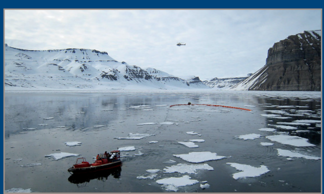
SINTEF A16027 Unrestricted

REPORT



Oil in Ice - JIP

Report no.: 21

"Oil in Ice" JIP: Testing of oil skimmers via field experiments in the Barents Sea, May 2009.

Ivar Singsaas, Kristin Rist Sørheim, Ragnhild Lundmark Daae, Bror Johansen, SINTEF, Lauri Solsberg, Counterspil Research Inc.

SINTEF Materials and Chemistry
Marine Environmental Technology

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SINTEF

Preface

SINTEF has in cooperation with SL Ross Environmental Research Ltd and DF Dickins Associates LLC on behalf of the oil companies AGIP KCO, Chevron, ConocoPhillips, Shell, Statoil and Total initiated an extensive R&D program; *Joint industry program on oil spill contingency for Arctic and ice covered waters.* This program was a 3-year program initiated in September 2006 and finalized in December 2009.

The objectives of the program were;

- To improve our ability to protect the Arctic environment against oil spills.
- To provide improved basis for oil spill related decision-making:
- To advance the state-of-the-art in Arctic oil spill response.

The program consisted of the following projects:

- P 1: Fate and Behaviour of Oil Spills in Ice
- P 2: In Situ Burning of Oil Spills in Ice
- P 3: Mechanical Recovery of Oil Spills in Ice
- P 4: Use of Dispersants on Oil Spills in Ice
- P 5: Remote Sensing of Oil Spills in Ice
- P 6: Oil Spill Response Guide
- P 7: Program Administration
- P 8: Field Experiments, Large-Scale Field Experiments in the Barents Sea
- P 9: Oil Distribution and Bioavailability

The program has received additional financial support from the Norwegian Research Council related to technology development (ending December 2010) and financial in kind support from a number of cooperating partners that are presented below. This report presents results from one of the activities under this program.

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Program Coordinator
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Funding Partners

R&D Partners

Cooperating Partners

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SINTEF REPORT

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Agip KCO; Chevron; ConocoPhillips; Shell; Statoil; Total; Norwegian Research Council, DEMO 2000 Program

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ABSTRACT

The main objective of the field testing was to test and verify the Ro-Clean Desmi and Framo skimmers in the field under more realistic conditions compared to what can be accomplished in basin testing. This includes lower oil thickness, temperature fluctuations, wind and a more dynamic ice field. The testing should also lead to a better understanding of the potential use of skimmers in ice-covered waters as well as practical experience with use of mechanical recovery in Arctic waters.

This report covers the testing of mechanical recovery equipment performed during the experimental field trial in the Barents Sea from 7. to 23. May 2009. The field trial was performed in the eastern part of the Barents Sea east of the island Hopen. The coast guard vessel KV Svalbard with its two MOB boats was an excellent platform for the testing. The crew onboard, both the officers and the young people doing their military service, did a great job during the entire field experiment.

The Ro-Clean Desmi Polar Bear skimmer can effectively recover cohesive oil slicks provided low concentrations of smaller ice pieces and slush ice (< 50 – 70 %) and a drum speed of 5 – 10 rpm. The buoyancy of the skimmer should be adjusted and further winterisation should be considered if it is going to be used under harsh Arctic conditions.

The Framo skimmer, as presented for testing, requires more development work on basic skimmer concepts to ensure that a fully functional machine is developed. The bristles and the scrapers must be improved and modifications to buoyancy are required. The triangular shape combined with use of thrusters was a successful combination and allowed the skimmer to move very well in ice. The skimmer processes ice quite well and is expected to ultimately have the potential to effectively recover oil in small ice concentrations up to 70 %. It has been agreed with Framo to continue the development of this skimmer over the next 6 months as part of the DEMO 2000 project. That includes taking into account the recommendations from the field experiment and also building a new lighter frame with one pump.

KEYWORDS	ENGLISH	NORWEGIAN
GROUP 1	Mechanical recovery	Mekanisk oppsamling
GROUP 2	Oil spill	Oljesøl
SELECTED BY AUTHOR	Oil recovery skimmers	Oljeopptakere
	Field trial	Feltforsøk
	Arctic	Arktis

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Executive summary

This report covers the testing of mechanical recovery equipment performed during an experimental field trial in the Barents Sea from 7. to 23. May 2009. The field trial was performed in the eastern part of the Barents Sea north-east of the island Hopen. The coast guard vessel KV Svalbard with its two MOB boats was an excellent platform for the testing. The crew onboard, both the officers and the young people doing their military service, did a great job during the entire field experiment.

Two oil recovery skimmer prototypes were tested during the field trial. The “Polar Bear” skimmer prototype was produced by Ro-Clean Desmi AS of Denmark. Framo of Norway supplied an early prototype of their brush drum skimmer for testing. Based on the testing performed during the field trial in 2009 and previous testing performed in the SINTEF Ice Basin in 2008 and early 2009, the following main conclusions have been drawn:

Ro-Clean Desmi Polar Bear skimmer:

The Polar Bear skimmer consists of six brush drums in a hexagonal shape and is a further development of the Helix 1000 skimmer. The results from testing of the Polar Bear Skimmer both in the ice basin and in the field indicate that it can be effective in collecting flowing oil when positioned in oil of varying slick thickness (several mm to several cm) among ice pieces. Cohesive oil slicks can be effectively drawn into the brushes provided that the drum speed is not too high (5 – 10 rpm in these tests) and the sump lip remains above the sea surface. The skimmer works best in the presence of low concentrations of smaller ice pieces and slush ice (< 50 - 70 %) and might also have the potential for application alongside larger ice floes.

The Polar Bear skimmer is an improvement over the Helix 1000 skimmer and can be a versatile device for oil spills in ice covered waters. The operation of the skimmer would benefit from improved buoyancy. An improved means of supporting the bundle of hoses connected to the pump could further increase the versatility connected to deployment, repositioning and operation of the skimmer. The skimmer has a robust construction and should be able to withstand ice pressure to some extent. If large pressure between ice floes is likely to occur the skimmer can be repositioned by a crane. The skimmer has a shield on top but if it is going to be used under harsh conditions (low temperatures and/or strong winds) further “winterisation” should be considered.

The Polar Bear is a medium size skimmer and should be able to recover 10 to 20 m^3/hr of oil or emulsion in low ice concentrations or when otherwise exposed to a relatively thick oil layer on an ongoing basis.

Framo brush drum skimmer:

The Framo skimmer is triangular in shape and features two brush drums on each side angled towards a bow flotation chamber. The skimmer is self-propelled through the use of two thrusters. It was concluded that a skimmer with thrusters, utilising this technology would be a useful mechanical recovery device for oil spills in ice. Due to the flow created under the brush drum and rotating augers the skimmer exhibited good small ice processing capabilities. The triangular shape combined with use of thrusters was a successful combination and allowed the skimmer to move effectively in ice. The Framo skimmer is expected to ultimately have the potential to recover oil in small ice concentrations up to 70 %.

The Framo skimmer, as presented for testing, requires more development work on basic skimmer concepts to ensure that a fully functional machine is developed. The bristles and the scrapers did not fully function but were damaged when operated leaving behind fragments of each. The bristle type did not appear to be suitable for picking up the test oil in the conditions encountered. Further work on these aspects is quite feasible and should result in full skimmer functionality.

Modifications to buoyancy and/or adjustable depth of brush drums are required. It has been agreed with Framo to continue the development of this skimmer over the next 6 months as part of the DEMO 2000 project. That includes taking into account the recommendations from the field experiment and also building a new lighter frame with one pump.

1 Introduction

In this project, oil spill response equipment manufacturers known to produce equipment with an expected potential for the recovery of oil in ice, were asked to supply ideas on development of new skimmer concepts for recovery of oil in ice. The manufacturers were asked to prepare a description of their concept for communication with the project Reference Group (RG) and decision by the Steering Committee (SC). Approximately 15 manufacturers were invited and three of them responded to the request. After discussions in the RG, two ideas were selected for further development.

During the field experiments in May 2009 the intention was to test and verify two newly developed skimmer concepts for recovery of oil in ice. The milestones up to the field testing were:

1. **April 2007: Testing of Framo HiWax skimmer in SINTEF ice basin (Singsaas *et al.*, 2008[B]).**
   Based on this testing Framo suggested a plough shaped skimmer with two brush drums based on the same frame as the HiWax skimmer.
2. **April 2007: Testing of Ro-Clean Desmi Ice skimmer and Helix skimmer in SINTEF ice basin (Singsaas *et al.*, 2008[A]).**
   Testing with Helix skimmer showed promising results and Ro-Clean Desmi came up with a suggestion for development of a new skimmer based on the same principle.
3. **June 2007: Reference Group meeting at SINTEF.**
   Three concepts were evaluated with representatives from the manufacturers presenting their concepts during the meeting. Further developments of the Framo and Ro-Clean Desmi concepts were recommended. Plans for these two concepts were prepared by the two manufacturers, sent to the RG for final recommendations and then approved by the SC.
4. **September 2008: Testing of Ro-Clean Desmi Polar Bear skimmer in SINTEF ice basin (Leirvik *et al.*, 2009).**
   This testing gave promising results and recommendations were given for some minor adjustments prior to testing/verification in the field experiment planned for 2009.
5. **January 2009: Testing of Framo ice skimmer in SINTEF ice basin.**
   Due to delay in development of the Framo concept this testing was performed with a test unit with only one brush drum instead of a prototype of the skimmer. The testing was valuable and gave Framo several ideas for improvement of the skimmer.

This report focuses mainly on the field experiment conducted in May 2009, but it also compares the results from the ice basin testing with the results from the field experiment for the two skimmers.

2 Objectives

The main objective of the field testing was to test and verify the Ro-Clean Desmi and Framo skimmers in the field under more realistic conditions compared to what can be accomplished in basin testing. This includes lower oil thickness, temperature fluctuations, wind and a more dynamic ice field. The testing should also lead to a better understanding of the potential use of skimmers in ice-covered waters, as well as practical experience with use of mechanical recovery in Arctic waters.

The May 2009 field trials were conducted in the Barents Sea north-east of the Hopen island near Svalbard as depicted in Figure 2.1 so that credible, realistic data could be obtained for operations in ice.

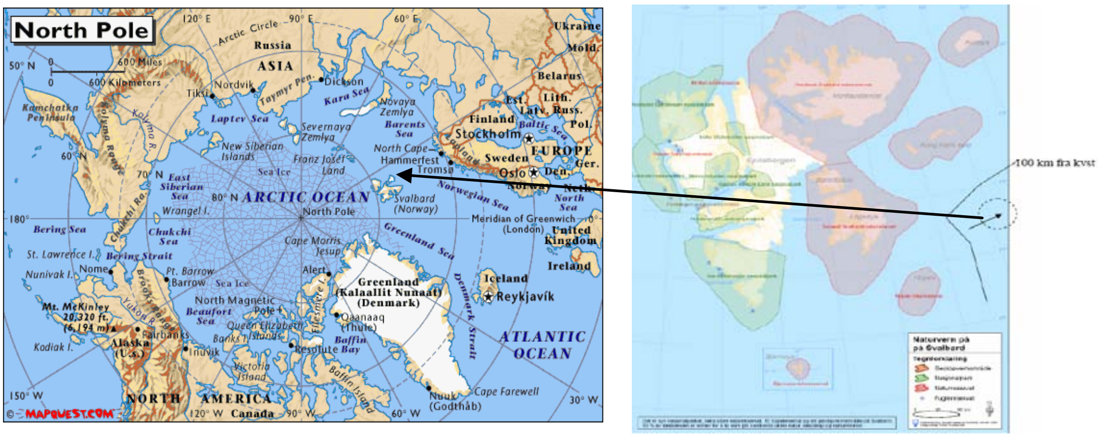


Figure 2.1 Location of May 2009 Field Trial (Position: N 77.6, E 30.9)

3 Experimental Background Information

3.1 Skimmers for testing

A combination of proposals and testing in the SINTEF ice basin in 2007 revealed that two skimmers had a higher potential for recovering oil in ice than the others (Singsaas *et al.,* 2008[A,B]). The two skimmers are manufactured by Frank Mohn of Norway and Ro-Clean Desmi A/S of Denmark. More specifically, Frank Mohn's Framo Skimmer, a self-propelled double brush drum unit, and the Ro-Clean Desmi Helix, a six brush unit intended for use in a stationary mode (and herein referred to as the "Polar Bear Skimmer") were chosen for testing and verification for the May 2009 field experiment. The skimmers were subjected to limited testing as requested by the Reference Group. Figures 3.1 and 3.3 show the two skimmers that were tested during the field experiment.

Frank Mohn Framo Skimmer

o Weight	1800 kg
o Hydraulic flow required	295 l/min
o Hydraulic pressure required	240 bar
o Power required	42 kW
o Type of pump	2 pumps; high pressure high viscosity screw pump.
o Max. pump capacity	2x70 m^3/hr.
o Max pressure	20 bar

The Framo prototype was equipped with metal discs installed on the brush drums as can be seen in figure 3.2. The purpose of these discs was to improve ice processing by pushing smaller ice pieces and floes down in the water to release the oil trapped in the ice. Under the brush drums an ice removal screw or auger was installed (not installed when the picture in figure 3.1 was taken), one on each side. The intention with this screw was to transport the smaller ice pieces pushed down by the metal discs backwards and away from the skimmer.

Figure 3.1 Framo skimmer during testing in the field.

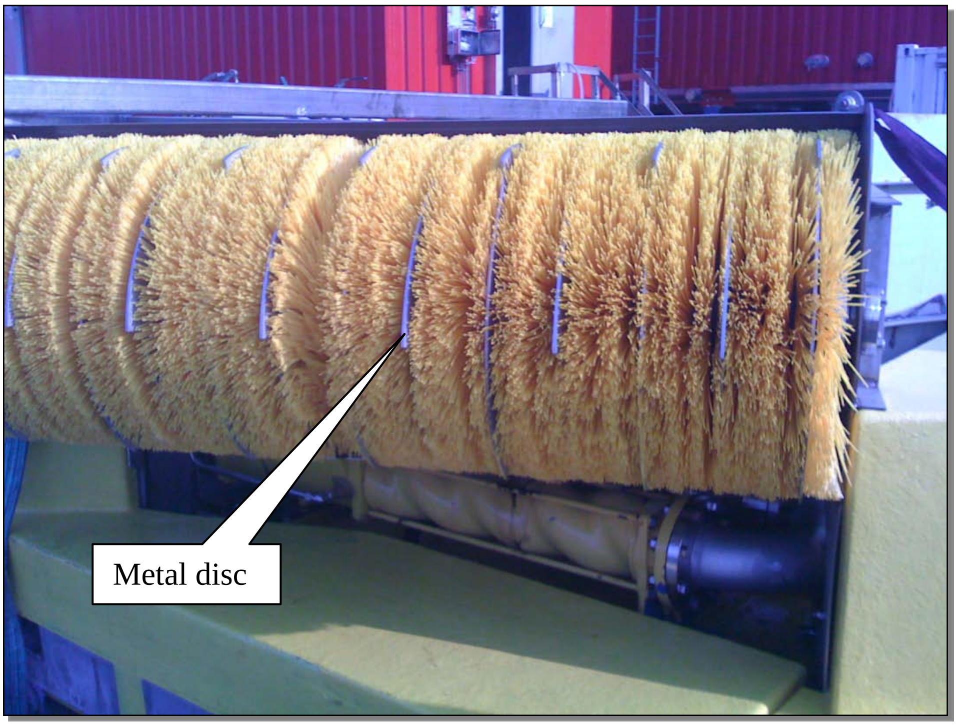


Figure 3.2 The Framo prototype showing one of the brush drums and the metal discs installed to remove ice.

Ro-Clean Desmi Polar Bear Skimmer

Technical data skimmer:

- Dimensions 2.25 x 2.50 x 1.85 m
- Weight 750 kg
- Number of brush modules 6 pcs.
- Number of brush wheels 9 pcs. per module
- Outer diameter of brush drum 290 mm

- Width of each brush module — 900 mm
- Bristle length — 100 mm
- Bristle material — PA 6
- Scraper/sealing device — Stainless steel/nitrile rubber

Technical data off-loading pump (DOP-DUAL 200):

- Type — Archimedes screw pump
- Capacity — 60 m^3/h
- Discharge pressure — 13 bar max
- Hydraulic flow — 0 - 130 l/min
- Hydraulic pressure required — 210 bar max
- Hydraulic connections — 3/4” TEMA male/female (supply/return)

Diesel hydraulic power supply

- Length — 2000 mm
- Width — 1000 mm
- Height — 1250 mm
- Weight — 900 kg (1100 kg full diesel tank)
- Hydraulic flow range — 0 - 160 l/min
- Max. cont. pressure — 210 bar
- Power — 47,6 kW at 2600 rpm (DIN 6271)
50 kW (DIN 70020)

Figure 3.3 Polar Bear skimmer during testing in the field showing hoses supported by ship’s crane.

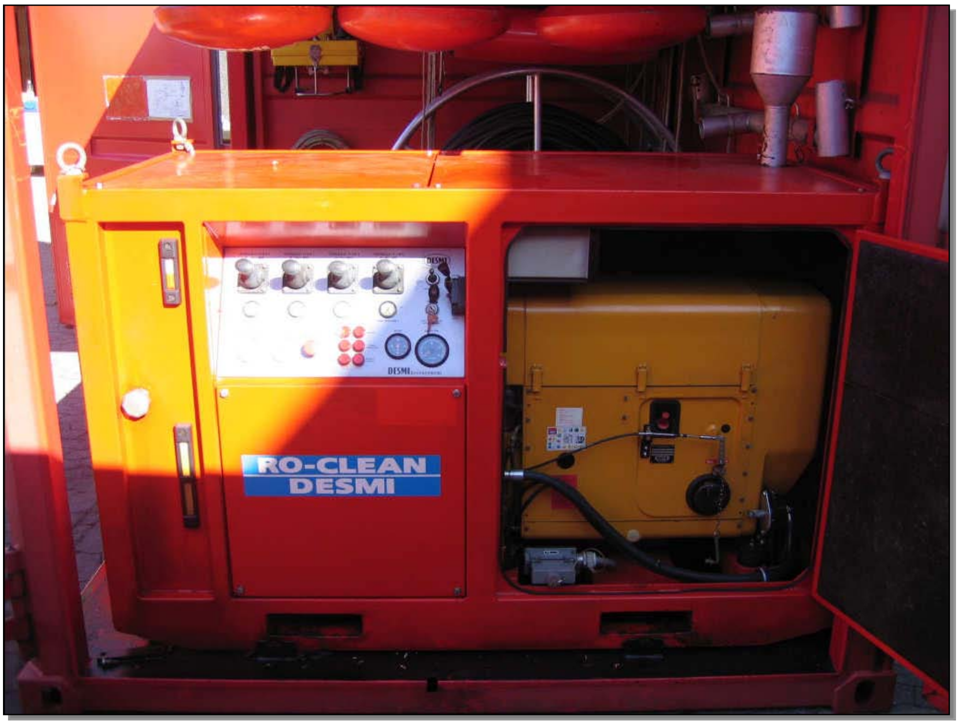


Figure 3.4 Hydraulic diesel power pack used during the field experiment

3.2 Vessel and working boats

The main vessel used was the K/V Svalbard owned by the Norwegian Navy (Figure 3.5). The vessel had two working boats (MOBs) and a helicopter available. The vessel was equipped with a large crane for skimmer operations toward the starboard side of the vessel. The vessel has two bow and two Azipod stern thrusters, which proved very helpful in keeping the vessel in position and in avoiding disturbances from drifting ice floes. The vessel was able to maintain an area clear of ice to help establish and sustain testing.

Figure 3.5 K/V "Svalbard", the main vessel used during the field experiment.

3.3 Testing set up

The testing arrangements were based on the experience gained from the field trial in 2008 (Singsaas et al., 2008[C]). In order to have maximum control over the emulsion released for testing, a boom was used for the experiments approximately 50 m in length, resulting in a theoretical diameter of 15 m when deployed in a circle. This area together the thickness proposed for testing conformed with regulations in the release permit specifying the amounts of oil allowed for use. Figure 3.6 shows the circular shape of the boom. It was positioned alongside the starboard side of K/V "Svalbard". An objective was to keep the ice concentration inside the boom between 30% and 70%. The experiments were conducted in relatively open areas within the ice field where ice was collected by using two working boats and 25 m of additional boom. The vessel had to use the thrusters occasionally to keep it in the appropriate position. At no time did the currents created by the thrusters significantly disturb the experiments and at no time did the ice in the boom escape.

Figure 3.6 Test set-up using a boom of 50 m and an air filled ring to keep the boom in position alongside the starboard side of KV Svalbard. May 16, 2009.

3.4 Testing scenario

Ice regime: The target ice cover was 30 – 50% with broken ice pieces and floes. In the first experiment some ice was lost due to repositioning of the vessel but this was compensated for by further narrowing the boomed-off area during the testing. In subsequent experiments, the ice concentration initially was somewhat higher than 50%. Ice was collected by using the working boats towing a 25 m boom (Figure 3.7).

Figure 3.7 Collecting ice in a 25 m boom at the same time as 50 m of boom is installed alongside the vessel. May 14, 2009.

The diameter of the ice floes collected varied from approximately 0,5 to 2 m in diameter. Little slush ice was collected. The ice thickness was estimated to be approximately 15 cm. Collecting the ice proved to be rather time consuming especially to avoid too much slush ice in the boom. The MOB boats had to pick one and one ice floe rather than moving through the ice field to pick up all ice floes in their way and at the same time also collecting slush ice in between the ice floes.

<u>Weather conditions:</u> The sea water temperature was measured to be approximately -1°C. The air temperature varied between -1°C and -4°C. The wind speed varied between 4 and 10 m/s. Because the experiments were performed in sheltered water within the ice field, there was no significant wave activity. The weather was mostly overcast and low cloud base but with some sunny weather in between. There was not much precipitation during the experiments.

<u>Oil/emulsion:</u> The same emulsion was used in these experiments as was used during the ice basin testing in 2007, the field experiment in 2008 and the ice basin testing in 2008 and 2009. This was an emulsion of an IF-30 bunker fuel with approximately 50% water and a viscosity of 5 – 7,000 cP at 0°C. The IF-30 bunker fuel (5 m^3) was shipped directly from the Slagen refinery to Tromsø. The emulsion was prepared alongside the quay in Tromsø pumping in sea water directly from the sea (figure 3.8).

Figure 3.7 Preparation of approximately 8-9 m^3 of emulsion along the quay in Tromsø and measurement of water content and viscosity. May 7, 2009.

3.5 Auxiliary equipment

- Boom:
  Norlense supplied 3 x 25 m sections of a 350 Boom with floating elements. This proved to be of sufficient size given the prevailing sea conditions. To keep the boom in an optimal circular position, an air-filled chamber was deployed adjacent to the Norlense Boom.
  Norlense supplied the air ring which was inflated and positioned outside of the 50 m boom that formed the contained test area in order to maintain its circular configuration
- Hoses for hydraulic operations:
  Ro-Clean Desmi and Framo brought hydraulic supply hoses and discharge hoses that were used during the experiments. The hydraulic hoses were mounted on hose reels.
- Pumps:
  SINTEF supplied pumps for re-mixing of emulsion and transferring emulsion to the sea and between tanks. The skimmers incorporated their own offloading pumps.
- Other equipment:
  - Sorbent booms and pads as well as bark were used to recover oil remaining on the sea surface and to take up oil contamination on ice floes and on the vessel's deck.
  - A number of tarpaulins were purchased prior to the field trial. These were used to protect the vessel side and the deck from oil contamination and for other purposes when required.
  - High pressure flushing was used to clean the vessel side and the skimmers and booms after the testing.

3.6 Documentation and laboratory analyses

The documentation recorded for the experiments was a combination of physical-chemical analyses, visual observations, and photos and videos.

The following aspects of testing were examined in detail:

Parameter	Measurement/registration
Flow of oil to the skimmer - access	Visual, photo, video
Deflection of oil/ice	Visual, photo, video
Increased oil viscosity	Sampling. Bohlin rotational viscosimeter. Measured at shear rate 10 s^{-1} and 0ºC.
Recovery effectiveness	Recovery per unit time. Measured tank levels after each test to calculate the volume of recovered liquid (emulsion and free water).
Free water recovered	After a short settling period free water was drained off. Measurement of tank levels before and after drainage.
Water in emulsion before and after recovery	Use of emulsion breaker (Alcopol) and heating to separate oil from water.

The following measurements/analyses were performed:

- At sea:
  - Sea water temperature (digital thermometer)
  - Air temperature (used KV Svalbard's measurements)
  - Water temperature (used KV Svalbard's measurements)
  - Temperature in the emulsion (digital thermometer)
  - Wind speed and direction (used KV Svalbard's measurements)
  - Emulsion layer thickness in test area (SINTEF oil thickness measurement device)
- Onboard research vessel (in ship's laboratory or SINTEF laboratory container):

- Prior to testing/pumping emulsion to sea:
    - Viscosity (Bohlin viscosimeter)
    - Water content in emulsion (emulsion breaker, heating and settling)
    - Measuring tank volume before and after pumping to sea (tank levels).
- During and after recovery:
    - Measuring tank volume before and after recovery (tank levels)
    - Measure free water recovered (settling in tank – tank levels)
    - Viscosity (Bohlin viscosimeter)
    - Water content in emulsion (emulsion breaker, heating and settling)

4 Time log

Date	Activity	Comments
7th May	Emulsion preparation	• Started to prepare emulsion just after arrival Tromsø.
8th May	Emulsion preparation commenced	• Further pumping gave good emulsion • Emulsion preparation finalised at approx 14.00. • Information meeting and initial SJA at 16.00 – 19.00 at Driv in Tromsø.
9th May	Loading and mobilisation KV Svalbard	• Loading finalised at 14.00 • People arrived KV Svalbard at 14.00. Safety instructions and drills. • Vessel left Breivika at 16.00.
10th May	Transit to site	• Increased rolling in the morning – not possible to do any preparations on deck.
11th May	Transit to site	• Emergency call Russian trawler south of Bjørnøya at 05.00 in the morning. • KV Svalbard was on site approximately 14.00-16.00 in the afternoon.
12th May	Transit to site	• KV Svalbard was replaced by KV Harstad at 03.00-04.00 in the morning and continued towards the test site. • Debrief after Russian trawler and general briefing about the activities onboard: o One person will concentrate on safety on deck. o During helicopter operations we will not be allowed to move on deck and loose items must be secured.
13th May	Arrival site	• Entered the ice field at 05.15 in the morning. • Meeting with ship's officers on the work plan for the day and SJA. • Transferred two crude oil tanks from Nordsyssel. • Fog – impossible to take off with the helicopter from the morning. • Started to unload the container and install the analytical equipment in the laboratory. Took samples and levels from all tanks. • Functionality testing of the two skimmers among ice floes, no oil or boom on the water. • Helicopter to Lance.

Date	Activity	Comments

14th May	1st day in the ice	• Weather conditions (07.30):
		  o Clear sky but fog on its way in.
		  o Temp.: -2,7°C
		  o Wind: 5,3 knots.
		• Meeting with work plan for the day and SJA.
		• Moved to an open area and started to collect ice and launch the boom along the vessel side. A large number of sea birds were seen in that area the day before and we were requested to move to another area.
		• Lance managed to get the helicopter in the air and we were recommended another area.
		• Collection of ice. Much small ice pieces and slush together with some large ice floes/pieces.
		• Installation of cargo hose.
		• 13.25-13.55 Running of Lynx helicopter on deck.
		• 14.00-16.30 Installation of boom and preparation for testing.
		• 17.55-20.00 Pumping of emulsion to the boom and testing of Framo skimmer inside boom.
		• 20.00-21.00 Flushing and removal of skimmer from the boom
		• 21.00-21.50 Helicopter testing on deck.
		• 21.50-02.00 Cleaning. Challenging due to small ice pieces and slush ice in the boom.

15th May	2nd day in the ice	• No testing this day. • Summarising the testing of the Framo skimmer. • 18.00 Meeting all participants to discuss the testing of the Framo skimmer and experience with the testing arrangements.
16th May	3rd day in the ice	• Meeting with ship's officers on the work plan for the day and SJA. • Testing of Ro-Clean Desmi skimmer • Started ice collection at 08.00. Collected single ice floes – more time consuming than expected. • 12.45-14.35 Pumping of 4.170 litres of emulsion into the boom area. Ice coverage estimated to be approximately 30 %, without the skimmer included. • 15.00-17.30 Totally five different tests with the Polar Bear skimmer in different ice coverage and oil thickness. • 18.30-21.00 Cleaning.
17th May	4th day in the ice	• Evaluation of results from the day before. • Observers over to Lance to watch dispersant test.

Date	Activity	Comments
18th May	5th day in the ice	• Meeting with the ship's officers on the work plan for the day and SJA. • Intention to do the first ISB test, but too bad weather in the morning. • Initiated a final short test of the Framo skimmer in ice only, no oil. • 14.00 Incident. The hoses to the Framo skimmer were caught in starboard thruster. • 14.35 Debrief after the incident. • Divers down to try to release the hoses from the thruster.
19th May	6th day in the ice	• Meeting with work plan for the day and SJA. • Divers continued to remove hoses from the thruster. • Further evaluation of results and planning for the ISB testing.
20th May	7th day in the ice	• Meeting with work plan for the day and SJA. • Preparations for first ISB test. Too high winds in the morning, but decreased rapidly in the afternoon. • 14.00-15.00 Successful test with 3M Fire Boom. • Recovery of burn residue, cleaning and recovery of boom. • Boom recovered at 22.00
21st May	8th day in the ice	• Professional film crew over to KV Svalbard. • Meeting with work plan for the day and SJA. • Preparations for second ISB test. • 10.00 Started to launch boom to sea. • 14.53-17.18 Successful test with AFTI Fire Boom. • Recovery of burn residue, cleaning and recovery of boom. • Started transit to Tromsø port late afternoon.
22nd May	Transit to port	• Debrief and summing up of the whole field trial • Cleaning and packing of laboratory and other equipment
23rd May	Transit to port	• Arrived Hammerfest in the morning for the helicopter to fly back to Oslo. • Arrived Tromsø around 20.00 in the evening • Unloading the next day.

5 Evaluation of results

5.1 Testing of the Polar Bear Skimmer

The Polar Bear skimmer was tested in the SINTEF ice basin in September 2008 (Leirvik *et. al.*, 2009). The key data from the basin testing are presented in table 5.1 as a background for discussions of the field data (May 2009).

Table 5.1 Results from basin testing of the Polar Bear skimmer in September 2008 (Leirvik et. al., 2009).

Test no	Ice coverage (%)	Drum speed (rpm)	Oil thickness (cm)	Duration (min: sec)	Total (litres)	Recovery rate (m^3/hr)	Free water (vol%)	Recovery rate emulsion (m^3/hr)
1	0	30	14.5	2:52	1230	26	15.5	22
2	0	15	5	1:34	834	32	15.5	27
3	0	5	4-5	12:39	604	2.9	57	1,2
4	30% broken	8	10/3.5	12:43	910	4.3	28	3.1
5	30% broken	3	10	35:30	766	1.3	N/D	1.3
6	30% broken	10	8	10:00	433	2.7	N/D	2.7
7	30% broken	10	12	10:00	1090	6.5	N/D	6.5
8	30% broken	10	7	10:00	616	3.7	N/D	3.7
9	30% broken	15	7-8	10:00	876	5.3	23	4.1
10	30% broken	15	7-8	10:00	936	5.6	37	3.5
11	30% broken	10	7-8	10:00	554	3.3	N/Q	3.3
12	100% slush	10	7-8	10:00	361	2.2	N/Q	2.2
13	100% slush	20	2-7	8:00	333	2.5	69	0.8
14	100% slush	5	2/4/9/12.5	10:00	401	2.4	31	1.7

N/D – not visually detected
N/Q- visually detected, but not quantified

Measurements taken and observations made during testing of the Polar Bear skimmer in the field trial (May 2009) are presented in Appendix A. Figure 5.1 shows testing of the Polar Bear skimmer during the field trial. Table 5.2 presents the key recovery data from the field testing.

Figure 5.1 Testing of the Polar Bear skimmer during the experimental field trial in May 2009.

Table 5.2 Results from field testing of the Polar Bear skimmer. May 16, 2009.

Test no	Ice cover (%)	Drum speed (rpm)	Oil thickness (cm)	Duration (min: sec)	Total * (litres)	Recovery rate (m^3/hr)	Free water (vol%)	Recovery rate emulsion (m^3/hr)
1	30	6	4	7:00	2660	22.8	53	11.6
2	30	6	2-3	14:00	1425	6.1	35	4
3	30	6	2	11:00	630	3.4	0	3.4
4	70	5	2-3	10:00	170	1	0	1
5	50	5	2-3	18:00	415	1.4	0	1.4

** Recovered liquid: emulsion and free water (when recovered).*

Figure 5.2 shows the measured volume of emulsion and free water recovered during the field trial in relation to increasing ice cover of approximately 30 to 70%. Oil slick thickness generally ranged from 2 to 4 cm. The data clearly indicate that recovery improves in lower ice cover (30% versus 70%) and in thicker slicks (4 cm versus 2-3 cm). The higher water uptake (test 1 and 2) in the low ice cover can be explained by the skimmer lying too low in the water when large amounts of oil were recovered by the brush drums and overwhelmed the skimmer's buoyancy. The result was water overflowing into the sump (and not being recovered by the brushes). The skimmer was then adjusted so that the crane held it in a more effective vertical plane. Oil could then contact the rotating brush drums without flowing directly into the sump. Essentially no free water was then recovered in subsequent tests.

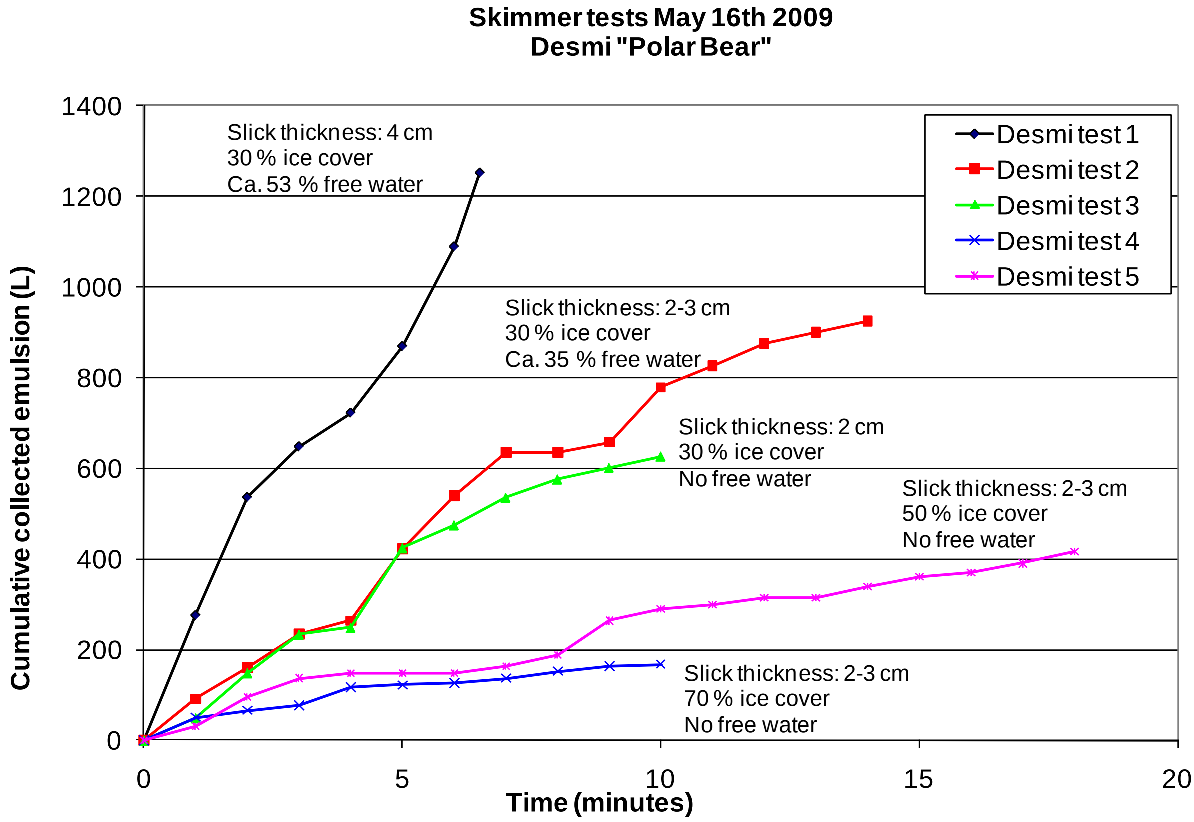


Figure 5.2 Measured volume of oil/free water recovered for Polar Bear skimmer as a function of time in 30%, 50% and 70% broken ice for slick thickness of 2-4 cm

5.1.1 Flow of emulsion to the skimmer

Access to the oil is one of the major challenges of mechanically recovering oil in ice-covered waters. The Polar Bear skimmer recovers oil that reaches the brush arrays quite effectively. Two of the brush drums on the prototype tested during the field trial had a diameter of 30 cm while the other four had a diameter of 40 cm. It was evident during the field testing that larger (40 cm) brush drums were positioned so as to minimise interference to oil flow due to the skimmer body. They reached further into the slicks and drew oil into the brushes more effectively than smaller (30 cm) brush drums (three of which existed for the purposes of comparison). Cohesive slicks, like the emulsion used in this testing, can be picked up by the brushes provided a moderate drum speed (5-10 rpm) is maintained.

The Polar Bear Skimmer used during the field work was a modified version of the hexagonal skimmer tested the previous September (2008) in the SINTEF ice basin. The reconstructed skimmer featured 4 larger brush drum arrays @ 40 cm and 2 brush drums with a diameter of 30 cm. The skimmer has built-in buoyancy but it was found that the ship's crane had to be used to maintain the vertical position of the skimmer in the water when the sump filled with oil and the skimmer floated so low that water overflowed into the sump. The crane was also effectively utilized to horizontally position the skimmer in the ice so that it contacted oil. This was necessary since the brush drums do not "process" or move ice pieces much larger than several centimetres. The skimmer actually works well in between ice pieces but had to be repositioned at regular intervals when the oil layer around and flow into the skimmer was reduced. The flow into the skimmer being reduced due to restrictions imposed by the ice in combination with oil uptake by the skimmer.

5.1.2 Ice processing

For the purposes of these tests, ice processing is defined as the skimmer's ability to deflect ice so that it has access to the oil. The Polar Bear skimmer can process relatively small ice pieces (several centimetres) to a certain degree in low ice cover (approximately 0-30%) due to the action of the rotating brush drums. With increasing ice cover, however, any ice processing capability visibly decreases. This is due to ice being unable either to be moved by the brush drums, except for small ice pieces, or to pass under the skimmer even though the drum direction of rotation is down into the water. The brushes are appropriate for the efficient collection of oil that flows at ambient temperatures. The skimmer has to be repositioned in an ice field on an ongoing basis regardless of ice concentration, in order to gain access to oil that is available in areas where there is little or no ice.

5.1.3 Separation of oil, water and ice

Uptake of free water by the Polar Bear skimmer is dependent on its vertical position in the water and the position of the sump lip so that it remains above the sea surface. Brush speed also influences water uptake. There was uptake of free water only in test number 1 when the vertical position of the Polar Bear was not maintained by the ship's crane. Otherwise, essentially no free water was recovered by the skimmer once proper vertically positioning adjustments were made and the brush drum speed was maintained at 5 or 6 rpm. During the field experiment, the submergence depth of the brushes in the water was estimated to be approximately 5 cm. This was deemed to be optimal for the most efficient operation of the skimmer.

Testing revealed that there was no discernible increase in the uptake of free water as it related to ice cover (Table 5.1). This is likely due to no change in skimmer operation as it is positioned in oil among ice pieces and therefore essentially functions in the same way regardless of the overall ice concentration. At the optimal vertical position and drum speed, the Polar Bear skimmer features brush arrays that seem to discriminate well between oil and water.

Because of the construction of the skimmer, it can not take up ice pieces, but slush ice can enter the sump. The skimmer is equipped with a powerful screw auger pump which is able to transfer some slush ice back to the receiving tank. Some uptake of ice was noted during these experiments.

5.1.4 Icing / freezing of equipment

The Polar Bear skimmer is of durable construction for application to ice infestations but does not incorporate other features, such as heated surfaces or a cover, specific for cold conditions. During the field experiment, the temperatures were moderate (-1 to -2^{o}C) and moderate winds (4 to 7 m/s). The skimmer was not exposed to extreme winter weather conditions. As long as the skimmer is in the water, the pump will not freeze. However in cold conditions, the upper parts of the brushes are exposed to wind and low temperatures. Also the content in the discharge hose could freeze if it contains emulsion and/or free water and is left for some time, for example, in between uses. The skimmer needs, therefore, to be modified before it is used under very cold conditions in the Arctic. An option could be to house the upper part of the brushes in a shield and to supply heat.

5.1.5 Other equipment aspects

The DOP pump used on the Polar Bear pumped intermittently and functioned well as did the skimmer's brushes. The latter are designed to recover flowing oils and were scraped very effectively by the robustly designed scraper mechanism. The bristle type is more appropriate for oil collection than for ice deflection. It would, therefore, be unrealistic to expect anything more than relatively small ice pieces or slush to be deflected or influenced by the brushes.

A relatively large hydraulically-operated reel was used to store the discharge and hydraulic lines. Manual spooling of the lines was required when these were retrieved. The hoses are quite bulky and so this retrieval procedure requires some review and planning so that it can be safely and effectively conducted by an appropriate number of personnel from a conveniently located position on deck.

The buoyancy chambers of the skimmer should allow positioning of the skimmer so that the sump lip remains above the water. The skimmer was designed as a free-floating unit that can be positioned among ice pieces and floes where it can be operated without further vertical adjustment. Further refinement of buoyancy is required.

5.1.6 Conclusions and recommendations

The results from testing of the Polar Bear Skimmer both in the ice basin and in the field indicate that it can be effective in collecting flowing oil when positioned in oil of varying slick thickness (several mm to several cm) among ice pieces. Cohesive oil slicks can be effectively drawn into the brushes provided that the drum speed is not too high (5 – 6 rpm in these tests) and the sump lip remains above the sea surface. The skimmer works best in low concentrations of small ice pieces and slush ice (< 50 - 70 %) and might also have the potential for application alongside larger ice floes.

The Polar Bear is a medium size skimmer that should recover 10 to 20 m^3/hr in low ice concentrations or when otherwise exposed to oil on an ongoing basis. The principle of this skimmer, with rotating brush drums, works quite well in small ice forms and in the open water between larger floes. Positioning and repositioning of the skimmer in slicks is required since ice is not actually moved aside by the brush drums nor does the skimmer have thrusters. Improvement to buoyancy will further increase the capability of this skimmer.

The manufacturer of the Polar Bear skimmer designed the skimmer with a hexagonal shape (6 brushes) rather than the helical form of the previously tested Helix Skimmer Adapter. Of the two brush sizes of 30 cm (2 brushes) and approximately 40 cm (4 brushes) tried during field testing, the larger brush arrays offer significant advantages, namely in terms of access to the oil, small ice piece processing, and capacity. The larger brush drums are located better strategically on the skimmer body so as to minimise interference with it. Furthermore, the straight-line brush arrays should have lower maintenance issues than the circular configuration of the Helix. The modified Polar Bear did not contain "winterisation" but did feature an umbilical for hoses that is attached to the top of the skimming unit and allowed improved deployment. (The smaller Helix Skimming Adapter remains a versatile device for smaller oil spills in ice-covered waters.)

It was interesting to note that the Polar Bear Skimmer was used to remove oil from the test area following its evaluation and was able to do so to the point where extremely thin multi-coloured sheen remained. The brushes are able to recover slicks that vary considerably in thickness.

The Polar Bear Skimmer can be a versatile device for oil spills in ice-covered waters. Based on this testing, the following recommendations have been made:

- Operation of the skimmer would benefit from improved buoyancy of the skimmer. The flotation should allow optimum positioning of the brush drums relative to the sea surface so that water does not overflow into the sump. This feature would allow the skimmer to be operated more independently of a crane for vertical positioning.
- The discharge hose and the hydraulic hoses are connected to the pump above the water. An improved means of supporting the bundle could further increase the versatility with which the skimmer can be deployed, repositioned, and operated.

- The 40 cm brush drums were determined to provide a significant improvement to skimming capability in ice over the smaller brush drums. Future evaluation programs should focus on verifying that this size is optimum for oil collection relative to the required buoyancy and skimming capacity.
- Given the necessity for a skimmer to chase oil between ice floes, the skimmer should be fitted with thrusters to provide manoeuvrability without having to rely on a ship's crane.
- The Polar Bear is ruggedly constructed and should be able to withstand ice pressure to some extent. However, it is recommended that the Polar Bear skimmer be used under ice conditions where large pressure between ice floes is more unlikely to occur and where the skimmer is repositioned by a crane if it should happen. Damage to the skimmer is expected to be minimal when it is used in between ice floes.
- Even if it has shields on top, the tested version of the Polar Bear Skimmer has no heat enhancement that might facilitate oil collection and transfer in harsh winter climates. If the skimmer is going to be used under harsh conditions with low temperatures and/or strong winds, further "winterisation" should be considered.

5.2 Basin testing of the Framo brush drum cassette

19. and 20. January 2009 the Framo brush drum cassette was tested in the SINTEF ice basin. This testing was intended to be a first testing of a concept prior to building a prototype oil-in-ice skimmer for testing during the experimental field trial in the Barents Sea in May 2009. The cassette was tested in an area of 4 x 4 metres in the ice basin (figure 5.3). The same emulsion as in previous testing was used, a 50 % emulsion of an IF-30 bunker oil. It had an initial viscosity of 13400 mPas @ 0°C (shear rate = $10s^{-1}$). The ice thickness during the testing was approximately 15 cm. Air temperature was -8ºC, oil temperature 1ºC and the water temperature 0ºC. in total four tests were performed, three without ice and one with ice present in the test area. Raw data from the individual tests are shown in Appendix C.

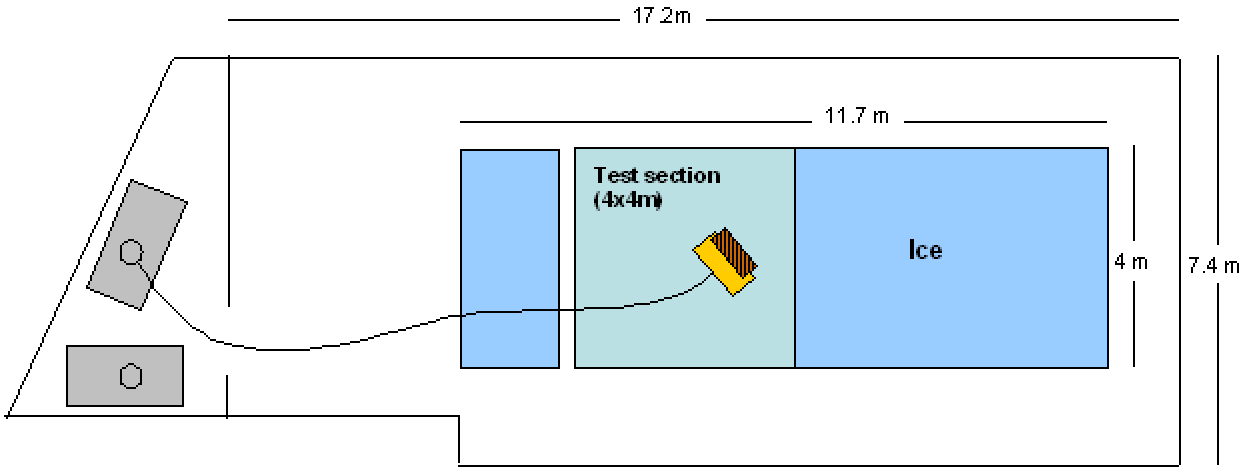


Figure 5.3 Testing arrangements in the SINTEF ice basin for testing of the Framo brush drum cassette. January 2009.

Figure 5.4 shows a sketch of the Framo brush drum cassette and figure 5.5 shows a picture from the basin testing in January 2009.

The testing gave a lot of valuable information to Framo as a basis for further development of a prototype. The following observations were made during the testing (19th and 20th January 2009):

1. The skimmer recovered much free water and discriminated poorly between emulsion and water. It is important that skimmers for use in ice-covered waters can also handle low oil thicknesses, which can be encountered under such conditions. It was suspected that the

water was captured mechanically by the stiff brushes coated with sticky emulsion and poured over the edge to the pump.

2. In a thicker oil layer and with the cassette in a right position the free water uptake was considerably reduced. However, with ice present the free water uptake increased again.
3. The total pumping rate varied from 2,3 – 5 m^3/hr., which is in line with other skimmers tested as part of this project.
4. The scraping mechanism did not work as intended as some of the emulsion was not scraped off but followed the brush drum all the way around.
5. The brush fibres were thicker and stiffer compared to other skimmers that have been tested in the ice basin as part of this project.
6. A grid was mounted over the entrance to the pump and slush ice collected here which plugged the pumping of emulsion.
7. Technically the cassette worked as intended with smooth adjustments of the rotational speed of the drum, running of thrusters and operations by the crane.

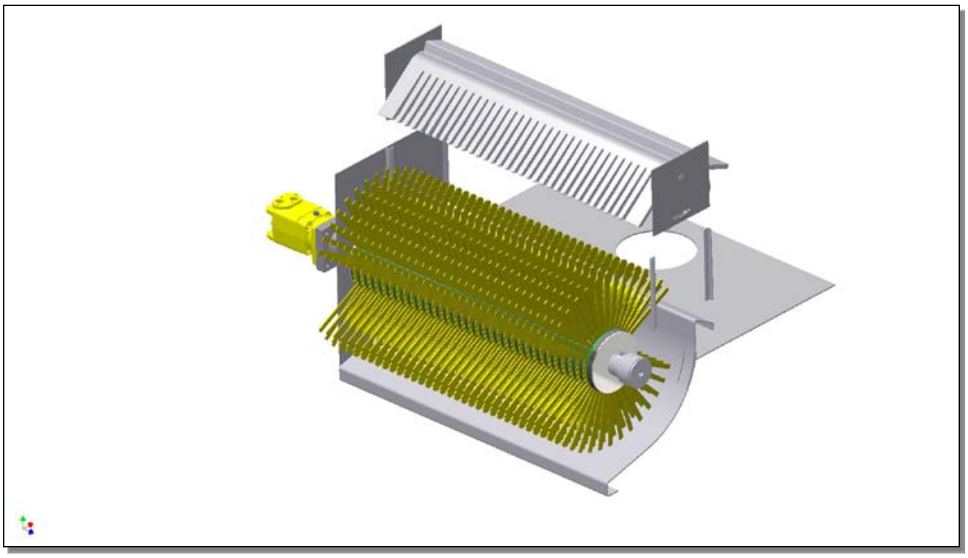


Figure 5.4 Sketch of the Framo brush drum cassette used during the SINTEF ice basin testing.

Figure 5.5 Picture from the ice basin testing of the Framo brush drum cassette. January 2009.

Based on this testing the following modifications were discussed:

- Further evaluation of the brush / bristle type. This includes thickness and stiffness.
- Construct a new scraping board that more effectively will remove oil from the brushes.
- Look into how to increase the oil recovery and decrease the uptake of free water. Two actions were discussed:
    - Increase the height of the threshold between the brush drum and the pump house so the water can be more easily drained off.
    - Increase the distance between the brushes and the surrounding cassette body so that water is not easily trapped by the brushes.
- Remove the grid in front of the pump to avoid blocking by slush ice. It is expected that the pump, which is a powerful screw pump, can pump slush ice and small ice pieces to the receiving tank.

Framo performed a test with a modified version of the cassette in their factory 27th February 2009. The cassette was tested in a small basin with oil and ice present. This was a successful test of the ice removal screw in combination with the brush cassette with ice discs (see 3.1 for description). After that testing a first prototype was built on the frame of Framo Super HiWax skimmer (figure 5.6). This prototype was then tested during the experimental field trial in May 2009 (FEX09).

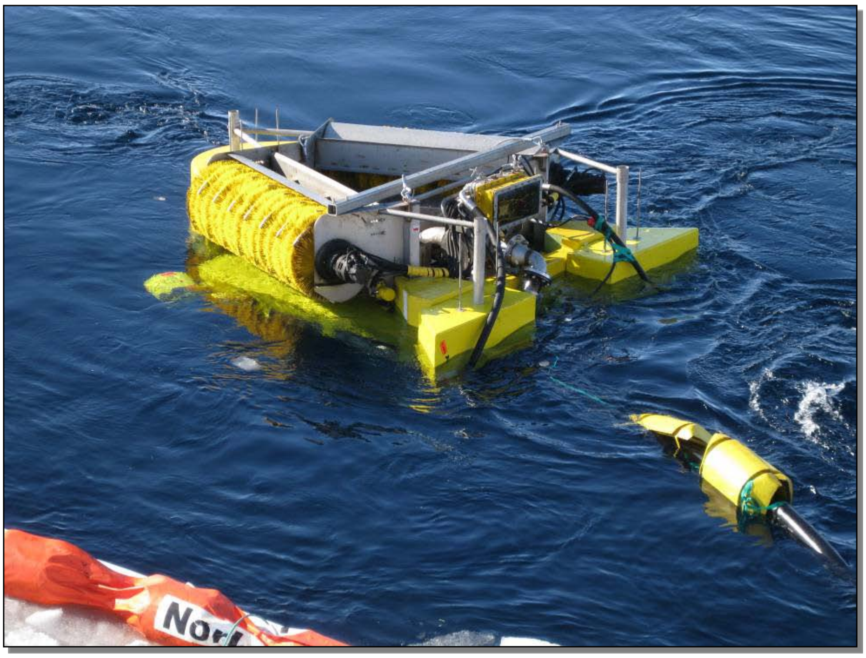


Figure 5.6 The Framo skimmer prototype on water during FEX09. May 14, 2009.

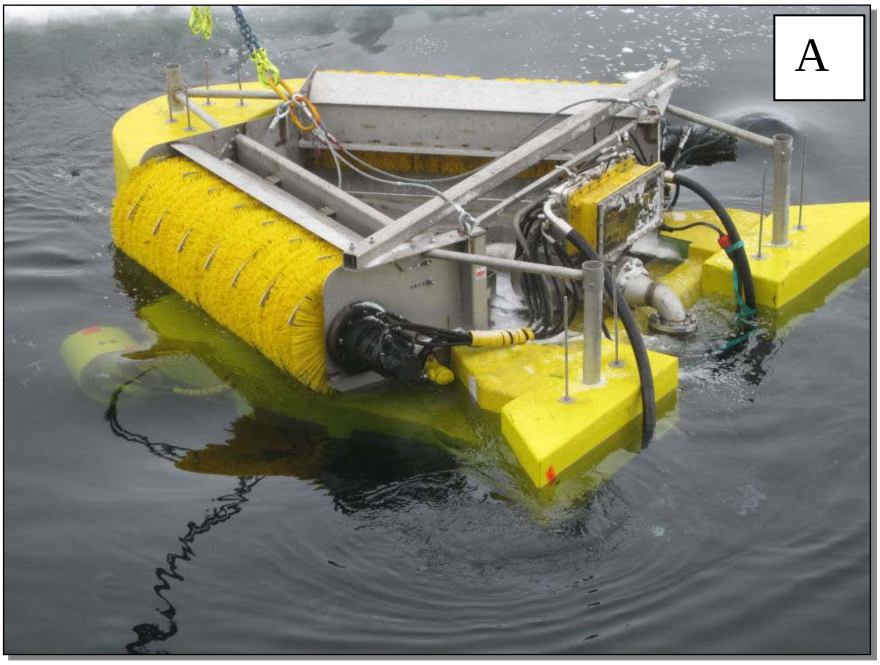
5.3 Testing of the Framo skimmer prototype during FEX09 (May 13 and 14, 2009)

The Framo skimmer was initially tested in different ice conditions without oil present. This testing was performed both inside the boom and without use of the boom. The main objective was to study the ice processing capability of the skimmer and the manoeuvrability by use of the thrusters. Only one test with oil present was performed. Some problems were experienced with pumping of oil to the boom and the bristles on the brush drums were damaged by the scraping board during previous testing without oil.

Observations made and the limited measurements taken from testing of the Framo skimmer are presented in Appendix B. Figure 5.7 shows testing of the Framo skimmer during the field trial, in open water outside the boom and in the boom with ice and emulsion present. During the test with emulsion present the following observations and measurements were made:

- Ice cover: 50 % with slush ice in between ice floes of different size (typically < 1 m in diameter).
- Emulsion thickness: approximately 4 cm.
- Skimming time: 30 min.
- Volume recovered liquid (emulsion + free water): 1774 litres.
- Volume recovered emulsion: 545 litres

This gave a total recovery of approximately 3,5 m^3/hr and emulsion recovery of approximately 1,1 m^3/hr. The uptake of free water was fairly high, up to approximately 69 %. It must be underlined that the testing conditions in this test were not optimal for testing of oil recovery, both with respect to the ice conditions (too much slush) and little emulsion (around 1000 litres).



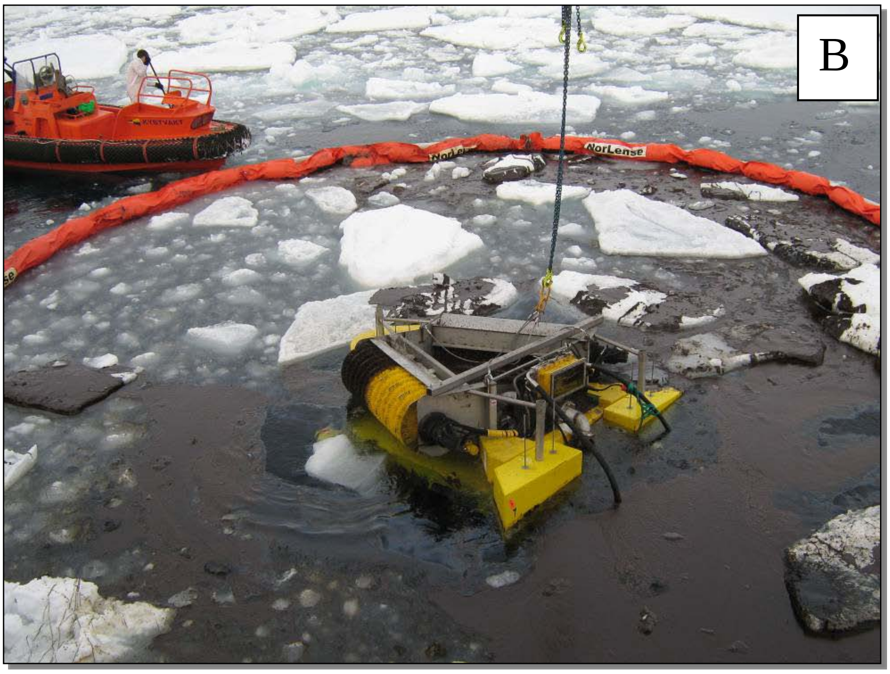


Figure 5.7 Testing of the Framo Skimmer during the experimental field trial in May 2009. A: in water outside the boom and B: in the boom with oil present.

5.3.1 Flow of emulsion to the skimmer

The Framo Skimmer is triangular in shape and features two brush drums on each side angled toward a bow flotation chamber. Because the skimmer is shaped like a vessel and is self-propelled, the strategy of applying the skimmer is to manoeuvre it in between ice floes where oil has accumulated. Field testing did confirm the excellent manoeuvrability of the skimmer.

The field trials did not reveal whether or not the angled brush drums can gain full access to slicks when the skimmer is advancing. However, it was clear that when a single brush drum did make contact with slicks then oil collection took place. The action of the brush drums rotating downward and the augers under the brush drums moving small ice pieces would contribute to oil flowing into the brushes. Problems with the bristle type and the scrapers precluded comprehensive testing to verify oil recovery.

The position of the Framo Skimmer in the water so that the brush drums make contact with the oil at an appropriate submergence depth is critical to effective operation. Again, further work is necessary to ensure that the buoyancy chambers/brush drums on the Framo Skimmer are adjusted so that optimum operation results. Instability was seen as the brush drums at times sat an angle to the horizontal. The heavy umbilical bundle of hydraulic and discharge hoses likely contributed to this situation. Both the buoyancy and umbilical issues could be readily resolved.

The Framo Skimmer presented for field testing did not undergo rigorous pre-test evaluation nor verification. It was concluded, however, based on the limited testing that was possible, that the Framo Skimmer represents mobile response technology that should prove very useful for the recovery of oil spills in an ice field when operated from a mother vessel. Due to the flow created under the drum brush by the brush and ice removal screw under the brush drum, the skimmer exhibited good small ice processing capabilities with low uptake of free water when operated at the intended draft. Testing was limited due to problems with the scrapers and brushes. Adjustment of the flotation and submergence depth of the brush drums were also seen to require improvement as well as a more effective means of deploying the umbilical bundle housing the hydraulic and discharge lines. One transfer pump would likely suffice rather than the two Moyno progressive cavity pumps that were installed on the device presented for testing.

5.3.2 Ice processing

The Framo Skimmer exhibited good small ice processing capabilities during testing when operated at the intended brush drum draft. The downward rotating brush drums create some flow underneath them which does move small ice pieces. These small ice pieces are then conveyed towards one end of the skimmer by augers rotating underneath the brush drums. The movement of ice pieces more than several centimetres (i.e., 5 to 10 cm) was not readily apparent. The very stiff bristles likely contributed to the ability of the skimmer to deflect the small ice pieces.

One of the most significant findings of the field work was the determination that a skimmer with thrusters, when sufficiently large and powered, can manoeuvre in between floes to gain access to spilled oil. Previous testing had focused on using a crane to deploy skimmers into oil and ice. When a crane is used, the positioning of a skimmer is highly dependent on the ability of the mother ship to maintain station. This can be a difficult task in high winds, currents, and moving ice. Although the Framo test program was relatively short, the concept of deploying a self-propelled skimmer into ice was substantiated during the 2009 field trials when the Framo skimmer was able to navigate through ice floes up to several metres in size.

5.3.3 Separation of oil, water and ice

The Framo skimmer was never tested in its optimum operating position in the water. Brush drums were angled horizontally and the sump flooded at times with the result that water uptake was relatively high. The heavy umbilical bundle also contributed to the compromised positioning of the skimmer in the water. When the skimmer incorporates brush drum technology and flotation, including adjustments, which result in more stable submergence depths of approximately 5 cm, it is expected that the brushes will be able to recover a flowing emulsion with low water uptake.

5.3.4 Icing / freezing of equipment.

The Framo skimmer was not subjected to extreme weather conditions during this testing. Air temperatures were moderate during the field trial (-1 to -2^{o}C), and heating options were not investigated during this testing. The skimmer was designed with a cover that would contribute to minimal influence from splashing and freezing of components, but would prevent any visual observations of the operation of brush drums in oil. Heated components could be investigated that would contribute to improved performance in harsher winter conditions.

5.3.5 Other equipment aspects

The flotation on the Framo skimmer required very involved mechanical adjustment. Hydraulic or other means should be used to allow quicker changes when the skimmer is being operated. These might relate to either the relative position of the flotation or more directly to optimizing the draft of the brush drums (the primary objective of such adjustments).

The Framo skimmer relies on a computer program to control various functions including brush speed and pumping. This electronic approach is overly sophisticated for a skimmer that relies on basic mechanical principles. A simplified approach for thruster controls should be possible.

One pump did not function. The Moyno progressive cavity pump that did work was able to move oil, slush, small ice pieces and water very effectively. One pump should be sufficient for skimming operations in ice if a 2-drum brush system is utilized.

The hydraulic accumulator on the power pack was stuck and had to be dislodged in order to start the engine when left for some time at temperatures of -8^{o}C.

5.3.6 Conclusions and recommendations

It was concluded that a skimmer with thrusters that utilizes brush drum technology would be a highly useful mechanical recovery device for oil spills in ice infestations. The Framo Skimmer, as presented for testing, requires more development work on basic skimmer components to ensure that a fully functional machine is developed.

The Framo skimmer is expected to ultimately have the potential to effectively recover oil in ice concentrations up to 70%. The discharge hose and the hydraulic hoses interfered with the oil and the ice and it was difficult to hold the skimmer in an optimal position. In other Framo Transrec skimming systems, the hydraulic and discharge hoses are incorporated into a bundle that is part of a hydraulic arm complete with cab. The Framo ice skimmer could be viewed as another skimming component to be used in conjunction with the Transrec arm.

Due to the flow created under the brush drum and the rotating augers, the skimmer exhibited good small ice processing capabilities. The uptake of free water should be low once issues with buoyancy adjustment and/or brush drum positioning are resolved.

The bristles and scrapers of the Framo skimmer did not fully function but were damaged when operated leaving behind fragments of each. The bristle type did not appear to be suitable for picking up the test oil in the conditions encountered. Further work on these aspects is quite feasible and should result in full skimmer functionality.

The triangular vessel shape of the skimmer together with its thrusters was a successful combination and allowed the skimmer to move very well in ice. This approach appears to have merit in being able to access and remove oil from among ice floes and pieces. It was not possible to determine how the vessel-shaped bow affected oil collection but the skimmer can manoeuvre between floes. The skimmer actually moves aside floes several metres in size which would allow access to oil.

The discharge hose was neither hung from a crane nor had floats attached to it when further sea trials in ice were conducted of the Framo during the field work. The means to safely and effectively handle the attached hoses remains an issue that requires further investigation if the Transrec arm is not used with this skimmer.

Based on the testing performed during the field trial the following recommendations have been made:

- Further refinement to the skimming components is required. A softer bristle type should be used for improved oil recovery but at the same time maintaining the good ice processing capabilities. Also the scraper mechanism must be improved
- A new frame is recommended and one pump only is required to give sufficient pumping capacity when operating in ice. This should contribute to decreasing the weight of the skimmer.
- The skimmer should be made more stable. That would include modifications to the buoyancy. It is also recommended to construct a mechanism that makes it possible to adjust the depth of the brush drums in the oil/water. This could be a hydraulic lifting mechanism.
- Further “winterisation” will be required for operation under harsh Arctic conditions.

5.4 Lessons learned

One of the objectives of the 2009 field experiment was to gain experience in field work based on the current and previous year’s experiments. The following summarizes the lessons learned from the 2009 field experiment:

- K/V Svalbard is an excellent vessel for field work in ice-covered waters in view of its size, manoeuvrability, deck space, onboard facilities, and ice-breaking capability. The Svalbard’s crane was a significant improvement over the crane utilized during the previous year’s field trials. The skimmers tested are both dependent on a crane that can be operated so that skimmer discharge and hydraulic hoses are controlled and do not interfere with skimming. The crane also aids either directly (as was the case for the Polar Bear) or indirectly (with the self-propelled Framo) in positioning the skimmers within the ice.

  The mobile Framo skimmer required a crane for deployment and the manner in which its discharge hose can be handled so as not to impede manoeuvrability remains to be resolved. This aspect should be closely examined prior to future field work with any skimmer featuring thrusters. Apart from that, K/V Svalbard functioned well as a base of operations for these experiments and the crew onboard the vessel were very helpful contributing significantly to the successful outcome of the whole experiment.
- The K/V Svalbard was able to create open areas within collections of ice floes where the test area could be established and where the skimmers could be deployed. This was possible because of the ability of the crew to skilfully manoeuvre and position the vessel in wind, current, and ice. Ongoing adjustments were required in winds that at times reached 25 knots. It is possible that similar techniques could be used by a mother ship in an actual spill to allow placement of skimmers in accumulations of oil where the skimmers could be operated most effectively.

- An inflatable ring was deployed outside of the boom that held ice pieces and into which oil was released to test the skimmers. The ring was very effective in maintaining the circular configuration of the boom so that evaluations could proceed without interruptions due to the boom collapsing in on itself and changing the effective ice concentration within the containment area.
- Ice collecting using booms was sometimes a lengthy process. When using the same technique of collecting ice in the future, boats equipped with tow post or bollard should be sent to areas to corral ice where a range of smaller ice pieces have accumulated The small floes more useful for testing can then be kept and other ice pieces discarded. The MOBs were useful for this purpose. Paravanes or bridles attached to connectors would improve and speed up towing collected ice.
- Skimmers designated for field testing in remote locations should be thoroughly checked in local field circumstances to ensure that they are fully functional prior to shipment. The operation of primary components requires review including such items as brushes, scrapers, buoyancy, transfer pump, umbilical lines, hydraulic and other fittings, power packs, gauges, and controls.
- The means to make adjustments to the submergence depth of a skimmer's pickup mechanism should be possible using hydraulic or other means so that changes can be quickly made when the skimmer is deployed and as conditions change. Otherwise, manual adjustments can be a lengthy process since the skimmer must be taken out of the water to reposition buoyancy and/or proper brush positioning.
- Floating rope and hoses should be used for towing and other purposes (skimmer discharge and hydraulics) to avoid these items from getting caught in the jet drives or propellers of the working boats or main vessel used. In other circumstances, a crane should be used to hold discharge and hydraulic hoses to avoid similar problems.
- An ASTM connector was used on the Norlense 35F boom in place of the standard double set of loops and rope connector. The ASTM, Universeal, Navy or other slide or simple mechanism should be used for connecting section ends. This is especially important when the boom is deployed (in the water) and contaminated with oil.
- Umbilical bundles that house hydraulic, electric, discharge or other lines must be attached to the skimmer and supported so that (1) the lines do not interfere with the positioning, manoeuvring, or operation of the skimmer and (2) there is no chance of the bundle submerging and becoming entangled in the ship's propulsion system (main propellers or thrusters).
- Since collapsible, lay-flat hose used for discharge can clog with ice pieces and have to be flushed with water in order to restore capability, rigid hose should be considered for use, particularly when long hose lengths, low temperatures, emulsion, and a small gear pump are all part of the operations.
- The manner in which the large bundles of hydraulic and discharge hoses are stored on deck requires review to ensure that both deployment and retrieval can be readily and safely accomplished. Reels were used in the 2009 trials that required manual assistance in order for the bundles to be retrieved so that they spooled on the reel. Their placement on deck also required planning.
- Shorter lengths of discharge hose were required than originally planned so that oils could be pumped into test areas. Longer hose lengths presented friction loss problems for the pumps so that discharge of the oil was not always possible.

- Skimmers should incorporate relatively simple technologies unless high degree of reliability can be guaranteed for e.g. computer programming, oil level sensors, and video cameras. This is in order to avoid operations being shut down due to equipment failure that provides secondary function to oil collection.
- Representatives from the manufacturers were again highly competent and knowledgeable and so were capable of troubleshooting and making repairs and modifications that were required in the field. Representatives from Framo and Ro-Clean Desmi participated during the 2009 field trial and worked well together providing key input to the testing. Such expertise is mandatory in any remote field program.
- It is critical to plan and conduct pre-test runs of the entire skimming systems in two modes. The first should involve solely on-deck operations where controls, fittings, power pack, and skimming and transfer components are run to verify that they are fully functional. The second phase of pre-test checking should be conducted in the water with all sub-systems operating so that adjustments are made to the submergence depth of the skimming mechanism and/or buoyancy/flotation, the pump is known to work, and positioning requirements (crane, thrusters, etc.) are fully understood by operators.
- Briefing meetings were held to review the day's activities prior to their commencement. These "risk management sessions" are important in assigning and clarifying roles and in identifying health and safety issues as well as mitigating procedures and equipment, e.g., personal protection equipment (PPE). An additional, related aspect that became evident during the 2009 trials was that it is vital to briefly halt work and identify methods to reduce risks if circumstances or plans change once the day's activities have begun.

6 Conclusions

The main findings from testing of the Polar Bear and Framo skimmers are summarized in Table 6.1.

Table 6.1 Summary of findings from skimmer testing

	Polar Bear	Framo
Overall performance	Finishing, quality of brushes and scrapers, construction details were excellent. Brush drums pick up flowing oil well.	Further refinements are required to skimming components. Manoeuvring in ice was highly successful.
Buoyancy/Stability	Water can overflow into sump when oil is collected. Modifications to buoyancy will improve performance.	Modifications to buoyancy and/or adjustable depth of brush drums are required.
Crane operation	Depends on crane for positioning in ice. Crane onboard K/V Svalbard was not ideal but was an improvement over crane on Lance (2008).	Skimmer is self-propelled. Crane used to hold umbilical lines. When crane was not used, problems arose due to lines submerging.
Ice processing	Dependent on repositioning in oil and ice by crane. Does not process medium or large ice pieces.	Capable of processing small ice pieces that can be moved by the brush drums and augers.
Separation oil, water and ice	Low free water uptake when submergence depth of brush drums is optimized. Brush speed of 5-6 rpm was optimal as was submergence depth of brush drums of 5 cm.	Action of brush drums and augers has a potential for contributing to low free water uptake. Also depends on optimal submergence depth and speed of brush drums.
Oil recovery	Test results indicate that this skimmer can be effective in collecting adhesive oils in low concentrations of small ice and slush ice (< 50 – 70%) and along ice floes.	Improvements required to scrapers, brushes, and flotation to prevent damage and allow more stable position in water.

The Polar Bear skimmer needs some adjustments of the buoyancy and if it is going to be used under harsh Arctic conditions further “winterisation” should be evaluated. Apart from that the skimmer should be ready for commercialisation.

The Framo ice skimmer has shown very good manoeuvring capabilities in ice. It has also shown promising capabilities in oil recovery, but further modifications and improvement are required. It is an interesting concept as it is one of very few skimmers that can operate away from a “mother” vessel by use of thrusters combined with a potential for recovery of oil in ice. It has been agreed with Framo to continue the development of this skimmer over the next year (as part of a DEMO 2000 project). That includes taking into account the recommendations from the field experiment and also building a new lighter frame with one pump.

7 Acknowledgement

The crew on the K/V Svalbard were highly competent in operating the crane, the main vessel and the MOB work boats. The representatives from the manufacturers are also acknowledged: Erik Refsgaard from Ro-Clean Desmi, and Trond Krøgenes and Odd Andre Boge from Frank Mohn Flatoy, all of whom worked very well in preparing and performing the testing and subsequent cleanup.

8 References

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Appendix A: Polar Bear skimmer testing . May 16, 2009

Position (12.00): N 76.48
E 29.20

Test no.: PB 1

Parameter	Measurements / comments
Start time Stop time	15:10 15:17
Ambient conditions: Weather Air temperature Water temperature Wind speed / direction Wave height / period	 Clear with low overcast. No precipitation - 1.5^{o}C - 1.5^{o}C 5.5 m/s, SE 0 / 0
Boom: Type and configuration Damage	 50 m Norlense. Air ring maintains circular configuration. None.
Ice: Concentration Size Thickness Slush ice Distribution Other	 Approximately 30%. 1 to 2-3 m 20 – 30 cm No Distributed unevenly in test area More ice was originally planned for this experiment. Ice collection took several hours 
Oil/emulsion: Oil type Volume released Viscosity start Temperature start Viscosity recovered	 IF-30 bunker fuel emulsified with approximately 50% water 4170 litres 4200 cP at 0^{o}C (sample taken in the boom prior to the first test – PB1). 3 ^{o}C in thick oil; 1-2^{o}C in thinner oil 5600 cP at 0^{o}C (sample taken from discharge hose during recovery).

Thickness start	Approximately 4 cm not uniform
Thickness after recovery	Estimated to be approximately 2-3 cm
Water content start	42% (sample taken in the boom prior to the first test – PB1).
Water content recovered	51% (sample taken from discharge hose during recovery).
Skimmer:	
Drum speed	6 rpm
Submergence depth	Approximately 5-10 cm
Wave response influence	No waves, but vertical movement affects performance.
Slush collected	No
Ice is processed	Yes, skimmer depresses small ice pieces and scrapes the emulsion.
Oil flows to device	Yes, steady oil flow
Skimmer repositioned	No
Recovery time	7 minutes
Other	Water enters sump since skimmer is sitting too low in water. Larger drums draw more oil into skimmer than smaller drums.
Performance:	
Liquid collected	2660 litres
Free water	1410 litres
Emulsion recovered	1250 litres
Scraper	Worked satisfactorily
Is freezing a factor	No 
Pump:	
Transfer	OK
Comments	Intermittent when sump full. Large capacity pump
Power pack:	
Hydraulic pressure	200 bar. Used the highest output for the skimmer.
Operation	OK. No interruptions.

Test no.: PB 2

Parameter	Measurements / comments
Start time Stop time	15:40 15:54
Ambient conditions: Weather Air temperature Water temperature Wind speed / direction Wave height / period	 Clear with low overcast. No precipitation - 1.3^{o}C - 1.5^{o}C 6.5 m/s, W-SW 0 / 0
Boom: Type and configuration Damage	 50 m Norlense. Air ring maintains circular configuration. None
Ice: Concentration Size Thickness Slush ice Distribution Other	 Approximately 30% 1 to 2-3 m 20 – 30 cm No Distributed unevenly in test area More ice was originally planned for this experiment. Ice collection took several hours 
Oil/emulsion: Oil type Volume released Viscosity start Temperature start Viscosity recovered Thickness start Thickness after recovery Water content start Water content recovered	 IF-30 bunker fuel emulsified with approximately 50 % water 4170 litres originally – no oil added for this test 4200 cP at 0^{o}C (sample taken in the boom prior to the first test – PB1). 3 ^{o}C in thick oil; 1-2^{o}C in thinner oil 7000 cP at 0^{o}C (sample taken from discharge hose during recovery). Approximately 4 cm not uniform Estimated to be approximately 2-3 cm 42% (sample taken in the boom prior to the first test – PB1). 52% (sample taken from discharge hose during recovery).

Skimmer:	
Drum speed	Approximately 6 rpm
Submergence depth	No waves, but vertical movement affects performance.
Wave response	No
influence	No
Slush collected	Yes, small pieces only are moved, steady oil flow
Ice is processed	Yes
Oil flows to device	No
Skimmer repositioned	14 minutes
Recovery time	Water enters sump since skimmer is sitting too low in water.
Other	Larger drum draws more oil into skimmer than smaller drum. Skimmer lists slightly to one side. Crane is used to hold skimmer higher in water.
Performance:	
Liquid collected	1425 litres
Free water	495 litres
Emulsion recovered	930 litres
Scraper	Worked satisfactorily
Is freezing a factor	No
Pump:	
Transfer	OK
Comments	Intermittent when sump full. Large capacity pump
Power pack:	
Hydraulic pressure	200 bar. Used the highest output for the skimmer.
Operation	Skimming interrupted when insulation in power pack cover briefly ignites.

Test no.: PB 3

Parameter	Measurements / comments
Start time	16:11:30
Stop time	16:22:30
Ambient conditions:	
Weather	Clear with low overcast. No precipitation
Air temperature	- 1.5°C
Water temperature	- 1.5°C
Wind speed / direction	5.5 m/s, W-SW
Wave height / period	0 / 0
Boom:	
Type and configuration	50 m Norlense. Air ring maintains circular configuration.
Damage	None.
Ice:	
Concentration	Approximately 30%
Size	1 to 2-3 m
Thickness	approximately 20 cm
Slush ice	No
Distribution	Distributed unevenly in test area
Other	More ice was originally planned for this experiment. Ice collection took several hours
Oil/emulsion:	
Oil type	IF-30 bunker fuel emulsified with approximately 50 % water
Volume released	4170 litres originally – no oil added for this test
Viscosity start	4200 cP at 0°C (sample taken in the boom prior to the first test – PB1).
Temperature start	3 °C in thick oil; 1-2°C in thinner oil
Viscosity recovered	7400 cP at 0°C (sample taken from discharge hose during recovery).
Thickness start	Approximately 2 cm not uniform
Thickness after recovery	Estimated to approximately 2-3 cm
Water content start	42% (sample taken in the boom prior to the first test – PB1).
Water content recovered	54% (sample taken from discharge hose during recovery).
Skimmer:	
Drum speed	6 rpm
Submergence depth	Approximately 5-6 cm
Wave response influence	No waves, but vertical movement affects performance.
Slush collected	No
Ice is processed	Yes, skimmer depresses small ice and scrapes the emulsion.
Oil flows to device	Yes, steady oil flow
Skimmer repositioned	No
Recovery time	11 minutes
Other	Larger drum draw more oil into skimmer than smaller drum.
Performance:	
Liquid collected	630 litres
Free water	0 litres
Emulsion recovered	630 litres
Scraper	Worked satisfactorily
Is freezing a factor	No

	
Pump: Transfer Comments	 OK Intermittent when sump full. Large capacity pump
Power pack: Hydraulic pressure Operation	 200 bar. Used the highest output for the skimmer. OK. No interruptions.

Test no.: PB 4

Parameter	Measurements / comments
Start time	16:45:30
Stop time	16:55:30
Ambient conditions:	
Weather	Clear with low overcast. No precipitation
Air temperature	- 1.8^{o}C
Water temperature	- 1.5^{o}C
Wind speed / direction	7 m/s, SE
Wave height / period	0 / 0
Boom:	
Type and configuration	50 m Norlense. Air ring maintains circular configuration.
Damage	None.
Ice:	
Concentration	Approximately 70%. Boom formed into 2 sections half used for testing
Size	1 to 2-3 m
Thickness	20 – 30 cm
Slush ice	No
Distribution	Evenly distributed
Other	Compressed boom yields target ice concentration
	
Oil/emulsion:	
Oil type	IF-30 bunker fuel emulsified with approximately 50 % water
Volume released	4170 litres originally – no oil added for this test
Viscosity start	4200 cP at 0^{o}C (sample taken in the boom prior to the first test – PB1).
Temperature start	3 ^{o}C in thick oil; 1-2^{o}C in thinner oil
Viscosity recovered	N/A
Thickness start	Approximately 4 cm not uniform
Thickness after recovery	Estimated to approximately 2-3 cm
Water content start	42% (sample taken in the boom prior to the first test – PB1).
Water content	N/A

recovered	
Skimmer: Drum speed Submergence depth Wave response influence Slush collected Ice is processed Oil flows to device Skimmer repositioned Recovery time Other	 5 rpm Approximately 5 cm No waves, but vertical movement affects performance. No No. Ice floes impede oil flow to skimmer. No. Little oil flow. Some oil does move between pieces. No 10 minutes Larger drums draw more oil into skimmer than smaller drums.
Performance: Liquid collected Free water Emulsion recovered Scraper Is freezing a factor	 170 litres 0 litres 170 litres Worked satisfactorily No
Pump: Transfer Comments	 OK Intermittent when sump full. Little oil recovered during this test.
Power pack: Hydraulic pressure Operation	 200 bar. Used the highest output for the skimmer. OK. No interruptions.

Test no.: PB 5

Parameter	Measurements / comments
Start time Stop time	17:14 17:32
Ambient conditions: Weather Air temperature Water temperature Wind speed / direction Wave height / period	 Clear with low overcast. No precipitation - 1.5°C - 1.5°C 6.5 m/s, W-SW 0 / 0
Boom: Type and configuration Damage	 50 m Norlense. Air ring maintains circular configuration. None.
Ice: Concentration Size Thickness Slush ice Distribution Other	 Approximately 50% 1 to 2-3 m 20 – 30 cm No Ice is distributed unevenly in test area. More ice was originally planned for this experiment. Ice collection took several hours 
Oil/emulsion: Oil type Volume released Viscosity start Temperature start Viscosity recovered Thickness start Thickness after recovery Water content start	 IF-30 bunker fuel emulsified with approximately 50% water 4170 litres originally – no oil added for this test 4200 cP at 0°C (sample taken in the boom prior to the first test – PB1). 3 °C in thick oil; 1-2°C in thinner oil 8100 cP at 0°C (sample taken from discharge hose during recovery). Approximately 4 cm not uniform Estimated to approximately 2-3 cm 42% (sample taken in the boom prior to the first test – PB1). 58% (sample taken from discharge hose during recovery).

Water content recovered	
Skimmer: Drum speed Submergence depth Wave response influence Slush collected Ice is processed Oil flows to device Skimmer repositioned Recovery time Other	 5 rpm Approximately 5 cm No waves, but vertical movement affects performance. No Yes, skimmer depresses small ice and scrapes the emulsion. Yes, steady oil flow No 18 minutes Larger drum draw more oil into skimmer than smaller drum.
Performance: Liquid collected Free water Emulsion recovered Scraper Is freezing a factor	 415 litres 0 litres 415 litres Worked satisfactorily No
Pump: Transfer Comments	 OK Intermittent when sump full. Large capacity pump
Power pack: Hydraulic pressure Operation	 200 bar. Used the highest output for the skimmer. OK. No interruptions.

Appendix B: Framo skimmer tests. May 14, 2009

Position (12.00): N 76.51
E 29.47

Test no.: Framo 1 (test run)

Parameter	Measurements / comments
Start time Stop time	19:25 19:55 Total skimming time: 30 min.
Ambient conditions: Weather Air temperature Water temperature Wind speed / direction Wave height / period	 High overcast. No precipitation - 1.0°C - 1.5°C 4.0 m/s; SE 0 / 0
Boom: Type and configuration Damage	 50 m Norlense. Boom configuration maintained well. No damage. Air ring maintains configuration
Ice: Concentration Size Thickness Slush ice Distribution Other	 Approximately 80 - 90% Up to several m, down to several cm 20-30 cm Yes Even 
Oil/emulsion: Oil type Volume released Viscosity start Temperature start Viscosity recovered Thickness start	 IF-30 bunker fuel emulsified with approximately 50% water 900 litres 6600 cP at 0°C (sample taken from tank prior to discharge). 1°C 6200 cP at 0°C (sample taken from recovery tank after testing). Approx 2 cm. Depending on position inside the boom. Unevenly distributed.

Thickness after recovery Water content start Water content recovered	N/A 49% (sample taken from tank prior to discharge). 62% (sample taken from recovery tank after testing).
Skimmer: Drum speed Submergence depth Wave response influence Slush collected Ice is processed Oil flows to device Skimmer repositioned Recovery time Other	 5-7 rpm Approximately 2-5 cm No waves No Yes, skimmer presses ice down and scrapes off and pumps the emulsion effectively. Skimmer is moved within oil and ice Yes, moved by skimmer thrusters 30 minutes Significant water uptake is observed, drum brush position relative to water is not optimum
Performance: Liquid collected Free water Emulsion recovered Scraper/wringer Is freezing a factor	 1774 litres 1229 litres 545 litres Brushes and scrapers incurred damage during initial dry run without oil No 
Pump: Transfer Comments	 OK One pump functions.
Power pack: Hydraulic pressure Operation	 Satisfactory, no problems

Test no.: Framo 2 May 18, 2009

Parameter	Measurements / comments
Start time Stop time	13:58 14:02
Ambient conditions: Weather Air temperature Water temperature Wind speed / direction Wave height / period Others	 Low overcast. No precipitation - 2.0^{o}C - 1.0 ^{o}C 10.0 m/s; N 6-8 cm/<1 second Sun appeared to warm oil in test area.
Boom: Type and configuration Damage	 No boom used
Ice: Concentration Size Thickness Slush ice Distribution Other	 Variable, large floes present that are uncontained Up to at least several metres and more 30 - 50 cm Yes Uneven Skimmer is released from crane and is supposed to manoeuvre through ice floes 
Oil/emulsion: Oil type Volume released Viscosity start Temperature start Viscosity recovered Thickness start Thickness after recovery	 No oil released

Water content start Water content recovered	
Skimmer: Drum speed Submergence depth Wave response influence Slush collected Ice is processed Oil flows to device Skimmer repositioned Recovery time Other	 5-7 rpm No No Yes, small ice pieces. N/A Skimmer is manoeuvred by thrusters
Performance: Liquid collected Free water Emulsion recovered Scraper/wringer Is freezing a factor	 No oil released
Pump: Transfer Comments	 One pump is functional; it is not used during these tests
Power pack: Hydraulic pressure Operation	 OK

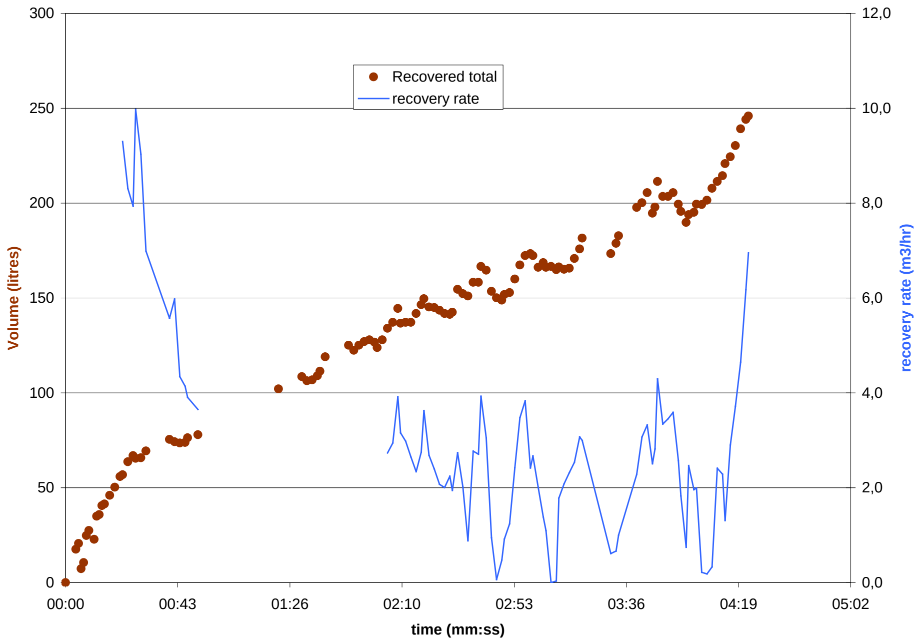
Appendix C: Framo brush drum cassette testing 19th and 20th January 2009 in SINTEF ice basin.

Test 1: **No ice**

Emulsion volume on surface : 881 liters
Average thickness : 5,5cm

Total volume recovered : 224
Free water drained off : 203
Emulsion recovered : 22 liters
% free water : 90%

Pumping rate (total): 3,6 m^3/hr
Pumping rate (emulsion) : 0,3 m^3/hr

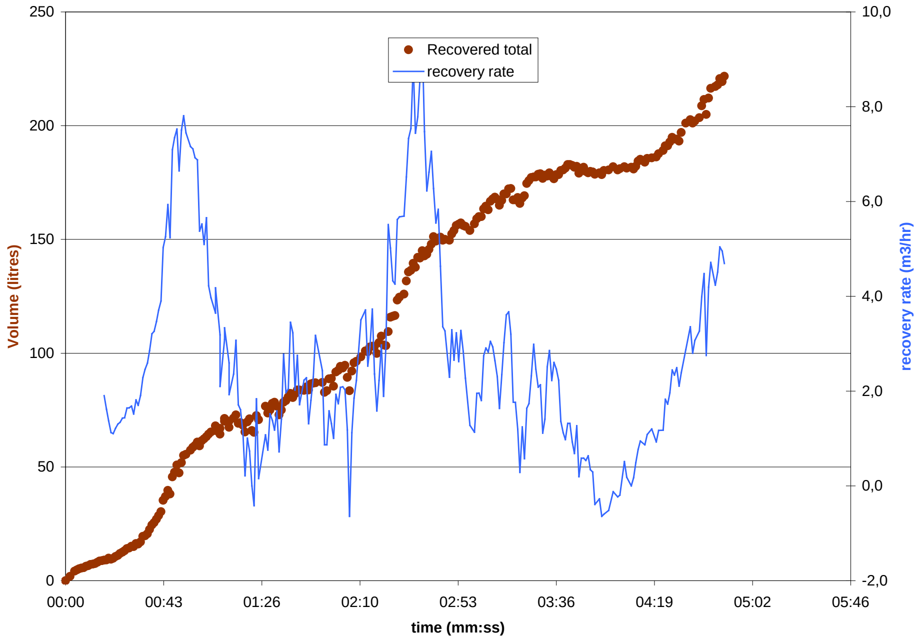


Test 2: No ice

Emulsion volume on surface : 1675 liters
Average thickness : 10,5cm

Total volume recovered : 200
Free water drained off : N/A
% free water : N/A

Pumping rate (total): 2,3
Pumping rate (emulsion) : N/A

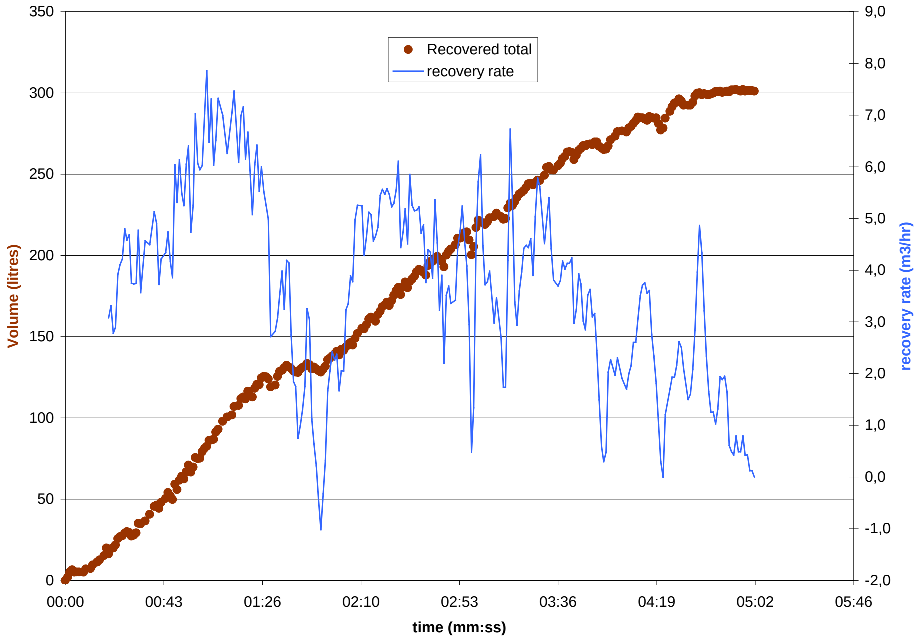


Test 3: No ice

Emulsion volume on surface : 1392 liters
Average thickness : 8,7cm

Total volume recovered : 283
Free water drained off : N/A
% free water : N/A

Pumping rate (total): 3,6
Pumping rate (emulsion) : N/A



Test 4: 50% ice

Emulsion volume on surface : 1109 liters
Average thickness no ice: 6,9 cm
Ice Coverage : 50%
Average emulsion thickness with ice: 13,8 cm

Total volume recovered : 609 liters
Free water drained off : 513 liters
Emulsion recovered : 96 liters
% free water : 84

Pumping rate (total): 5,0m^3/hr
Pumping rate (emulsion) : 0,8m^3/hr