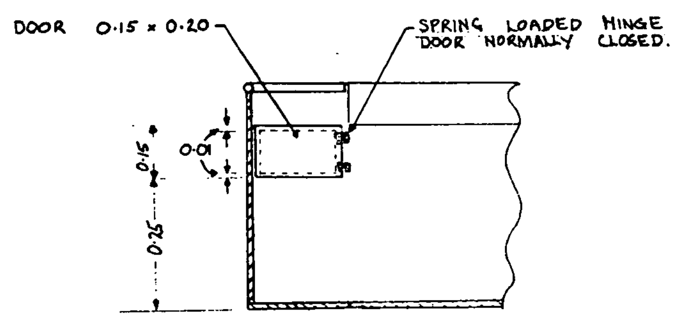


SECTION "C-C"

APPENDIX B

ZAHN VISCOSIMETER INFORMATION

CENTRAL SCIENTIFIC CO., INC.

ZAHN VISCOSIMETER
CSC NO. 027134 .

1. INTRODUCTION

The Zahn Viscosimeter is a portable device for quickly measuring the viscosity of such liquids as paint, lacquer, varnish, syrup and oil. The viscosity of a liquid measured by this device is expressed in Zahn numbers, that is, the time in seconds required for a definite volume (44 cm^3) of liquid to flow through the Viscosimeter. Five models are available to measure viscosities ranging from 20 to 1200 centipoises. The models differ only in the size of the orifice in the bottom of the cup; See Specifications.

The Zahn Viscosimeter offers many advantages as:

* Simplicity of use; no special skill is required.

* Convenience; it is small and lightweight.

* Fast Operation; measurements can be made in less than a minute.

* Durability; cup is a one-piece construction.

* Corrosion Resistance; stainless steel fabrication resists corrosion.

2. DESCRIPTION

The device consists basically of a bullet-shaped cup with an oriface at the bottom and a loop-type handle at the top. A small ring is fitted to the handle for a finger support, used to keep the cup in a vertical position when the device is withdrawn from the liquid being tested. Also affixed to the handle is an adjustable bracket designed to hold an all-metal thermometer, such as No. 019380-001 or 19385-001.

JG 6-23-78

3. SPECIFICATIONS

CSC NO. 027134

Model Number	-001	-002	-003	-004	-005
Orifice Diam., Inches	0.078*	0.108*	0.148*	0.168*	0.208*
Centipoise Range, Approx.	20-85	30-170	170-550	200-900	250-1200+
Zahn Range in Seconds, Approx.	40-85	20-70	25-60	20-65	15-60
Accuracy, Seconds	1	1	3	3	3
Suggested Applications	Very thin oil	Thin oil or lacquer	Medium oil or mixed plants	Heavy Mix-tures	Very Heavy Mixtures

*Tolerance on all orifices is ± 0.010 inch.

Overall length, inches	13-3/4
Cup Dimensions, Inches	
Depth	2-3/8
Width	1-5/8
Cup Capacity, cm^3	44
Weight, oz.	4

4. OPERATION

Procure a stop watch such as No. 073515 and a thermometer such as No. 091380-001 or 019835-001 to measure the viscosity of a liquid with the Zahn Viscosimeter, the following procedure is recommended.

1) Insert the thermometer into the holes of the bracket of the viscosimeter.

2) Stir the liquid thoroughly, dip the cup into the liquid and note the temperature.

3) Adjust the bracket so the the thermometer stem is out of the cup.

4) Slip a finger in the ring, lift the Viscosimeter completely out of the liquid and start the stop watch when the top edge of the cup breaks the surface.

5) Stop the watch when the steady flow of the liquid from the orifice suddenly stops.

6) Repeat steps 2 thruough 5 until satisfactory checks are obtained.

7) Express viscosity in Zahn seconds.

8) Clean the viscosimeter with an appropriate solvent and dry with soft, lint-free tissue.

No general formula is available to convert Zahn viscosity in seconds to other units of viscosity. However, the use of the Zahn viscosimeter minimizes the need for converting to other units.

For those few applications in which such a direct correlation is required, a conversion curve can be constructed from test data. Such a curve applies only to the particular liquid used in obtaining the data.

An empirical formula cannot be applied because not all liquids have the dame flow characterisitics with respect to the cup's surface, even though they may have the same absolute viscosity. Thus, a particular value of Zahn seconds is equal to a particular value in other units only for a specific liquid.

Temperature affects the viscosity of a liquid; therefore, it is recommended that several tests be made with the same liquid over the expected temperature range, and that the data be tabulated.

For quality control purposes a viscosity-temperature curve is even better than a table. To prepare such a curve, first obtain a sample of the liquid to be controlled when the liquid is at optimum viscosity. Then determine the viscosity, in Zahn seconds, in a 5-degree or 10-degree steps over the temperature range which will be encountered in control measurements.

Viscosity comparisons can be made in the production area or in the laboratory with any viscosimeter having an orifice of the same size as that used in preparing the table or curve.

5) MAINTENANCE

The Zahn Viscosimeter requires no special maintenance other than taking precautions to avoid damage to the orifice. After use, clean the device with appropriate solvent and dry with soft, lint-free tissue.

6. ACCESSORIES AND REPLACEMENTS

Description:	CSC #
All Metal Thermometer, range from -10° to $+110^{\circ}$C	019380-001
All Metal Thermometer, range from 0° to 220°F	019385-001
Stopwatch with 1/5 second divisions	073515-000

APPENDIX C
SAMPLE DATA SHEET

OIL SKIMMING BOW TEST # ______ DATE ____________

TEST CONDUCTED BY: ________________________________

TARGET ICE CONCENTRATION ______ (%) TYPE OF OIL ____________

TARGET SLICK THICKNESS __________ (mm) TARGET VEL. ________ (m/s)

QUANTITY OF OIL AVAILABLE __________ (l)

AIR TEMP. _____ _____ _____ _____ AVG. ________ (C)

WATER TEMP. _____ _____ _____ _____ AVG. ________ (C)

OIL TEMP. _____ _____ _____ _____ AVG. ________ (C)

OIL THICKNESS __ __ __ __ __ __ __ __ __ __
__ __ __ __ __ __ __ __ __ __ AVG. ____ (mm)

AVERAGE SKIMMER VELOCITY __________ (m/s) RUN LENGTH ______ (m)

THICKNESS OF OIL IN SKIMMER ___ ___ ___ ___ AVG. _____ (mm)

QUANTITY OF OIL RECOVERED _______ (l) % WATER IN RECOVERED OIL ________ (%)

ACTUAL QUANTITY OF OIL RECOVERED ___________ (l)

COMMENTS

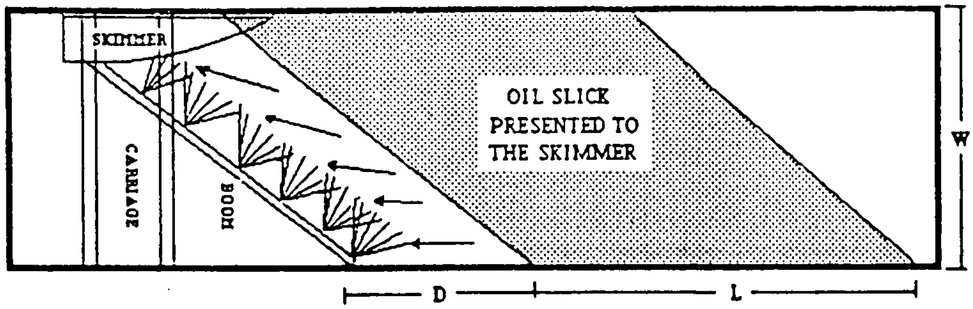
BEFORE TEST

AFTER TEST

APPENDIX D

SAMPLE CALCULATION

SAMPLE CALCULATION



Oil Presented to Model

$$Q_p = L \times W \times (1 - c) \times t$$

where Q_p = Quantity of oil presented (l)
L = Length of experiment (m)
W = Width of basin (m)
c = Ice concentration (%)
t = Oil slick thickness (mm)

Model Efficiency

$$\eta = \frac{Q_R}{Q_p} \times 100$$

where Q_R = oil recovered

Example: Test #6. Data from Table

L = 15 m
W = 4.9
c = 70% = 0.70
t = 5.8 mm
Q_R = 23.4 l

$$Q_p = 15(4.9)(1 - 0.7)(5.8) = 127.9 \text{ l}$$

$$\eta = \frac{23.4}{127.9} \times 100 = 18.3\%$$