SINTEF REPORT

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TITLE

Development of Data Sets from Experimental Oil Spills for OWM Algorithm and Model Testing and Validation

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CLIENT(S)

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REPORT NO.	CLASSIFICATION	CLIENTS REF.	
STF66 A04025	Unrestricted	Dr. Richard Prentki	
CLASS. THIS PAGE	ISBN	PROJECT NO.	NO. OF PAGES/APPENDICES
Unrestricted	82-14-03047-1	661189	63
ELECTRONIC FILE CODE		PROJECT MANAGER (NAME, SIGN.)	CHECKED BY (NAME, SIGN.)
Final report.doc		Mark Reed	Janne L.M. Resby
FILE CODE	DATE	APPROVED BY (NAME, POSITION, SIGN.)	
	2004-03-29	Tore Aunaas, Research Director	

ABSTRACT

Field data and weathering data from the following field trials are presented in this report:

- Haltenbanken 1989
- MIZ-experiment (in ice) 1993
- NOFO-trial 1994
- NOFO-trial 1995
- NOFO-trial 1996 (limited data)
- UK trials 1997 (AEA-trials)

Additionally, the surface oil data from the Deep Spill 2000 experiment is presented.

A short overview over each field trial is given together with the data sets, and weathering predictions made by the SINTEF Oil Weathering Model. The data sets has been developed and collated as a basis for validation testing of various oil weathering models, and we hope that these data will be valuable for other insitutes/organisations for this purpose.

KEYWORDS	ENGLISH	NORWEGIAN
GROUP 1	Chemistry	Kjemi
GROUP 2	Environment	Miljø
SELECTED BY AUTHOR	Field data	Feltdata
	Weathering data	Forvitringsdata
	Oil spills	Olje utslipp

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1 Introduction

1.1 Background and objectives

In 1998 SINTEF Applied Chemistry completed the Phase I review "Revision of MMS Offshore Continental Shelf Oil-Weathering Model: Evaluation," OCS Study MMS 98-0031 for MMS. This review recommended:

- upgrading to an existing state-of-the-art OWM
- additional improvements needed to maintain state-of-the-art and to meet needs of MMS users
- spill data sets that would be suitable for model testing and validation.

The recommendations described in the Phase 1 report, lead to a follow-up study " Revision of the OCS Oil-Weathering Model: Phases II and III". The objectives of this study are:

1) to obtain and adapt the SINTEF Oil Weathering Model (OWM) to MMS needs,
2) to expand the OWM oil library to include oils of interest to MMS, and
3) to develop and collate data sets identified in Phase I from experimental oil spills for validation testing of various OWModels.

This report is connected to the last objective in this study: Task 7: "Development of Data Sets from Experimental Oil Spills for OWM Algorithm and Model Testing and Validation"

A framework for this task 7 was described in the MMS OWM Phase I Technical Meeting held in Anchorage, in March, 1998 with two alternative approaches:
One approach at that time was that SINTEF, in collaboration with organizations like Alun Lewis Oil Spill Consultant in UK, CEDRE in France, and NOOA in US should try to develop a JIC program to address:

- model sensitivity testing
- preparation and archival of specified data sets
- testing of model algorithms.

Many data sets of potential interest were identified in the Phase I Report (OCS Study MMS 98-0058), and MMS would like to see an eventual such JIC program developed in a manner which could facilitate use of the data in OWM testing, for use with models, such as the NOAA ADIOS model, in addition to with the SINTEF OWM. During the project period, it appeared, however, to be difficult to develop such an extended JIC program. We therefore agreed with MMS that SINTEF proceeded alone in this task with the limited budget from MMS allocated for task 7 to address the two last scopes/goals: i.e. preparation of available oil spill data sets, and in testing / validating these ground-truth data with the new version of the SINTEF OWM only. The data sets presented in this report can however, be used by any organizations /model operators in model algorithm testing / validation.

1.2 Conclusions and recommendations from the Phase 1 report

In the Phase I Report (OCS Study MMS 98-0058, chap. 5.1.), criteria for an "ideal data set" from experimental oil releases at sea was specified with respect to:

- Environmental background data
- Oil characterization (original oil properties and changes as function of weathering)
- Documentation – Standardized methods for sampling and analysis

- Sampling frequency
- Replicate samples

An overview of experimental oil releases were identified and preliminary evaluated. None of the field trials satisfied the strict criteria for an “ideal data set”, both with respect to methodology and data-documentation. However, this lack of the “ideal data set” should not prevent us from using the best series of these data sets for calibration/validation of oil weathering models. However, it also became very obviously during this review that many of the older data sets from experimental trials had a very limited potential for model calibration-/validation. This caused by varying quality of the data due to lack of consistent procedures for sampling and analytical methodology.

Some recent field trials had, however, more well-documented and suitable procedures for field sampling and further analysis. The preliminary conclusion from this preliminary review was that data from recent field trials in UK and Norway (se below) had a potential for calibration/verification of oil weathering models, and an effort in collecting all relevant data from these series should be given priority in task 7:

UK: Field trials in the North Sea from the period 1992-97: These experiments have been conducted on a yearly basis with different objectives. The more recent experiments have well documented and suitable procedures for sampling and further analysis. These field trials cover several crude oil (Forties, Alaska North slope) and different bunker fuels. The weathering time ranges from only hours to several days and the weathering parameters include (emulsification, evaporation, natural dispersion, water soluble components, emulsion viscosity, emulsion stability, water droplets distribution in emulsion and others). Some of these UK sea trials also include extensive monitoring of dispersed oil concentrations versus time and also measurements of droplet sizes of the dispersed oil droplets. Some relevant data seemed to be available from e.g. AMOP-publications by AEA Technology, however, e.g. More extensive environmental data from the field test is needed in order to make then appropriate as validation data-sets.

Norway: Field trials in the North Sea and in the marginal ice zone of the Barents Sea from the period (1989-96): In Norway, field experiments have been conducted on an almost yearly basis since late 70's, but only some of the trials were considered to be relevant for our purpose. The SINTEF-89 and MIZ-93 trials give data sets which can be used to compare weathering of the same crude oil type at a North Sea and an Arctic environment. These trials and the later NOFO trials (1994/95/96) have used well-documented and suitable procedures for sampling and further analysis. The weathering time ranges from one day up to seven days, and the weathering parameters include emulsification, evaporation, natural dispersion, water-soluble components, emulsion viscosity, and emulsion stability, among others. Data are available from SINTEF as reports and publications.

1.3 Datasets collected presented in this report

In the period from December 2002 to July 2003, an effort was made to collect all relevant data from the recommended series of field trials. As a result, data-set from the following trials are presented in this report:

- Haltenbanken 1989
- MIZ-experiment (in ice) 1993
- NOFO-trial 1994
- NOFO-trial 1995
- NOFO-trial 1996 (limited data)

- UK trials 1997 (AEA-trials)
- Surface oil data from the Deep spill 2000 experiment

The data-sets from the earlier field tests in UK are not included in this report. This is due to lack of available documentation of environmental data during the field tests. Lewis Oil Spill Consultant in UK did an extensively search for obtaining data reports from field various field trials in UK at the library at MCA (Maritime and Coastal Agency in Southampton) without any success.

Weathering data, wind speed, temperature and film thickness are presented from the trials. For the trials including dispersant treatment, only the weathering data before dispersant treatment is presented in this report.

The film thicknesses parameters used as input to the model for the predictions of the different trials, are based on the film thickness data measured in the individual trials.

2 The Haltenbanken experiment 1989

2.1 The field experiments

This experiment was organized by the oceanographic research company OCEANOR with SINTEF (IKU) and NINA as partners. The oil was released at Haltenbanken (65º 00 N, 08º 00 E) 10.05 am July 1st. The oil was released from a small tanker by a hose hanging above the sea surface. The release of total 30 tons took 16 minutes, forming a small and concentrated oil slick in the beginning.

The first samples were collected 5 minutes after the oil was released and a comprehensive sampling program was carried out during the next four days. The results of the physico-chemical properties of the surface samples are given in the following tables. The results are average values of 2-3 replicate samples.

2.2 Objectives

This full-scale experimental oil spill was carried out to study several objectives:

1. Evaluation of different types of oil spill drifters (Argos positioned buoys) versus oil drift
2. Intercalibration of different aerial surveillance systems
3. Study of weathering processes of the Sture Blend crude (also here called Oseberg Blend)
4. Study interactions between a drifting oil slick and sea birds

2.3 Conclusions

Generally, the measured changes in the oil properties with time gave a good agreement with predicted data of Sture based on small-scale laboratory experiments and using the SINTEF Oil Weathering model.

Due to relatively rough weather conditions during the release, the oil was discharged vertically into the sea from a hose (1-3 meter above sea surface). This release arrangement resulted in a temporary mixing of the oil into the seawater, leading to a relative high starting film thickness. An initial filmthickness of 20 mm has therefore been used in the model predictions. Additionally, the tanker had to use its thrusters (side propellers) during the discharge to keep distance to the oil slick. It is therefore reason to believe that this could cause additional mixing of oil and water and lead to higher water uptake for the samples from the first 5 – 30 minutes.

Weathering data for Sture blend is included in the report. Sture blend is the present name of the Oseberg Blend used in 1989. Sture is the name of an Oil Terminal on the west coast of Norway. Crude oil from the various wells at the Oseberg field is the main contributor to this terminal. There may be some minor variation in the chemical composition to the Sture blend due to the daily variation in the daily production at the various field.

Predicted evaporation, water uptake and emulsion viscosity together with field data is shown in Figure 2.1, Figure 2.2 and Figure 2.3, respectively.

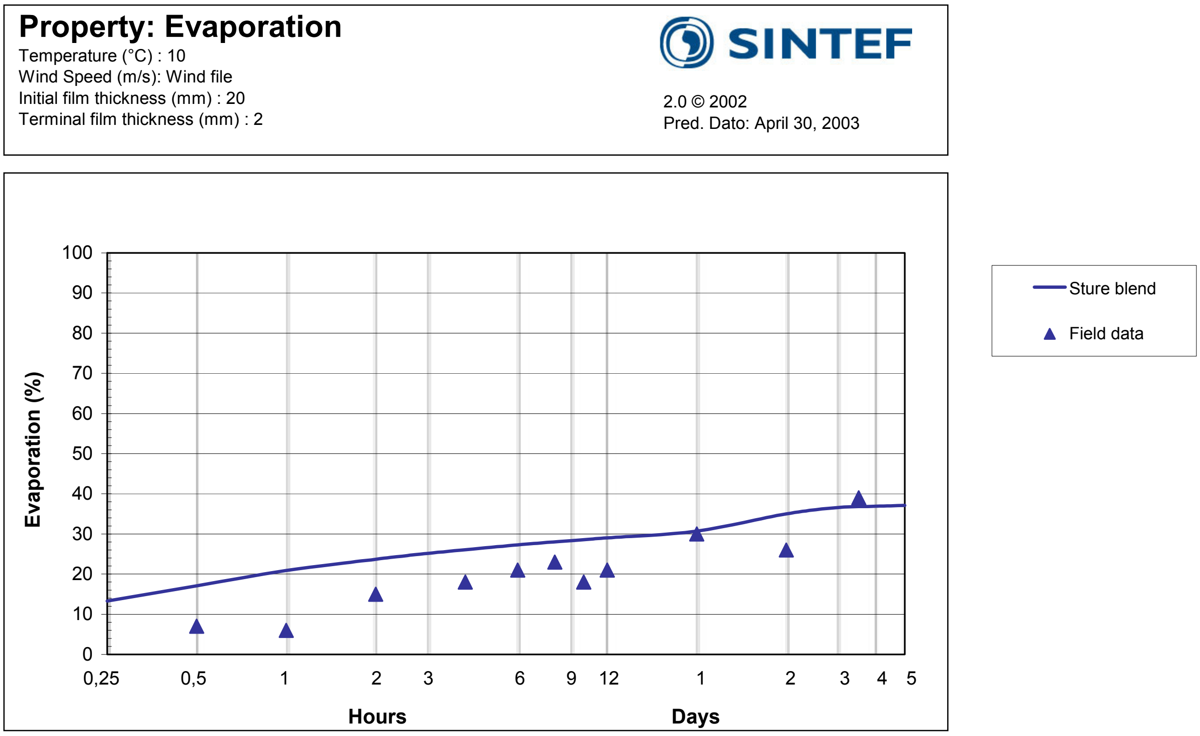

Figure 2.1 : Predicted evaporation and field data Haltenbanken 1989.

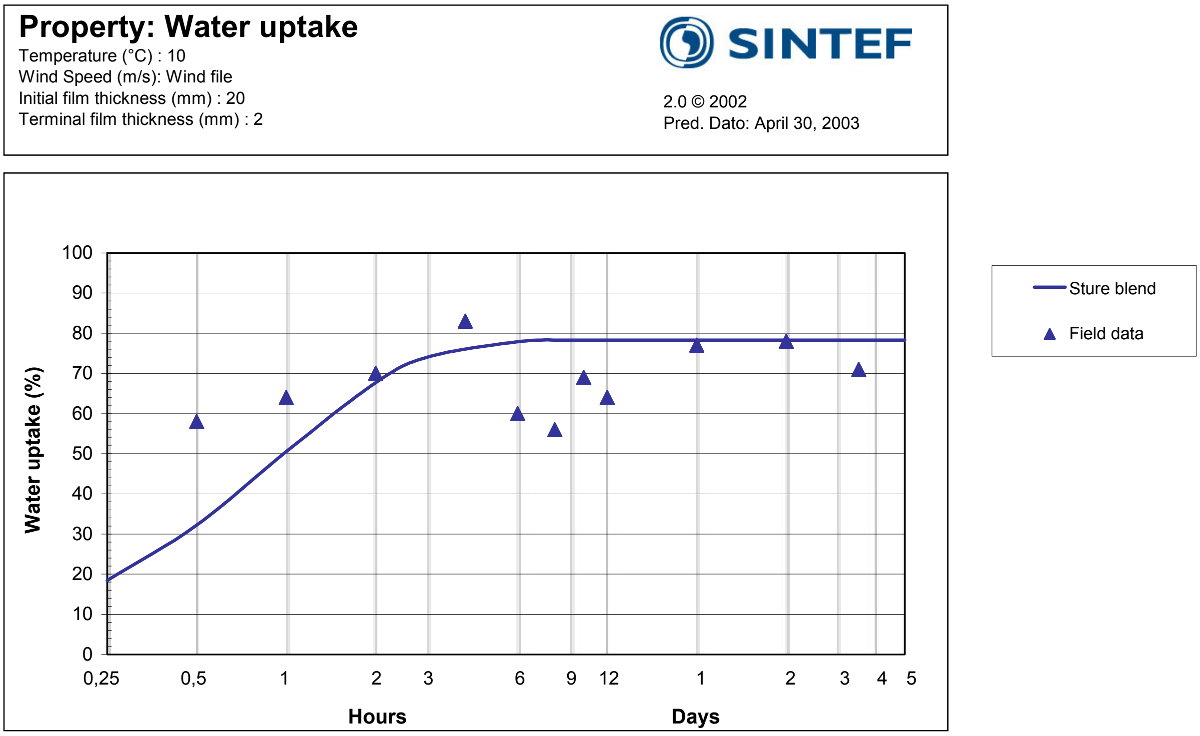

Figure 2.2 : Predicted water uptake and field data Haltenbanken 1989.

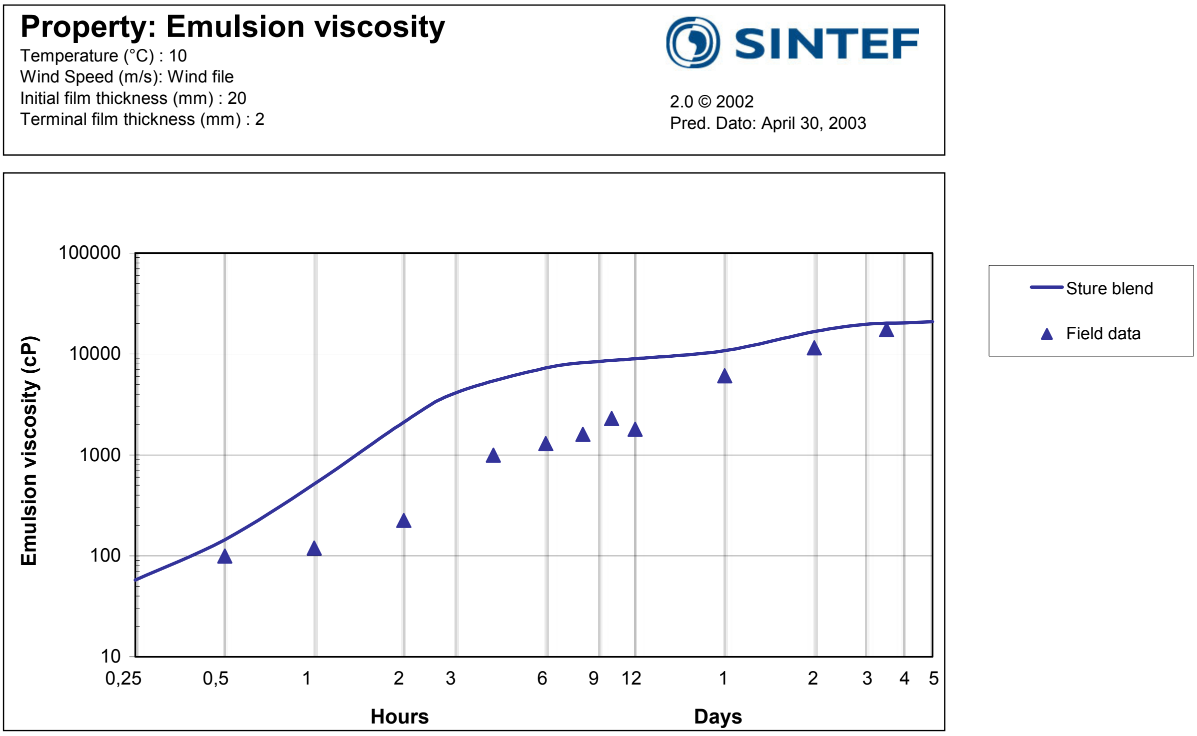

Figure 2.3 : Predicted emulsion viscosity and field data Haltenbanken 1989.

2.4 Field data Haltenbanken 1989

Table 2.1 *:Physico-chemical properties on waterfree residues of Sture Blend (1989 crude)and their water-in-oil emulsions.*

Table 2.2 *:Water content and stability of the w/o-emulsions.*

Table 2.3 *: Wind conditions at Haltenbanken July 1989.*

Table 2.4 *: Input data for weathering predictions Sture blend.*

Table 2.1 :Physico-chemical properties on waterfree residues of Sture Blend (1989 crude)and their water-in-oil emulsions.

Station	Time (weathering at sea)	Evap. loss (wt.%)	Water cont. (vol.%, total)	Viscosity[1] (10°C, cP)	Density emulsion (kg/l)	Density oil (kg/l	Flash-point (°C)	Pour-point (°C)	Int.f. tension (mN/m)	Chemical disp.-ability	Film Thickness [2] (mm)
0 (crude)	0	0	0	12.4	0.855	0.855	-	-22	21	Good	-
1	5 min.	1	42	39.0	0.900-	-	<5°C	-	-	Good	-
2	10 min.	5	50	-	-		5.1	-	-	Good	3.2 (1.3)[2]
3	15 min.	2	53	6	0.944	0.872	13	-13	-	Good	7.7 (4.3)
4	30 min.	7	58	100	0.955	0.867	20	-	-	Good	6.5 (-)
5	1 hour	6	64	120	0.971	0.882	33	-	-	Good	2.4 (1.7)
6	2 hours	15	70	225	0.975	0.888	102	-6	-	Good	4.3 (2.1)
7	4 hours	18	83	1000	1.003	0.892	>100	-	-	Reduced?	4.4 (-)
8	6 hours	21	60	1300	0.965	0.895	>100	-2	12	Good	4.0 (-)
9	8 hours	23	56	1600	0.970	0.895	>100	-	-	Good	1.8 (0.1)
10	10 hours	18	69	2300	0.978	0.893	>100	-	-	Good	6.1 (2.8)
11	12 hours	21	64	1800	0.974	0.902	>100	+7	10	Good	-
12	1 day	30	77	6100	-	0.910	>100	+14	9	Reduced	2.4 (0.5)
13	2 days	26	78	11500	-	0.917	>100	+18	3	Bad	-
14	3.5 days	39	71	17500	-	0.935	>100	+32	-	Bad	-

1)The viscosity measurements were performed at shear rates 100 s^{-1} for the samples taken at stations 0 to 6, and shear rate 10 s^{-1} for the samples taken at stations 7 to 14.
2) The number in brackets gives the standard deviation based on three parallel film thickness measurement samples.

Table 2.2 :Water content and stability of the w/o-emulsions.

Station	Age	Total water content (vol.%)	Expelled water after 24 h settling (Vol.%)	Expelled water after by 24 h settling of chemically treated emulsions (Vol.%)	Total expel. water (Vol.%)	Water residue in emulsion	Stability[1?] of emulsion	Efficiency[2)] of chemical
0 (crude)	0	-	-	-	-	-	-	-
1	5 min.	42	-	42	42	-	-	1.0
2	10 min.	50	-	50	50	-	-	1.0
3	15 min.	53	22	30	52	1	.58	.98
4	30 min.	58	13	40	53	5	.78	.91
5	1 hour	64	45	17	62	2	.30	.97
6	2 hours	70	15	50	65	5	.79	.93
7	4 hours	83	6	74	80	3	.93	.96
8	6 hours	60	3	50	53	7	.95	.88
9	8 hours	56	0	50	50	6	1.00	.89
10	10 hours	69	0	66	66	3	1.00	.96
11	12 hours	64	0	59	59	5	1.00	.92
12	1 day	77	0	67	67	10	1.00	.87
13	2 days	78	0	73	75	5	1.00	.94
14	3.5 days	71	0	54	54	17	1.00	.76

1) *Fraction of total water content left in w/o-emulsion after 24 h settling, (0 -> emulsion is totally broken, 1.0 -> emulsion not broken).*
2) *Fraction of total water content expelled after chemical treatment with Alcopol 0 60% and 24 h settling (0 -> no water expelled, low efficiency, 1.0 -> all water expelled, high chemical efficiency).*

Table 2.3 : Wind conditions at Haltenbanken July 1989.

Start date :		**01.07.1989**	
Cum. time (h)	**Sea temp. (°C)**	**Wind speed (m/s)**	**Direction (°)**
0	9.6	11.3	287
3	9.8	10.1	337
6	9.8	8.4	350
9	9.8	7.5	164
12	9.8	6.9	262
15	9.8	3.9	1
18	9.6	7.8	273
21	9.6	6.3	96
24	9.9	7.5	230
27	10.1	5.4	263
30	10.2	6.9	14
33	10.2	7.5	26
36	10.2	7.5	157
39	10.1	14.3	214
42	10.1	16.1	231
45	9.8	24.2	279
48	9.6	25.1	256
51	9.6	22.1	247
54	9.8	17.0	312
57	9.8	16.1	266
60	9.8	11.0	233
63	9.8	8.7	255
66	9.8	4.8	325
69	9.9	3.6	30
72	9.9	4.2	86

Table 2.4 : Input data for weathering predictions Sture blend.

Fresh oil properties	
Specific Gravity (60 F/60 F)	0.85
Pour Point (°C)	-9
Reference temperature #1 (°C)	13
Viscosity at ref. temp.#1 (cP)	11
Vanadium (ppm wt.)	-
Nickel (ppm wt.)	-
Asphaltenes (wt. %)	-
n-Pentane Insolubles (wt. %)	-
Flash Point (°C)	-
Wax Content (wt. %)	-
Dispersable for visc. <	2000
Poorly dispersable for visc. >	7000
Maximum water uptake (%) at 5°C/13°C	80

-: *Data missing*

True boiling point curve	
Temperature (°C)	**Cumulative volume (%)**
90	10.62
120	16.74
145	21.48
160	24.23
205	32.29
250	40.62
295	50.27
350	61.09
420	70.84
565	89.12

Film thickness (mm)	
Initial	20
Terminal	2

Weathering properties (laboratory data)				
	Fresh	**150°C+**	**200°C+**	**250°C+**
Boiling temperature (°C)	-	185	250	303
Volume topped (%)	0	16	28	39
Residue (wt %)	100	86	76	65
Specific gravity (g/l)	0.847	0.877	0.892	0.907
Pour point (°C)	-3	6	15	18
Flash point (°C)	-	38	80	119
Viscosity at 13°C (cP)*	10	25	65	350
Viscosity of 50% emulsion (cP)*	-	190	480	2800
Viscosity of 75% emulsion (cP)*	-	1400	2600	6300
Viscosity of max water (cP)*	-	950	10000	14000
Maximum water content (%)	-	80	80	78
Halftime for water uptake (hrs)	-	0.13	0.1	0.18
Stability ratio	-	0,79	0.705	1

- : *Not measured*
* : *Viscosity measured at shear rate $10s^{-1}$.*

3 MIZ-1993

3.1 The field experiments

An experimental oil spill in the Barents Sea marginal ice zone (MIZ) was performed in the last part of April 1993. 26 m^3 of Sture blend was released approximately 45 km inside the ice edge at an ice concentration of approximately 90%. During a 7 day period of sampling and analysis of the surface oil/emulsion, the slick drifted to a position approximately 6 km from the ice edge, and the ice concentration varied from 70-90%. The dominant wind direction was from the ice towards open water, and the wave energy conditions were relatively low most of the time. The wind speed was 6-10 m/s and the temperature -16-0°C.

Objectives

The intention of the experimental oil spill in the marginal ice zone was to contribute further to existing knowledge about the behaviour of oil under Arctic conditions and to acquire knowledge about the specific conditions (wind, waves, ice conditions, drift and spreading) in the marginal ice zone.

Conclusions

Measurements performed during the MIZ experimental oil spill showed that oil spilled in ice will have a relatively high oil film thickness (often in cm-range) compared to oil spills in open waters (maximum 1 to 4 mm). The measured film thickness in the MIZ experiment ranged from 5-120 mm of emulsion. This is caused by a reduced spreading due to the presence of ice. The ice acted as a barrier and prevented spreading, especially at high ice concentrations. As a result of the high oil film thickness combined with low temperatures, the evaporation of the light components in the oil was low compared to experimental oil spills in open waters. The emulsification was low.

Prediction of evaporation, water uptake and emulsion viscosity for oil in ice (90% ice coverage), oil in open waters and field data from the MIZ-experiment is shown in Figure 3.1, Figure 3.2 and Figure 3.3 respectively.

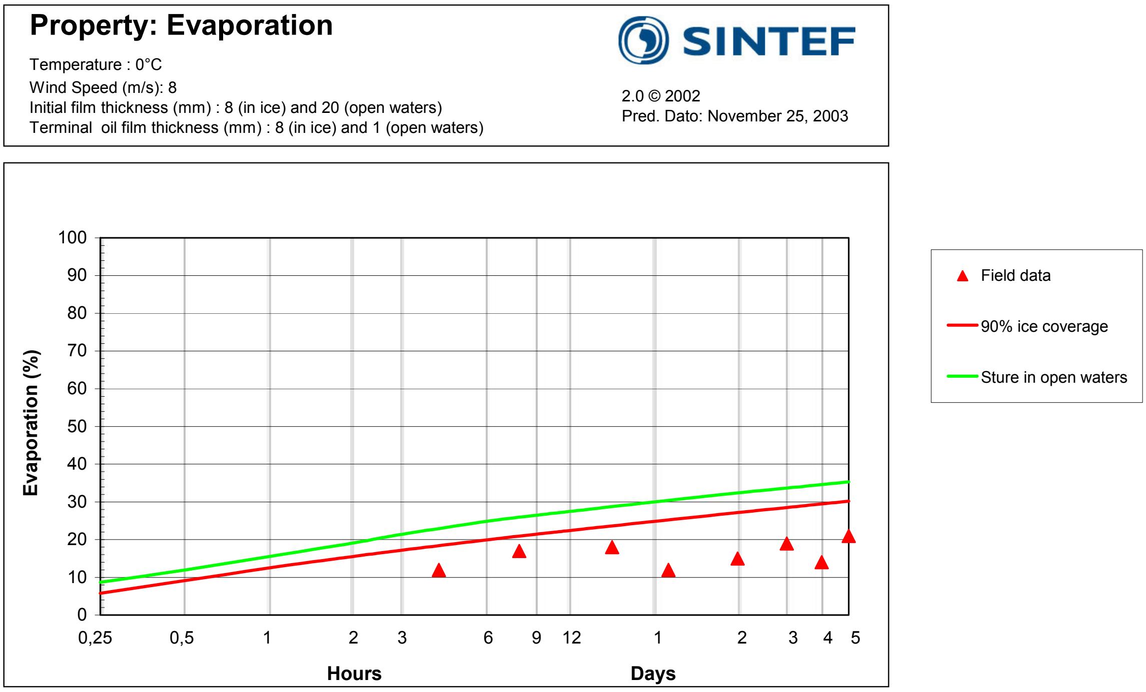

Figure 3.1 Predicted evaporation and field data Sture blend MIZ 1993.

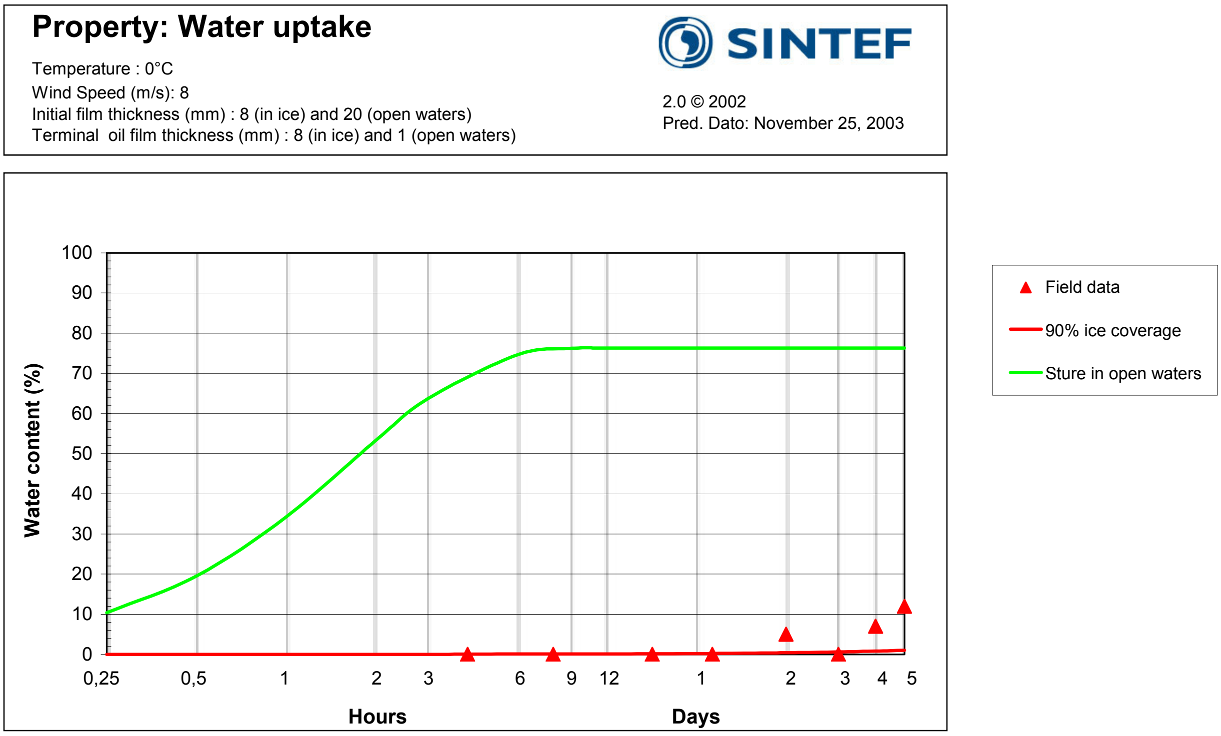

Figure 3.2 : Predicted water uptake and field data Sture blend MIZ 1993.

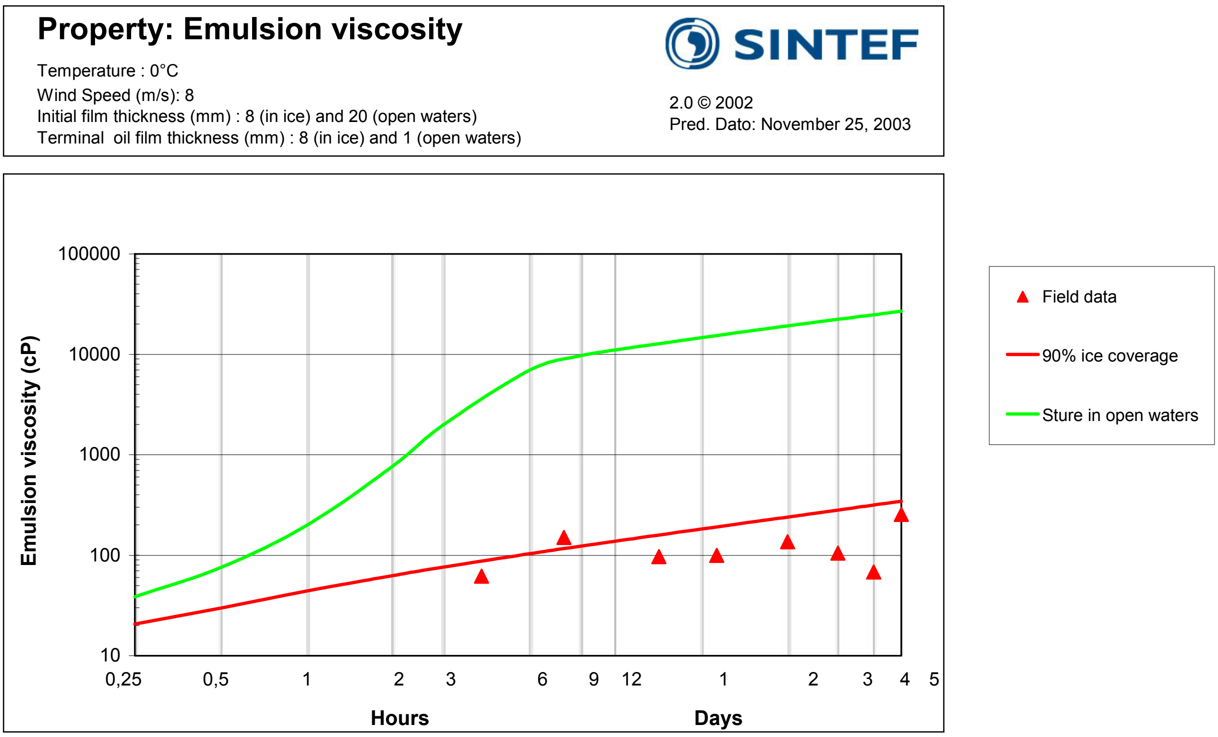

Figure 3.3 : Predicted emulsion viscosity and field data Sture blend MIZ 1993.

3.2 Field and input data MIZ 1993

The data from samples taken of the oil slick is given in the tables described here.

Table 3.1 : Field data Sture blend MIZ 1993.
Table 3.2 : Input data for weathering predictions of Sture blends behaviour at sea.

Table 3.1 : Field data Sture blend MIZ 1993.

	Time (Days)	Water content (%)	Viscosity (cP) at $100s^{-1}$ 0-6°C emulsion	Density (kg/L) emulsion	Density (kg/L) Oil/residue	Evaporation (Vol%) (based on density))	Evaporation (Vol%) (based on GC)	Pour point	Interfacial tension (mN/m)	Dispersibility
Crude oil	0	0	32		0,847	0	0	-3	27,5	Good
Crude oil	0	0	33		0,847	0	7			Good
Thick oil	0,17	0	62		0,872	8	12	6	18,4	Good
Oil film	0,33	0	150		0,872	13	17	0	19,2	Good
Emulsion	0,71	0	97	0,928	0,88	17	18			Good
Thick oil	3	0	105		0,89	24	19	12	11,2	Good
Thick oil	4	7	68	0,908	0,882	19	14	12	6,7	Good
Thick oil	5	12	255	0,903	0,887	21	21	12	5,3	Good
Thick oil	5,2	1	240	0,895	0,885	20	22			Good
Thin oil	6	6	300	0,895	0,89	24	23			Good
Thick oil	7	20	680	0,912	0,893	25	24	12	3,3	Good/reduced

Table 3.2 : Input data for weathering predictions of Sture blends behaviour at sea.

Fresh oil properties	
Specific Gravity (60 F/60 F)	0.847
Pour Point (°C)	-3
Reference temperature #1 (°C)	13
Viscosity at ref. temp.#1 (cP)	10
Vanadium (ppm wt.)	-
Nickel (ppm wt.)	-
Asphaltenes (wt. %)	-
n-Pentane Insolubles (wt. %)	-
Flash Point (°C)	-
Wax Content (wt. %)	-
Dispersable for visc. <	2000
Poorly dispersable for visc. >	9000
Maximum water uptake (%) at 5°C/13°C	80

-: *Data missing*

True boiling point curve	
Temperature (°C)	**Cumulative volume (%)**
90	10.62
120	16.74
145	21.48
160	24.23
205	32.29
250	40.62
295	50.27
350	61.09
420	70.84
565	89.12

Film thickness (mm)	
Initial	8
Terminal	8

Weathering properties (laboratory data)				
	Fresh	**150°C+**	**200°C+**	**250°C+**
Boiling temperature (°C)	-	185	250	303
Volume topped (%)	0	16	28	39
Residue (wt %)	100	86	76	65
Specific gravity (g/l)	0.847	0.877	0.892	0.907
Pour point (°C)	-3	6	15	18
Flash point (°C)	-	38	80	119
Viscosity at 13°C (cP)*	10	25	65	350
Viscosity of 50% emulsion (cP)*	-	190	480	2800
Viscosity of 75% emulsion (cP)*	-	1400	2600	6300
Viscosity of max water (cP)*	-	950	10000	14000
Maximum water content (%)	-	80	80	78
Halftime for water uptake (hrs)	-	0.13	0.1	0.18
Stability ratio	-	0,79	0.705	1

- : *Not measured*
* : *Viscosity measured at shear rate* $10s^{-1}$.

4 NOFO exercise 1994

4.1 The field experiments

The NOFO oil-on-water exercise 1994 was Phase 1 of a series of 3 field trials. Phase 1 included two surface releases and treatment with dispersant. The experiments were performed at the Frigg field in June 1994.

Objectives

The main objectives of the field trials were:

◊ To verify laboratory studies on the rate of weathering (evaporation, natural dispersion and emulsification) of Sture Blend crude oil and determine the extent of changes in these processes caused by the application of dispersant.

◊ To assess quantitatively the effectiveness of aerially applied dispersant by following the fate and weathering properties of two slicks of partially weathered North Sea crude oil (one treated and one control slick).

◊ To define the operational parameters required for practical dispersant treatment strategies.

◊ To provide a realistic training scenario for oil spill combat personnel.

Releases

Two slicks, each of 20 m^3 fresh, stabilized Sture Blend crude were released about 1 nautic mile (nm) apart. The oil were pumped gently on the sea surface by using the Transrec system (leading to a generally lower starting film thickness compared to the e.g. 1989-Haltenbanken experiment). One slick, called Tango, was treated with the dispersant Corexit 9500 from a S61-N helicopter with a Rotor tech TC-3 underslung bucket after 3 hours weathering of the oil at sea. A re-application of dispersant on the same slick was performed after totally 7 hours weathering of the oil. The Tango slick disappeared totally from the sea surface and dispersed into the water column within 12 hours at sea.

The other slick, Charlie, was used as control slick the first day. The second day, about 29 hours after the oil had been released, and after the Tango slick had disappeared, the Charlie slick was treated with Corexit 9500. Soon after this treatment, the slick dispersed into the water column.

Conclusions

The main conclusions from the field experiments were:

◊ The Sture Blend lost about 45 vol.% of its volume due to evaporation and reached a viscosity of approximately 9000 cP (at shear rate 10 s^{-1}) within 28 hours at sea. The water content in the emulsions was 75-80%.

◊ The weathering predictions (evaporation and emulsification) of the Sture Blend crude (from 1993) proceeded similarly to what was observed in the Haltenbanken trial in 1989 with the Sture Blend (from 1989).

◊ The dispersant applications resulted in decreased emulsion water content and decreased emulsion viscosity. The oil/emulsion disappeared totally into the water column.

The quality of the data are good and gave valuable input to the IKU Oil Weathering Model and formed basis for further refinements and verifications of the algorithms in the model.

Further details from the field experiments are described in Lewis *et al*., 1995 and Strøm-Kristiansen and Daling, 1994.

Data from the Charlie slick and from Tango slick before dispersant treatment is presented in this report. Predicted evaporation, water uptake and emulsion viscosity from SINTEF OWM is presented together with field data in Figure 4.1, Figure 4.2 and Figure 4.3, respectively.

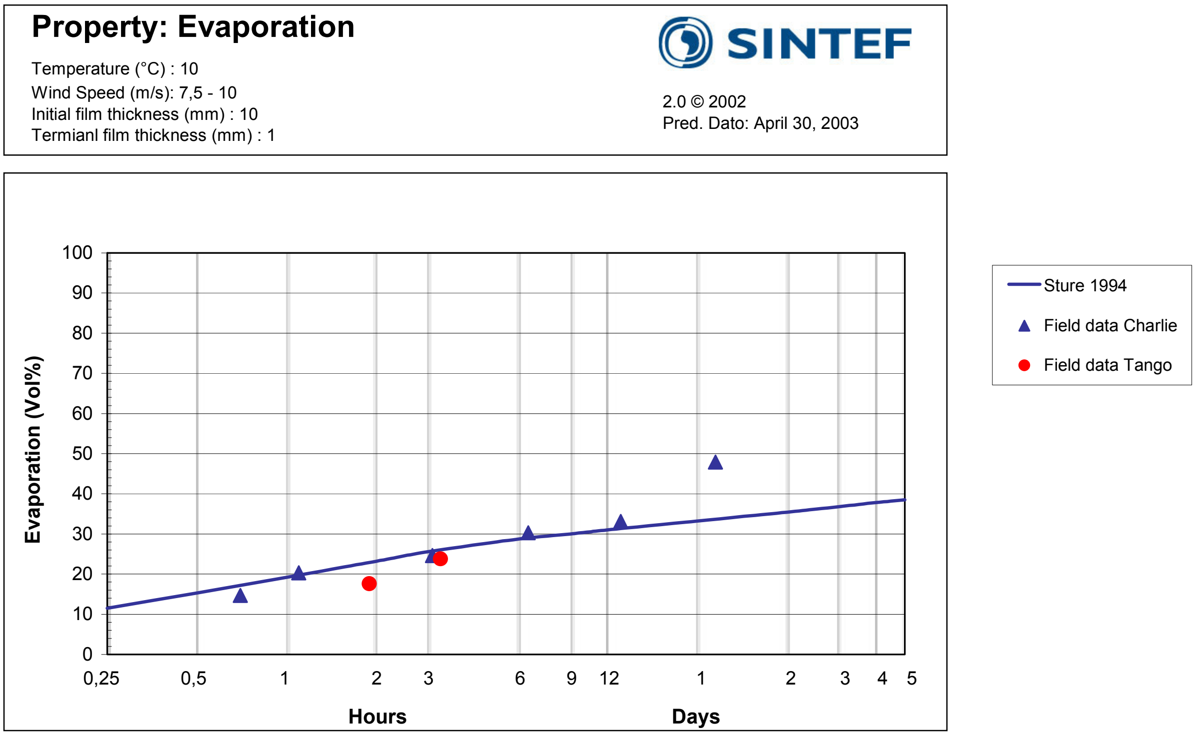

Figure 4.1 : Predicted evaporation and field data, Sture blend 1994.

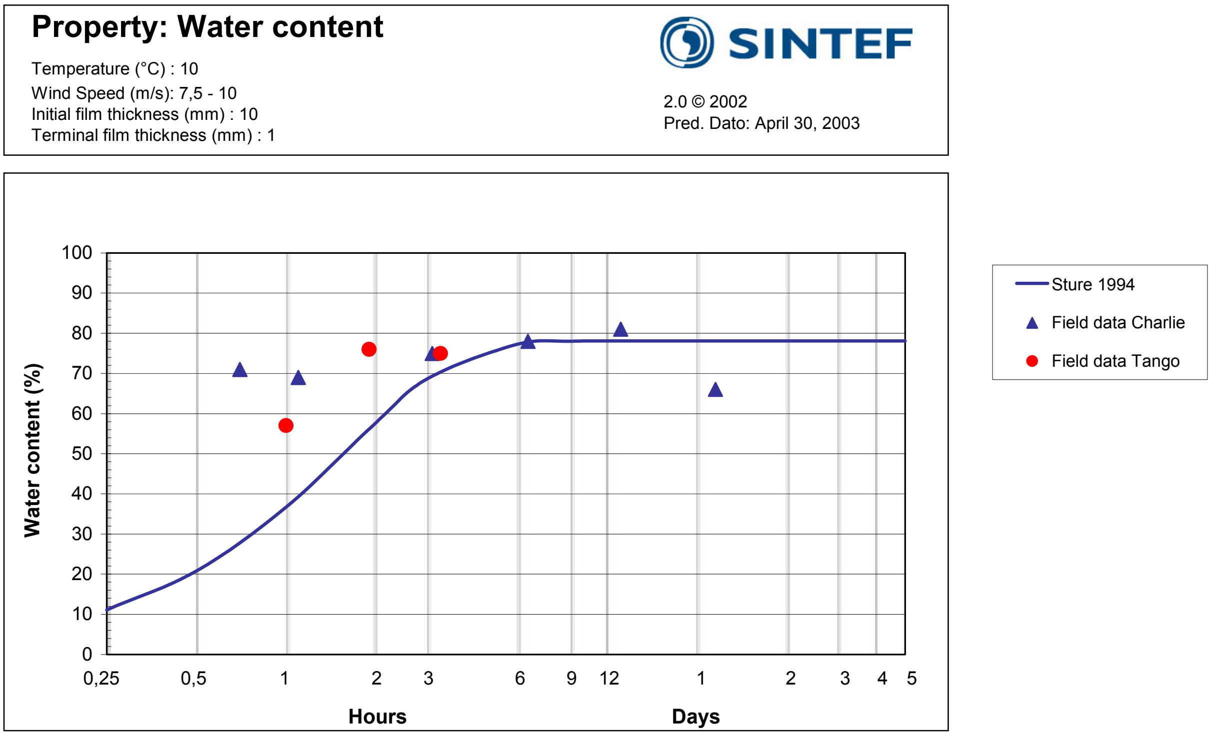

Figure 4.2 : Predicted water uptake and field data, Sture blend 1994.

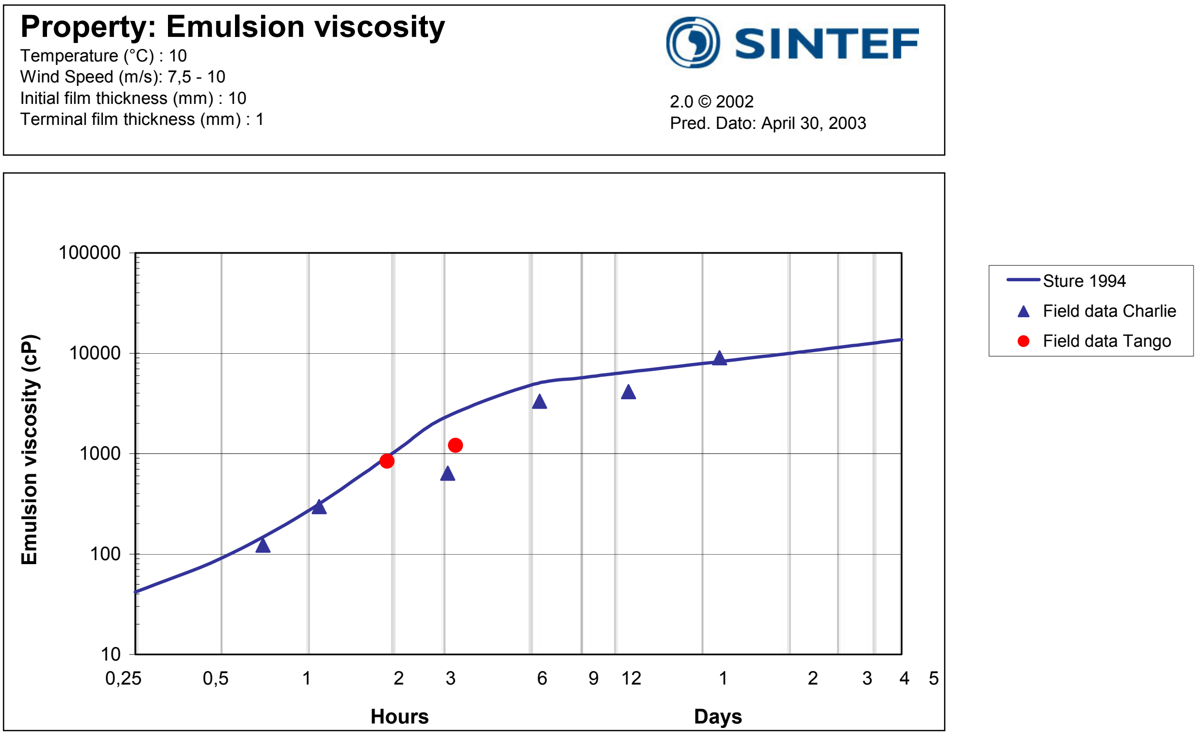

Figure 4.3 : Predicted emulsion viscosity and field data Sture blend 1994.

4.2 Field and input data 1994

The data from samples taken of the oil slick are given in the tables described here.

Table 4.1 : Physico-chemical properties on waterfree residues of Sture Blend and their water-in-oil emulsions from the control slick (Charlie) in the North Sea field trial in June 1994 (-: not performed, GC: gas chromatography, WOR is water-to-oil ratio, IFT is interfacial tension, D is fractional dehydration of emulsion).

Table 4.2 : Physico-chemical properties on water-free residues of Sture Blend and their water-in-oil emulsions from the treated slick (Tango) in the North Sea field trial in June 1994 (-: not performed, GC: gas chromatography, WOR is water-to-oil ratio, IFT is interfacial tension, D is fractional dehydration of emulsion).

Table 4.3 : Wind conditions at June 1994 Frigg field trial.

Table 4.4 : Input data for weathering predictions of Sture blends behaviour at sea.

Table 4.1 : Physico-chemical properties on waterfree residues of Sture Blend and their water-in-oil emulsions from the control slick (Charlie) in the North Sea field trial in June 1994 (-: not performed, GC: gas chromatography, WOR is water-to-oil ratio, IFT is interfacial tension, D is fractional dehydration of emulsion).

Charlie sampling station	Weathering time (Hours)	Evaporation (wt.%) Density *	Evaporation (wt.%) GC	Pour point water-free residue (°C)	Flash point water-free residue (°C)	IFT water-free residue (mN/m)	Emulsion water content (vol.%)	Emulsion water content (WOR)	Emulsion dispersibility
Fresh	0	0	0	0	-	24	0		
C1	0.2	4.6	-	-	22	-	55	1.2	-
C2	0.7	14.7	-	-	36	-	71	2.5	-
C3	1.1	20.3	19.8	15	58	19	69	2.2	Good
C5	3.1	24.6	-	18	90	-	75	3.0	Good
C6	6.5	30.3	-	21	-	-	78	3.5	-
C8	13.3	33.1	32.7	24	-	7	81	4.3	Reduced/bad
C11	27.7	47.9	43.2	-	-	3 **	66	1.9	Bad

Charlie sampling station	Viscosity (cP) Haake Rotovisco RV20 Water-free residue ($100s^{-1}$)	Viscosity (cP) Haake Rotovisco RV20 Emulsion ($10s^{-1}$)	Viscosity (cP) Bohlin 88BV Emulsion ($10s^{-1}$)	Density (g/mL) Emulsion	Density (g/mL) Water-free residue	Emulsion stability D_{1h}	D_{3h}	D_{24h}	D_{10d}	Effect of Alcopol O60% on emulsion ($D_{Alc.}$)	Emulsion film thickness (mm) •
Fresh	10				0.846						
C1	21 ± 1	-	75	0.949	0.857	1.0	1.0	1.0	1.0	-	12.9
C2	82 ± 5	123	271 ± 162	0.981	0.875	0.9	1.0	1.0	1.0	1.0	3.5 ± 1.4
C3	113	297 ± 4	845	0.981	0.884	0.3	1.0	1.0	1.0	1.0	1.8 ± 0.2
C5	190	638 ± 171	1410 ± 85	0.991	0.892	0.0	0.3	0.3	-	1.0	1.9 ± 0.7
C6	356 ± 27	3333 ± 197	4130	0.996	0.901	0.0	0.0	0.0	-	0.7	1.1 ± 0.2
C8	554 ± 78	4159 ± 199	5010 ± 255	1.002	0.906	0.0	0.0	0.0	0.5	0.8	-
C11	-	9023	12400	0.993	0.931	0.0	0.0	0.0	0.0	-	0.1 ± 0.02

*: *Based on predictions of oil density assuming zero water uptake.* ** : *Very difficult to measure.* •: *Based on pad extraction.*

Table 4.2 : Physico-chemical properties on water-free residues of Sture Blend and their water-in-oil emulsions from the treated slick (Tango) in the North Sea field trial in June 1994 (-: not performed, GC: gas chromatography, WOR is water-to-oil ratio, IFT is interfacial tension, D is fractional dehydration of emulsion).

Tango sampling station	Weathering time (Hours)	Evaporation (wt.%) Density *	Evaporation (wt.%) GC	Pour point water-free residue (°C)	Flash point water-free residue (°C)	IFT water-free residue (mN/m)	Emulsion water content (vol.%)	Emulsion water content (WOR)	Emulsion dispersibility
Fresh	0	0	0	-	-	24	0		
T2	1.0	17.6	-	-	-	-	57	1.4	Good
T3	1.9	23.8	23.6	-	-	-	76	3.2	-
T4	3.3	22.0	-	-	-	16	75	2.9	Good
T5 **	3.8	24.2	-	-	-	11	63	1.7	Good
T7	5.3	25.4	-	-	-	-	71	2.5	-
T8	7.5	28.6	-	-	-	4	73	2.7	Good/reduced
T9 ***	7.9	28.9	26.7	-	-	****	49	1.0	Good

Tango sampling station	Viscosity (cP) Haake Rotovisco RV20 Water-free residue ($100s^{-1}$)	Viscosity (cP) Haake Rotovisco RV20 Emulsion ($10s^{-1}$)	Viscosity (cP) Bohlin 88BV Emulsion ($10s^{-1}$)	Density (g/mL) Emulsion	Density (g/mL) Water-free residue	Emulsion stability D_{1h} D_{3h} D_{24h}	Effect of Alcopol O60% on emulsion ($D_{Alc.}$)	Emulsion film thickness (mm) •
Fresh	10				0.846			
T2	64 ± 7	-	602 ± 187	0.963	0.880	1.01.0 1.0	-	1.4 ± 0.7
T3	142 ± 4	840 ± 57	1415 ± 148	0.992	0.890	0.20.7 0.8	1.0	2.7 ± 1.4
T4	181 ± 11	1207 ± 164	1960	0.989	0.887	0.00.0 0.1	1.0	1.9 ± 0.2
T5 **	273 ± 68	1177 ± 324	1975 ± 148	0.975	0.891	0.00.0 0.0	0.9	1.8 ± 0.9
T7	277 ± 77	1838 ± 190	2500 ± 127	0.986	0.893	0.00.0 0.0	0.7	2.4
T8	342 ± 85	2813 ± 149	3595 ± 318	0.990	0.899	0.00.0 0.0	0.4	1.9
T9 ***	374 ± 64	892 ± 15	744 ± 119	0.961	0.899	0.01.0 1.0	0.8	-

*: *Based on predictions of oil density assuming zero water uptake.* ** : *After 1st treatment**** : *After 2nd treatment*
**** : *Impossible to measure* •: *Based on pad extraction.*

Table 4.3 : Wind conditions at June 1994 Frigg field trial.

Start date :	07.06.1994	
Cum. time (h)	**Wind speed (m/s)**	**Direction (°)**
0	8,2	245
4	9,8	255
8	8	243
12	8,2	230
16	8,2	250
20	8	260
24	7,5	270
28	8	290
32	8	290
120	8	290

Table 4.4 : Input data for weathering predictions of Sture blends behaviour at sea.

Fresh oil properties	
Specific Gravity (60 F/60 F)	0.847
Pour Point (°C)	-3
Reference temperature #1 (°C)	13
Viscosity at ref. temp.#1 (cP)	10
Vanadium (ppm wt.)	-
Nickel (ppm wt.)	-
Asphaltenes (wt. %)	-
n-Pentane Insolubles (wt. %)	-
Flash Point (°C)	-
Wax Content (wt. %)	-
Dispersable for visc. <	2000
Poorly dispersable for visc. >	9000
Maximum water uptake (%) at 5°C/13°C	-

-: *Data missing*

True boiling point curve	
Temperature (°C)	**Cumulative volume (%)**
90	10.62
120	16.74
145	21.48
160	24.23
205	32.29
250	40.62
295	50.27
350	61.09
420	70.84
565	89.12

Film thickness (mm)	
Initial	10
Terminal	1

Weathering properties (laboratory data)				
	Fresh	**150°C+**	**200°C+**	**250°C+**
Boiling temperature (°C)	-	185	250	303
Volume topped (%)	0	16	28	39
Residue (wt %)	100	86	76	65
Specific gravity (g/l)	0.847	0.877	0.892	0.907
Pour point (°C)	0	9	18	21
Flash point (°C)	-	38	80	119
Viscosity at 13°C (cP)*	10	25	65	350
Viscosity of 50% emulsion (cP)*	-	190	480	2800
Viscosity of 75% emulsion (cP)*	-	-	2600	6300
Viscosity of max water (cP)*	-	-	-	-
Maximum water content (%)	-	80	80	78
Halftime for water uptake (hrs)	-	0.13	0.1	0.18
Stability ratio	-	0.2	0.705	1

- : *Not measured*
* : *Viscosity measured at shear rate* $10s^{-1}$.

5 NOFO exercise 1995

5.1 The field experiments

The NOFO oil-water exercise 1995 included totally four surface releases and one sub-surface releases of stabilized Troll crude oil. The experiments were performed at the Frigg field in August 1995. The slicks were followed for about 0.5 - 2 days.

Objectives
The main objectives of the dispersant and underwater release activities at the Frigg field during the NOFO 1995 oil on water exercise were:

◊ To study the behavior, rate of spreading and weathering (evaporation, emulsification, natural dispersion etc.) of crude oil slicks released both from surface and sub-surface (107 meters depth simulating sub-sea pipeline leakage).
◊ To support valuable input data to the IKU Oil Weathering Model. These data will form basis for further refinements of the algorithms in the model.
◊ To assess the effectiveness of different methods of applying dispersant concentrates on oil slicks (from boat and helicopter).
◊ To study the capability of satellite-tracked drifting buoys to simulate the drift of surface and dispersed oil under various environmental conditions.
◊ To calibrate aerial remote sensing sensors (in aircraft, helicopter, and satellites) with ground truth data of the surface oil slicks.

Surface releases (day 1)
Three surface release slicks, each of 15 m^3 (Release rate: $1m^3$ / min) of stabilized Troll crude oil, were released about 1 nm apart:
◊ One slick (designated Hotel), was treated with Corexit 9500 from a S61-N helicopter using a SOKAF 3000 underslung bucket after 2 hours weathering of the oil at sea. The thick emulsion of the Hotel slick totally disappeared from the sea surface and was dispersed into the water column just after the dispersant application, and only sheen was left behind.
◊ The other slick, (designated Bravo), was treated with Corexit 9500 from the response vessel Gullbas using the Clearspray system, after 2 hours weathering. The treatment caused the Bravo emulsion initially to lose water before the thick part of it gradually dispersed into the water column.
◊ The third slick, (Charlie), was used as a control slick.

Results from the Charlie slick are presented in this report.

Sub-surface release (day 2)
Two slicks, each of 25 m^3 of stabilized Troll crude oil, were released about 1 nm apart:
◊ One slick, designated Uniform, was released by pumping the oil from 106 m depth. The oil was released without any gas present and resulted in a 2 to 5 mm thick surface slick of emulsion. No data are reported from this experiment due to very limited sampling.
◊ The other slick, Sierra, was a <u>surface</u> release and was used as a control for the Uniform slick.

Conclusions
The main conclusions from the 1995 NOFO sea trial were:

◊ A modern dispersant, correctly applied with a helicopter bucket or with spray arms from a ship, within the oils “window of opportunity” for dispersant use, is capable of dispersing the thick oil completely, within 10-30 minutes.

◊ No significant w/o-emulsification, of the oil in the underwater plume was observed, probably due to the low release pressure and that no gas was released with the oil (this was simulating a pipeline leakage).

The weather conditions were rougher during the Phase 1 trial with 8 to 10 m/s wind compared to Phase 2, where the wind speed varied between 7 and 4 m/s wind on Day 1 and 6 and 2 m/s on Day 2.

A more entire overview of the total field trial is given in The Operation Plan (Brandvik *et al*., 1995-a), the Cruise Report (Jensen *et al*., 1995) and the main technical report (Brandvik *et al*., 1995-b). The analyses data are presented in Strøm-Kristiansen *et al*., 1995.

Predicted evaporation, water uptake and emulsion viscosity from SINTEF OWM is presented together with field data for the Charlie and Sierra slicks in Figure 5.1, Figure 5.2 and Figure 5.3, respectively. The observed water content and emulsion viscosity of the Sierra slick was lower than for the Charlie slick. The Sierra emulsions taken during the first hour were very unstable, and both the water content and viscosity was probably under-estimated. The weather conditions were calmer during the Sierra release (2-6 m/s wind). The deviation in the viscosity from the OWM may be explained by that the majority of offshore field experiments which the development of the empirical algorithms are based on, have been performed under moderate to rough weather conditions (typical 6-15 m/s wind). Another explanation may also be due to that the input to the model are based on emulsion prepared in the laboratory (using the rotating flasks) that are simulating a more higher energy level.

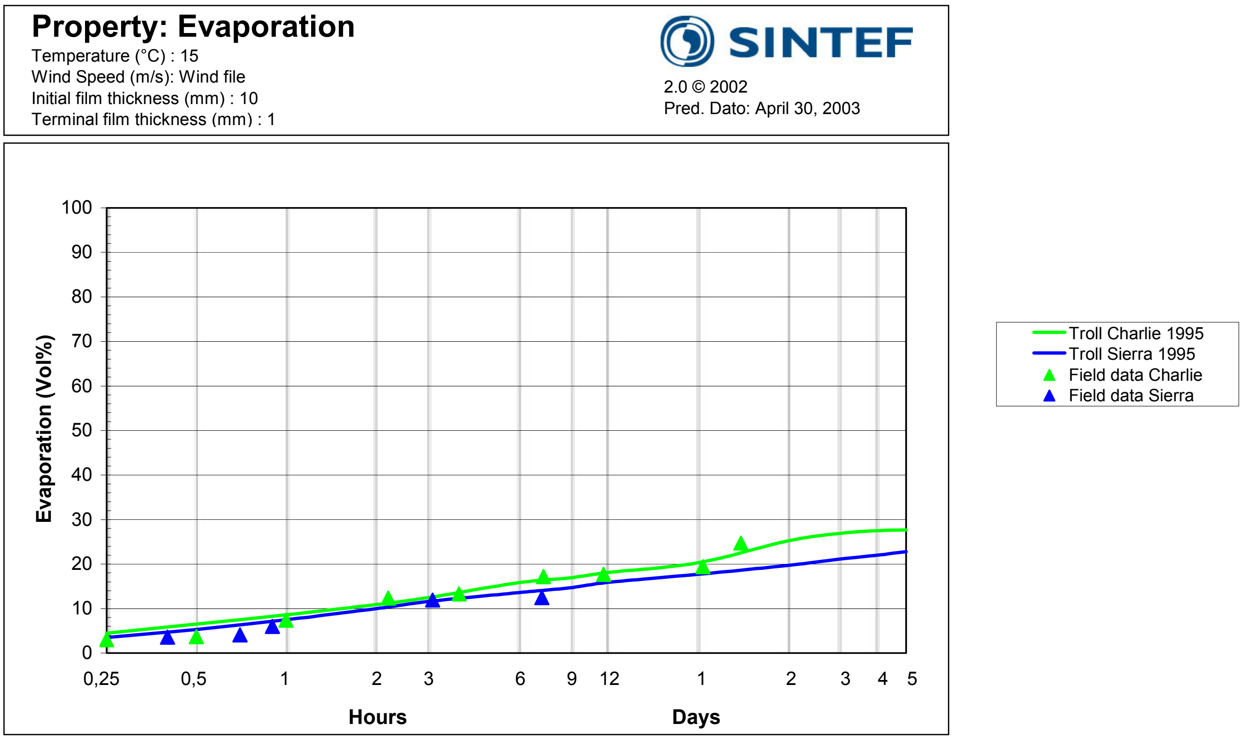

Figure 5.1 : Predicted evaporation and field data Troll crude oil, Charlie and Sierra 1995.

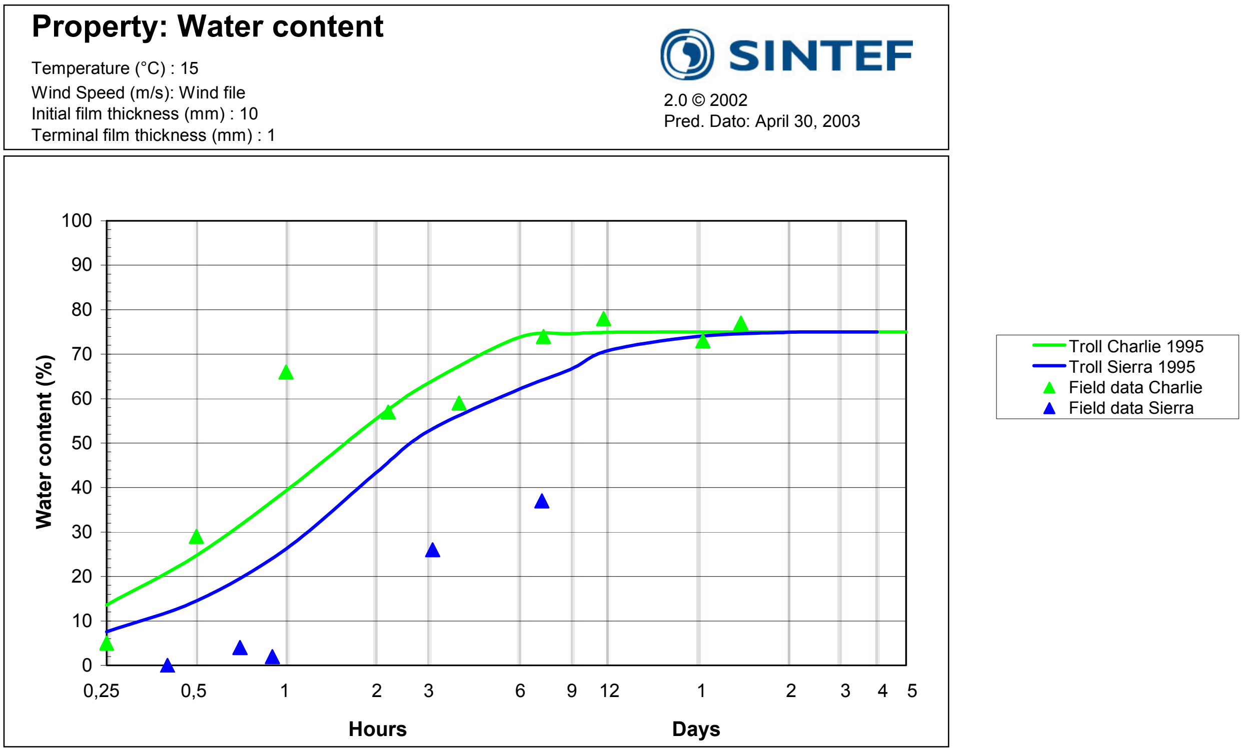

Figure 5.2 :Predicted water content and field data Troll crude oil, Charlie and Sierra 1995.

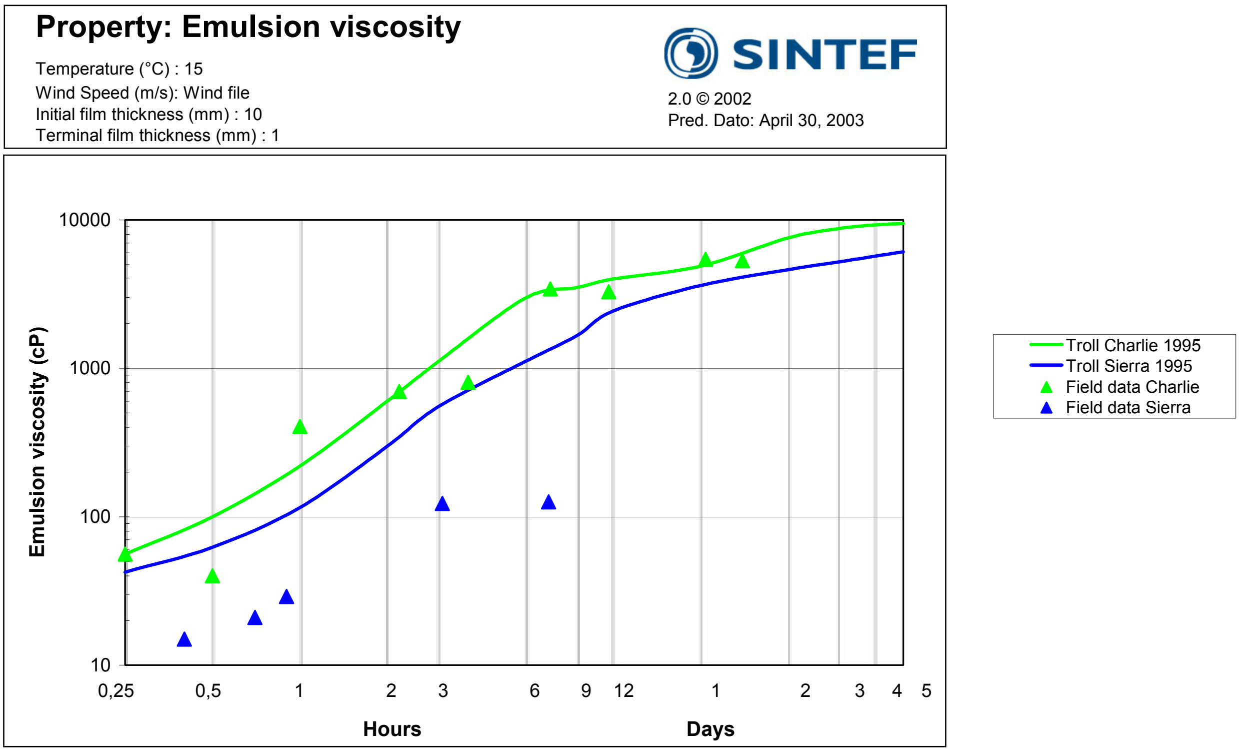

Figure 5.3 : Predicted water content and field data Troll crude oil, Charlie and Sierra 1995.

5.2 Field and input data 1995

The data from samples taken of the oil slick is given in the tables described here.

Table 5.1: Physico-chemical properties on waterfree residues of Troll crude and their water-in-oil emulsions from the control slick Day 1 (Charlie) in the North Sea field trial in August 1995.

Table 5.2 : Physico-chemical properties on waterfree residues of Troll crude and their water-in-oil emulsions from the control slick Day 2 (Sierra) in the North Sea field trial in August 1995.

Table 5.3 : Wind conditions at August 1995 Frigg field trial. Charlie slick.

Table 5.4 : Wind conditions at August 1995 Frigg field trial. Sierra slick.

Table 5.5 : Input data for weathering predictions of Troll crude oil behaviour at sea.

Table 5.1: Physico-chemical properties on waterfree residues of Troll crude and their water-in-oil emulsions from the control slick Day 1 (Charlie) in the North Sea field trial in August 1995.

W/o emulsion properties												
							Stability		**Emul brea. eff.		Film thickness (mm)	
Sampling station	**Weath. time (hours)**	**Water cont. (vol.%)**	**Density (g/mL)**	**Viscosity (cP)**	**Shear rate (s^{-1})**	**Dispers-ibility**	***D_{1h}**	***D_{24h}**	***D_{1h}**	***D_{24h}**	**Pad**	***In-situ***
C0	0	0	0.886	-	-	Good	-	-	-	-	-	-
C1	0.25	5	0.903	56 ± 14	20	-	-	-	-	-	-	10.3 ± 4.2
C2	0.5	29	0.935	•40 ± 6	20	-	0.35	0.59	0.40	0.77	-	6.0 ± 1.4
C3	1.0	66	0.983	405 ± 92	20	-	0.15	0.79	0.87	0.88	2.2 ± 0.2	3.5 ± 0.7
C4	2.2	57	0.974	699 ± 1	8	Good	0.24	0.51	1.00	1.00	••1.2 ± 0.1	5.0 ± 1.7
C5	3.8	59	0.977	805 ± 76	8	Good	0.01	0.14	0.89	0.96	•••1.0 ± 1.3	8.5 ± 2.1
C6	7.3	74	0.996	3435 ± 64	8	Red. disp.	0.01	0.16	0.73	0.93	-	10.0 ± 2.8
C7	11.6	78	1.000	3280 ± 127	8	Red. disp.	0.00	0.01	-	0.41	••••2.1 ± 0.4	7.5 ± 2.4
C9	25.0	73	0.995	5430 ± 339	8	Bad disp.	0.00	-	0.57	0.76	-	10.0
C10	33.5	77	1.001	5320	8	-	0.00	0.01	0.83	0.89	-	6.3 ± 3.1

Waterfree residue properties							
Sampling station	**Weath. time (hours)**	**Evap. loss (wt.%)**	**Density (g/ml)**	**Viscosity (cP, 100 s^{-1})**	**Pour point (°C)**	**Flash point (°C)**	**Interf. tension (mN/m)**
C0	0	0	0.886	21	-39	-	10.4
C1	0.25	3.0	0.897	42	-	34	-
C2	0.5	3.7	0.898	40	-	42	-
C3	1.0	7.4	0.902	64	-21	64	-
C4	2.2	12.4	0.908	83	-14	116	0.8
C5	3.8	13.3	0.909	99	-	125	-
C6	7.3	17.2	0.914	168	-6	-	0.6
C7	11.6	17.7	0.914	193	-	-	-
C9	25.0	19.4	0.916	217	-3	-	0.4
C10	33.5	24.7	0.923	200	-	-	0.3

-: *Not performed.*
*: *D is fractional dehydration of emulsion. D_{1h} is effect after 1 hour, D_{24h} is effect after 24 hours. D=0: no water settled. D=:1 all water settled.*
**: *Effect of 500 ppm concentration of the emulsion breaker Alcopol O60%, relative to the oil volume.*
•: *Unstable emulsion that was broken during measurement.*
••: *Pad sample gave 38 µm emulsion film thickness (in IR "black" area, finish aircraft, Lewis, 1995).*
•••: *Pad sample and cylinder measurement are not comparable values; taken in different parts of the slick.*
••••: *Pos. B 26 µm (IR "black" area, German aircraft, Lewis, 1995), pos. C 9 µm (UV area, German aircraft, Lewis, 1995).*

Table 5.2 : Physico-chemical properties on waterfree residues of Troll crude and their water-in-oil emulsions from the control slick Day 2 (Sierra) in the North Sea field trial in August 1995.

W/o emulsion properties												
							Stability		****Emul brea. eff.**		**Film thickness (mm)**	
Sampling station	**Weath. time (hours)**	**Water cont. (vol.%)**	**Density (g/mL)**	**Viscosity (cP)**	**Shear rate (s^{-1})**	**Dispers-ibility**	***D_{1h}**	***D_{24h}**	***D_{1h}**	***D_{24h}**	**Pad**	***In-situ***
S0	0	0	0.886	-	-	Good	-	-	-	-	-	-
S1	0.4	0	0.898	•15 ± 2	20	-	-	-	-	-	-	5.8 ± 1.8
S2	0.7	4	0.904	•21 ± 2	20	-	0.00	1.00	1.00	1.00	-	6.8 ± 2.8
S3	0.9	2	0.903	•29	20	-	0.00	0.63	-	-	-	4.8 ± 1.6
S4	3.1	26	0.938	123 ± 9	8	-	0.00	0.62	1.00	1.00	4.5 ± 1.4	6.3 ± 3.2
S6	7.2	37	0.951	126 ± 4	8	-	0.00	1.00	0.91	1.00	1.9 ± 0.4	3.4 ± 1.7

Waterfree residue properties						
Sampling station	**Weath. time (hours)**	**Evap. loss (wt.%)**	**Density (g/ml)**	**Viscosity (cP, 100 s^{-1})**	**Pour point (°C)**	**Flash point (°C)**
S0	0	0	0.886	21	-39	-
S1	0.4	3.6	0.898	41	-	-
S2	0.7	4.1	0.899	42	-	38
S3	0.9	6.0	0.901	55	-27	52
S4	3.1	11.9	0.908	80	-18	110
S6	7.2	12.5	0.908	105	-12	119

-: *Not performed.*

•: *Unstable emulsion that was broken during measurement.*

*: *D is fractional dehydration of emulsion. D_{1h} is effect after 1 hour, D_{24h} is effect after 24 hours. D=0: no water settled. D=:1 all water settled.*

**: *Effect of 500 ppm concentration of the emulsion breaker Alcopol O60%, relative to the oil volume.*

Table 5.3 : Wind conditions at August 1995 Frigg field trial. Charlie slick.

Cum. time (hours)	Wind (m/s)	Direction (°)	Cum. time (hours)	Wind (m/s)	Direction (°)
*0.0	6.5	274	22.0	6.1	222
0.5	5.9	281	22.5	6.1	248
1.0	6.4	267	23.0	7.0	248
1.5	6.5	314	23.5	7.0	267
2.0	7.0	268	24.0	7.0	290
2.5	6.8	274	24.5	6.6	259
3.0	6.2	263	25.0	7.5	267
3.5	7.2	270	25.5	7.0	281
4.0	7.0	270	26.0	7.5	284
4.5	7.5	253	26.5	7.5	321
5.0	7.5	143	27.0	5.6	276
5.5	7.0	262	27.5	5.6	281
6.0	7.5	278	28.0	5.2	278
6.5	6.6	276	28.5	5.6	270
7.0	6.6	253	29.0	6.1	284
7.5	5.6	287	29.5	5.6	262
8.0	5.2	250	30.0	5.6	298
8.5	4.7	262	30.5	5.6	278
9.0	6.1	250	31.0	5.2	276
9.5	5.6	284	31.5	4.7	270
10.0	5.6	259	32.0	4.7	290
10.5	5.6	245	32.5	4.2	270
11.0	5.6	242	33.0	3.8	287
11.5	5.6	262	33.5	3.3	278
12.0	5.2	250	34.0	2.3	264
12.5	5.2	264	34.5	1.4	256
13.0	4.7	253	35.0	2.3	256
13.5	4.7	245	35.5	2.3	222
14.0	4.7	253	36.0	2.8	236
14.5	4.2	231	36.5	2.8	219
15.0	4.7	233	37.0	3.3	203
15.5	5.2	233	37.5	3.3	200
16.0	5.2	208	38.0	3.3	208
16.5	6.1	208	38.5	3.8	228
17.0	6.1	222	39.0	2.8	208
17.5	6.6	233	39.5	3.3	222
18.0	7.0	200	40.0	2.8	203
18.5	7.5	208	40.5	3.3	191
19.0	8.0	312	41.0	3.3	197
19.5	7.5	214	41.5	2.8	214
20.0	7.0	236	42.0	2.3	217
20.5	7.5	225	42.5	1.9	219
21.0	7.0	270	43.0	2.3	211
21.5	6.1	239	43.5	2.3	200
			120.0	2.3	200

*: *Start time is 06^{30} 15^{th} August 1995.*

Table 5.4 : Wind conditions at August 1995 Frigg field trial. Sierra slick

Cum. time (hours)	Wind (m/s)	Direction (°)	Cum. time (hours)	Wind (m/s)	Direction (°)
*0.0	5.6	270	8.0	2.8	219
0.5	6.1	284	8.5	3.3	203
1.0	5.6	262	9.0	3.3	200
1.5	5.6	298	9.5	3.3	208
2.0	5.6	278	10.0	3.8	228
2.5	5.2	276	10.5	2.8	208
3.0	4.7	270	11.0	3.3	222
3.5	4.7	290	11.5	2.8	203
4.0	4.2	270	12.0	3.3	191
4.5	3.8	287	12.5	3.3	197
5.0	3.3	278	13.0	2.8	214
5.5	2.3	264	13.5	2.3	217
6.0	1.4	256	14.0	1.9	219
6.5	2.3	256	14.5	2.3	211
7.0	2.3	222	15.0	2.3	200
7.5	2.8	236	120.0	2.3	200

*: *Start time is 11^{00} 16^{th} August 1995.*

Table 5.5 : Input data for weathering predictions of Troll crude oil behaviour at sea.

Fresh oil properties	
Specific Gravity (60 F/60 F)	0.893
Pour Point (°C)	-12
Reference temperature #1 (°C)	13
Viscosity at ref. temp.#1 (cP)	27
Vanadium (ppm wt.)	-
Nickel (ppm wt.)	-
Asphaltenes (wt. %)	-
n-Pentane Insolubles (wt. %)	-
Flash Point (°C)	3
Wax Content (wt. %)	-
Dispersable for visc. <	3000
Poorly/not dispersable for visc. >	7000
Maximum water uptake (%) at 5°C/13°C	-

-: *Data missing*

True boiling point curve	
Temperature (°C)	**Cumulative volume (%)**
65	1.43
90	3.04
150	9.57
180	13.83
240	24.49
320	45.71
375	57.21
420	63.49
525	83.78
565	87.99

Film thickness (mm)	
Initial	10
Terminal	1

Weathering properties (laboratory data)				
	Fresh	**150°C+**	**200°C+**	**250°C+**
Boiling temperature (°C)	-	210	255	300
Volume topped (%)	0	8	15	24
Residue (wt %)	100	93	87	78
Specific gravity (g/l)	0.893	0.903	0.909	0.919
Pour point (°C)	-39	-15	-9	3
Flash point (°C)	3	50	80	119
Viscosity at 13°C (cP)*	27	49	83	200
Viscosity of 50% emulsion (cP)*	-	343	593	1300
Viscosity of 75% emulsion (cP)*	-	1815	2673	4790
Viscosity of max water (cP)*	-	-	-	-
Maximum water content (%)	-	75	75	75
Halftime for water uptake (hrs)	-	0.09	0.07	0.13
Stability ratio	-	0.78	1	1

- : *Not measured*
* : *Viscosity measured at shear rate $10s^{-1}$.*

6 NOFO exercise 1996

6.1 The field experiments

The NOFO oil-water exercise 1996 included two surface releases and one sub-surface release of stabilized Troll crude oil with gas present. The experiments were performed at the Frigg field in June 1996.

Objectives

The objectives of the 1996 exercise were :

◊ To determine how the weathering processes (evaporation, water-in-oil emulsification and natural dispersion) of Troll crude oil proceeded in the control (Charlie) and the treated slick (Hotel, treated by helicopter with the new “Response 3000” bucket) after dispersant application.

◊ To determine how the surface slick resulting from the underwater release (designated Uniform) of Troll crude oil combined with gas (GOR of 1:67), behaved.

◊

The field trials in both 1995 and 1996 were performed in order to form basis for building up an operational and cost-effective dispersant response in Norway (for terminals, refineries, offshore oil fields etc.).

Surface releases

Two surface released slicks of fresh, stabilized Troll crude oil were released about 1 nm apart:

◊ One slick, (designated Hotel), was treated with the dispersant Corexit 9500 from a S61-N helicopter using the newly developed underslung bucket “Response 3000” (described in Brandvik 1996b) after 4 hours weathering of the oil at sea. The treated part of the Hotel slick totally disappeared from the sea surface and dispersed into the water column just after the dispersant application.

◊ The other slick, Charlie, was used as a control slick.

Sub-surface releases

In 1995 field trial the oil was released without any gas present, in the 1996 field trials compressed air was used to simulate an oil-gas blow-out.

◊ One release of fresh, stabilized Troll crude oil, together with compressed air simulating gas, was released from 106 m depth (not discussed in this report, due to too low film thickness for surface oil sampling).

Conclusions

The main conclusions from the experiments were :

◊ Troll crude oil emulsified slowly and reached a maximum water content of approximately 60 vol.% and a viscosity of 2000 cP (shear rate 10 s^{-1}) after 10 hours weathering at the sea surface. These measured values were lower than the predicted values due to unstable emulsions. The weather conditions were rather calm, with an average wind speed of about 4 to 5 m/s, and too low to cause breaking waves. The same situation occurred during the August 1995 trials when the Sierra slick was monitored on Day 2 (5 to 6 m/s wind).

The physico-chemical properties of surface oil from the field experiment in 1996 are further described by Strøm-Kristiansen *et al*., 1996.

Weathering data from the Charlie slick and the Hotel slick before dispersant treatment is presented in this report. Predicted evaporation, water uptake and emulsion viscosity from SINTEF OWM is presented together with field data in Figure 6.1, Figure 6.2 and Figure 6.3 respectively.

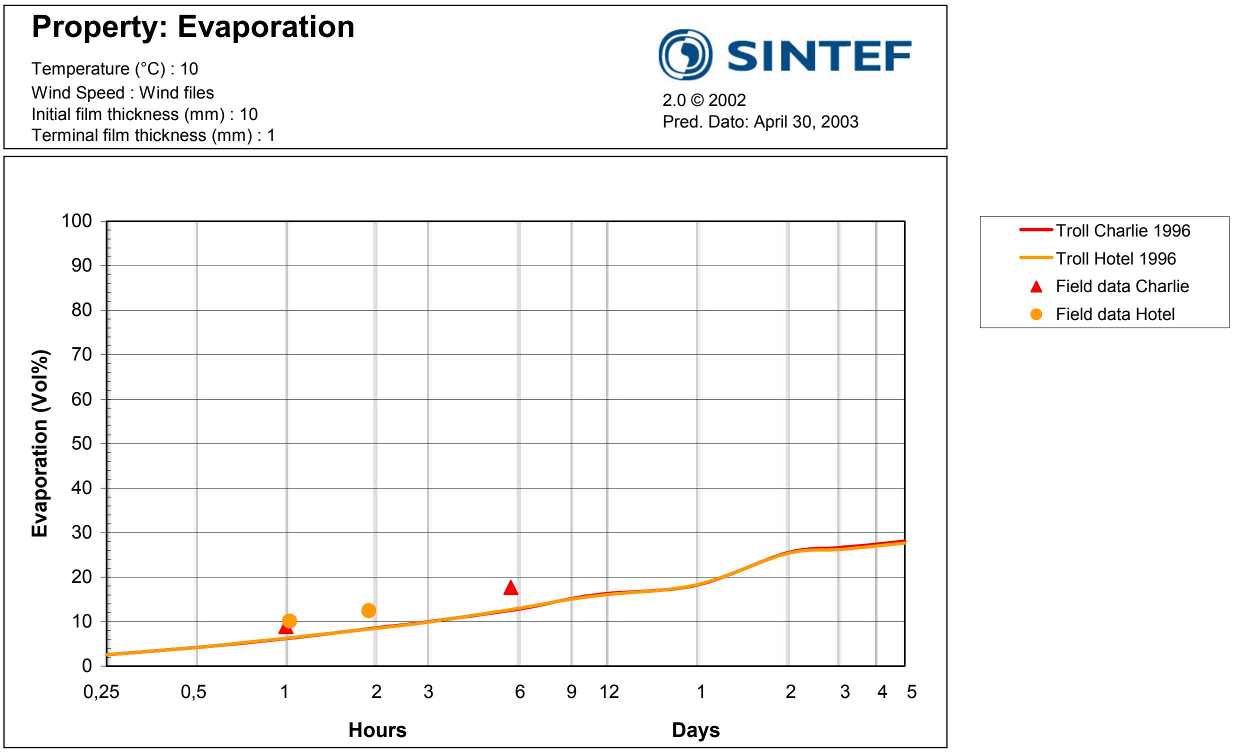

Figure 6.1 : Predicted evaporation and field data Troll crude oil Charlie and Hotel 1996.

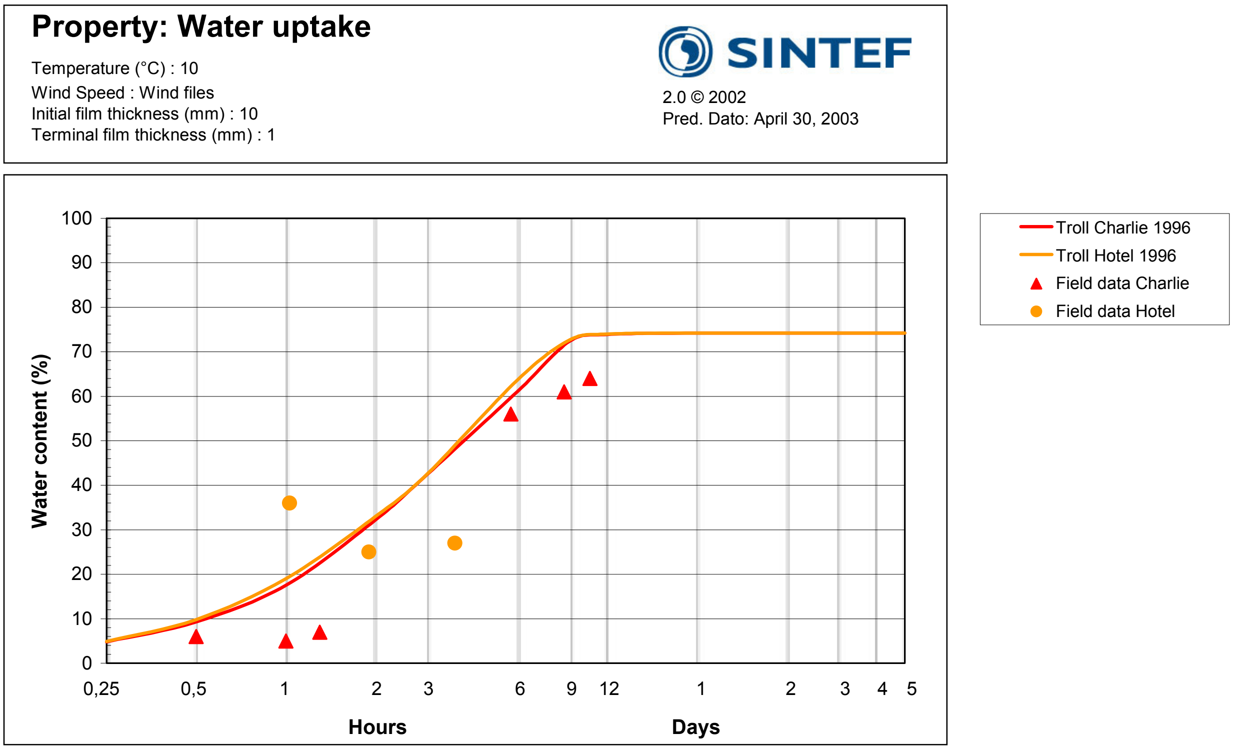

Figure 6.2 Predicted water uptake and field data Troll crude oil Charlie and Hotel 1996.

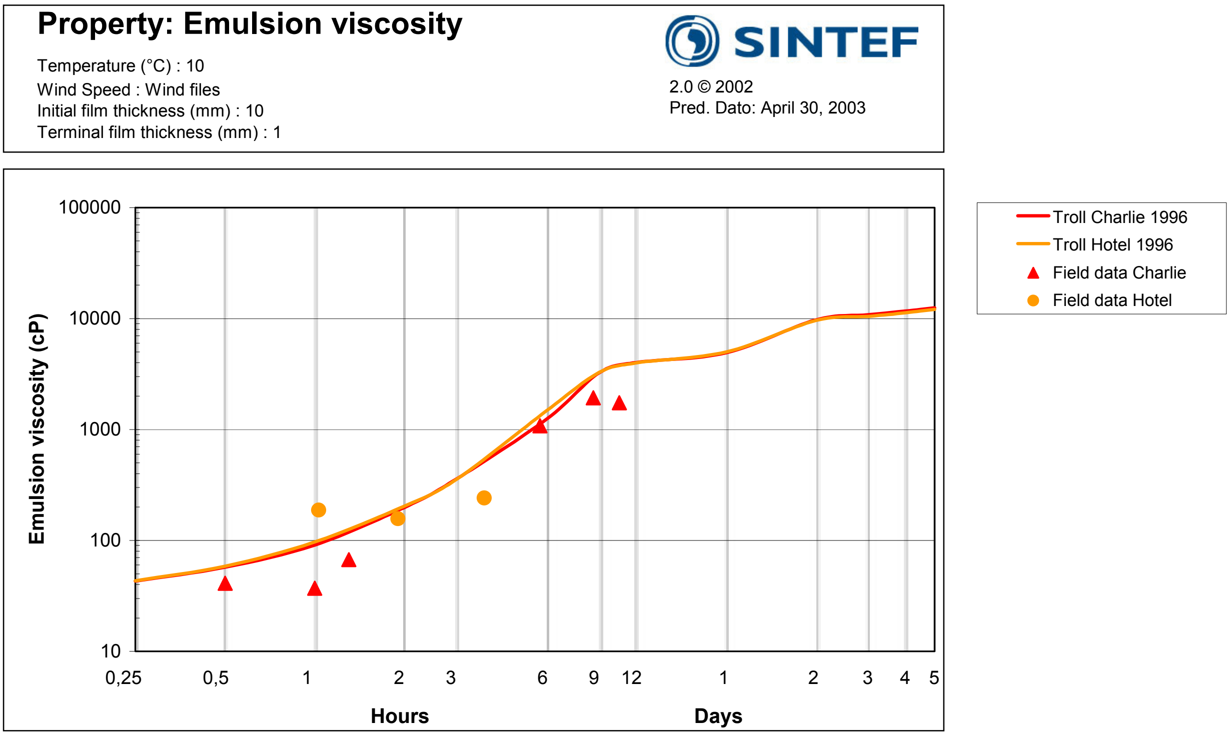

Figure 6.3 : Predicted emulsion viscosity and field data Troll crude oil Charlie and Hotel.

6.2 Field and input data 1996

The data from samples taken of the oil slick are given in the tables described here.

Table 6.1 : Overview surface oil sampling in Charlie slick (control) 11 - 12 June 1996.

Table 6.2 : Physico-chemical properties on water-free residues of Troll crude and their water-in-oil emulsions from the control slick Day 1 (Charlie) in the North Sea field trial in June 1996.

Table 6.3 Physico-chemical properties on water-free residues of Troll crude and their water-in-oil emulsions from the helicopter treated slick released on Day 1 (Hotel slick) in the North Sea field trial in June 1996.

Table 6.4 : Wind conditions at June 1996 Frigg field trial. Charlie slick.

Table 6.5 : Wind conditions at June 1996 Frigg field trial. Hotel slick.

Table 6.6 : Input data for predictions of Troll crude oil behaviour at sea.

Table 6.1 : Overview surface oil sampling in Charlie slick (control) 11 - 12 June 1996.

ID	**Date**	**Time (local)**	**Weathering time**	**Latitude / Longitude** **GPS (Global Pos. System)**	**Film Thickness (cylinder, *in-situ*)**	**Pad sample**	**Comments**
Charlie	11.06.	08.00 - 08.15	0•				Release of Charlie slick.
C1	"	08.23	0.13	60.00.255 / 002.24.888			Full set of samples collected in thick part of the slick). Slick front just before sampling (08.19): 60.00.305 / 002.24.857.
C2-A	"	08.45	0.5	60.00.322 / 002.25.032			Full set of samples collected in thick part of the slick.
C2-B	"	08.50	0.6	60.00.322 / 002.25.032	3 mm		
C3	"	09.15	1.0	60.00.392 / 002.25.268			Full set of samples collected in thick part of the slick (at buoy 9810). Slick front just before sampling: 60.00.413 / 002.25.269.
C4	"	09.33	1.3	60.00425 / 002.25.432			Full set of samples collected in thick part of the slick (at buoy 9810). Slick front just before sampling: 60.00.472 / 002.25.498.
C7-A	"	13.53	5.6	60.00.135 / 002.25.595 60.00.318 / 002.25.097	5 mm 10 mm 10 mm		GPS positions were logged during the 3 thickness measurements.
C7-B	"	13.55	5.7	60.00.135 / 002.25.595			Full set of samples collected in thick part of the slick (at buoy 9810).
C8-A	"	16.51	8.6	60.01.361 / 002.23.752			Full set of samples collected in thick part of the slick. Lots of thick emulsion.
C8-B	"	16.55	8.7	60.01.353 / 002.23.742	15 mm		
C9	"	18.45	10.5				
C10-A	12.06	14.25	30.2	60.01.398 / 002.29.092		1	
C10-B	"	"	30.2	60.01.367 / 002.29.081		1	

•: Time 0 is 08.15.

Table 6.2 : Physico-chemical properties on water-free residues of Troll crude and their water-in-oil emulsions from the control slick Day 1 (Charlie) in the North Sea field trial in June 1996.

W/o emulsion properties												Water-free residue properties	
						Stability		**Emul brea. eff.		Em. film thickness			
Sampling station	**Weath. time (hours)**	**Water cont. (vol.%)**	**Density (g/mL)**	**Viscosity (cP)**	**Shear rate (s^{-1})**	**$*D_{1h}$**	**$*D_{24h}$**	**$*D_{1h}$**	**$*D_{24h}$**	**Pad (mm)**	***In-situ* (mm)**	**Evap. loss (wt%)**	**Density (g/mL)**
C0	0•	0	0.887			-		-	-	-	-	0.0	0.887
C1	0.1	0	0.891	44	10	0.0	0.0	0.0	0.0	-	-	-	0.892
C2-A	0.5	6	0.904	41	10	1.0	1.0	1.0	1.0	-	-	2.6	0.897
C2-B	0.6	-	-	-	-	-	-	-	-	-	3	-	-
C3	1.0	5	-	37	10	1.0	1.0	1.0	1.0	-	-	-	-
C4	1.3	7	0.912	67	10	0.7	0.7	0.7	0.7	-	-	8.9	0.904
C7-A	5.6		-							-	5 10 10	-	-
C7-B	5.7	56	0.975	1080	10	0.0	0.0	0.9	0.9	-	-	16.2	0.913
C8-A	8.6	61	0.981	1930	10	0.0	0.0	0.0	1.0	-	-	17.7	0.914
C8-B	8.7	-	-	-	-	-	-	-	-	-	15	-	-
C9	10.5	64	0.983	1740	10	0.0	0.2	0.0	0.9	-	-	16.4	0.913
C10-A	30.2	-	-	-	-	-	-	-	-	0.002	-	-	-
C10-B	30.2	-	-	-	-	-	-	-	-	0.001	-	-	

•: Time 0 is 08.15, 11 June (oil release finished).
-: Not performed.
**: D is fractional dehydration of emulsion. D_{1h} is effect after 1 hour, D_{24h} is effect after 24 hours. D=0: no water settled. D=:1 all water settled.*
***: Effect of 500 ppm concentration of the emulsion breaker Alcopol O 60 %, relative to the emulsion volume.*

Table 6.3 Physico-chemical properties on water-free residues of Troll crude and their water-in-oil emulsions from the helicopter treated slick released on Day 1 (Hotel slick) in the North Sea field trial in June 1996.

W/o emulsion properties												**Water-free residue properties**	
						Stability		****Emul brea. eff.**		**Em. film thickness**			
Sampling station	**Weath. time (hours)**	**Water cont. (vol.%)**	**Density (g/mL)**	**Viscosity (cP)**	**Shear rate (s^{-1})**	***D_{1h}**	***D_{24h}**	***D_{1h}**	***D_{24h}**	**Pad (mm)**	***In-situ* (mm)**	**Evap. loss (wt%)**	**Density (g/mL)**
H0	0•	0	0.889			-	-	-	-		-	0.0	0.889
H1-A	1.03	36	0.948	188	10	1.0	1.0	0.9	0.9	-	-	10.1	0.906
H1-B	1.5									-	13 15	-	-
H1-C	1.6	-	-	-	-	-	-	-	-	-	2	-	-
H1-D1	1.67	-	-	-	-	-	-	-	-	1.70	4	-	-
H1-D2	1.67	-	-	-	-	-	-	-	-	0.75	5	-	-
H1-E	1.7	-	-	-	-	-	-	-	-		-	-	-
H2-A	1.9	25	0.938	157	10	0.8	0.8	1.0	1.0		-	12.5	0.908
H2-B	3.7	27	-	241	10	-	-	-	-		-	-	-
Disp. appl.				-		-	-	-	-		-	-	-
H3-A	4.00	25	0.940	130	10	0.2	0.6	0.3	0.8	0.13	-	14.8	0.911
H3-B	4.07	-	-	-	-	-	-	-	-	0.05	-	-	-
H3-C	4.13	-	-	-	-	-	-	-	-	0.04	-	-	-
H4••	8.3	60	0.981	2480	10	0.1	0.1	0.1	0.2	-	-	20.3	0.917
H5-A	9.5	-	-	-	-	-	-	-	-	-	4	-	-
H5-B	9.5	-	-	-	-	-	-	-	-	-	15	-	-
H5-C	9.5	-	-	-	-	-	-	-	-	-	10 - 15	-	-

•: *Time 0 is 09.15 (oil release finished).*
••: *Sample collected in a minor area of the Hotel slick not hit by dispersant.*
-: *Not performed.*
*: *D is fractional dehydration of emulsion. D_{1h} is effect after 1 hour, D_{24h} is effect after 24 hours. D=0: no water settled. D=:1 all water settled.*
**: *Effect of 500 ppm concentration of the emulsion breaker Alcopol O60%, relative to the oil volume.*

Table 6.4 : Wind conditions at June 1996 Frigg field trial. Charlie slick.

Cum. time (hours)	Wind (m/s)	Direction (°)	Cum. time (hours)	Wind (m/s)	Direction (°)
*0.0	4.7	174.4	17.0	4.2	174.4
0.5	4.7	149.1	17.5	4.7	143.4
1.0	4.2	177.2	18.0	4.7	120.9
1.5	4.7	160.3	18.5	2.3	154.7
2.0	4.7	168.8	19.0	2.3	154.7
2.5	4.7	180.0	19.5	3.3	208.1
3.0	4.2	160.3	20.0	2.3	230.6
3.5	3.8	157.5	20.5	2.8	278.4
4.0	4.2	149.1	21.0	4.2	275.6
4.5	5.2	137.8	21.5	6.1	298.1
5.0	5.6	146.3	22.0	8.0	289.7
5.5	5.6	168.8	22.5	10.3	309.4
6.0	3.3	174.4	23.0	10.8	309.4
6.5	6.1	157.5	23.5	11.3	292.5
7.0	6.6	135.0	24.0	11.3	300.9
7.5	7.0	149.1	24.5	10.3	295.3
8.0	7.0	160.3	25.0	10.3	303.8
8.5	7.5	174.4	25.5	8.9	295.3
9.0	7.0	146.3	26.0	8.9	292.5
9.5	6.6	157.5	26.5	8.9	281.3
10.0	6.6	163.1	27.0	9.4	286.9
10.5	7.0	188.4	27.5	9.4	331.9
11.0	6.6	157.5	28.0	9.4	264.4
11.5	6.1	180.0	28.5	8.4	289.7
12.0	6.1	177.2	29.0	8.4	275.6
12.5	6.1	163.1	29.5	8.9	292.5
13.0	5.6	171.6	30.0	8.9	261.6
13.5	6.1	154.7	30.5	8.4	222.2
14.0	5.6	168.8	31.0	8.9	275.6
14.5	5.6	168.8	31.5	8.4	264.4
15.0	5.6	160.3	32.0	8.4	267.2
15.5	5.6	168.8			
16.0	5.2	165.9			
16.5	5.2	168.8			

*: *Start time is* 08^{00} *11th June 1996* (start oil release).

Table 6.5 : Wind conditions at June 1996 Frigg field trial. Hotel slick.

Cum. time (hours)	Wind (m/s)	Direction (°)	Cum. time (hours)	Wind (m/s)	Direction (°)
*0.0	4.2	177.2	16.0	4.2	174.4
0.5	4.7	160.3	16.5	4.7	143.4
1.0	4.7	168.8	17.0	4.7	120.9
1.5	4.7	180.0	17.5	2.3	154.7
2.0	4.2	160.3	18.0	2.3	154.7
2.5	3.8	157.5	18.5	3.3	208.1
3.0	4.2	149.1	19.0	2.3	230.6
3.5	5.2	137.8	19.5	2.8	278.4
4.0	5.6	146.3	20.0	4.2	275.6
4.5	5.6	168.8	20.5	6.1	298.1
5.0	3.3	174.4	21.0	8.0	289.7
5.5	6.1	157.5	21.5	10.3	309.4
6.0	6.6	135.0	22.0	10.8	309.4
6.5	7.0	149.1	22.5	11.3	292.5
7.0	7.0	160.3	23.0	11.3	300.9
7.5	7.5	174.4	23.5	10.3	295.3
8.0	7.0	146.3	24.0	10.3	303.8
8.5	6.6	157.5	24.5	8.9	295.3
9.0	6.6	163.1	25.0	8.9	292.5
9.5	7.0	188.4	25.5	8.9	281.3
10.0	6.6	157.5	26.0	9.4	286.9
10.5	6.1	180.0	26.5	9.4	331.9
11.0	6.1	177.2	27.0	9.4	264.4
11.5	6.1	163.1	27.5	8.4	289.7
12.0	5.6	171.6	28.0	8.4	275.6
12.5	6.1	154.7	28.5	8.9	292.5
13.0	5.6	168.8	29.0	8.9	261.6
13.5	5.6	168.8	29.5	8.4	222.2
14.0	5.6	160.3	30.0	8.9	275.6
14.5	5.6	168.8	30.5	8.4	264.4
15.0	5.2	165.9	31.0	8.4	267.2
15.5	5.2	168.8			

*: *Start time is* 09^{00} 11^{th}*June 1996* *(start oil release).*

Table 6.6 : Input data for predictions of Troll crude oil behaviour at sea.

Fresh oil properties	
Specific Gravity (60 F/60 F)	0.893
Pour Point (°C)	-12
Reference temperature #1 (°C)	13
Viscosity at ref. temp.#1 (cP)	27
Vanadium (ppm wt.)	-
Nickel (ppm wt.)	-
Asphaltenes (wt. %)	-
n-Pentane Insolubles (wt. %)	-
Flash Point (°C)	3
Wax Content (wt. %)	-
Dispersable for visc. <	3000
Poorly/not dispersable for visc. >	7000
Maximum water uptake (%) at 5°C/13°C	-

-: *Data missing*

True boiling point curve	
Temperature (°C)	**Cumulative volume (%)**
65	1,43
90	3,04
150	9,57
180	13,83
240	24,49
320	45,71
375	57,21
420	63,59
525	83,78
565	87,99

Film thickness (mm)	
Initial	10
Terminal	1

Weathering properties (laboratory data)				
	Fresh	**150°C+**	**200°C+**	**250°C+**
Boiling temperature (°C)	-	210	255	300
Volume topped (%)	0	8	156	24
Residue (wt %)	100	93	87	78
Specific gravity (g/l)	0.893	0.903	0.909	0.919
Pour point (°C)	-39	-15	-9	3
Flash point (°C)	3	50	80	119
Viscosity at 13°C (cP)*	27	49	83	200
Viscosity of 50% emulsion (cP)*	-	343	593	1300
Viscosity of 75% emulsion (cP)*	-	1815	2673	4790
Viscosity of max water (cP)*	-	-	-	-
Maximum water content (%)	-	75	75	75
Halftime for water uptake (hrs)	-	0.09	0.07	0.13
Stability ratio	-	0.78	1	1

- : *Not measured*

* : *Viscosity measured at shear rate $10s^{-1}$.*

7 AEA field experiments UK 1997

7.1 The field experiments

During the AEA'97 Experimental Sea Trial outside UK, September 17th - 24th, the target was therefore to let the oils weather at sea to a stage where the weathered and emulsified oils were considered to be more difficult to disperse. During these experimental field trials the following three oils were released and weathered at sea prior dispersant application with Corexit 9500:

- 50m^3 Forties weathered for 2 days at sea prior to treatment of 2.5m^3 Corexit 9500
- 20m^3 IFO-180 Heavy bunker fuel weathered for 4.5 hours at sea prior to treatment of 0.9m^3 Corexit 9500 followed by a 2nd treatment 23-25 hours at sea (2.0 m^3 Corexit 9500)
- 31m^3 Alaska North Slope (ANS) crude (designated "Alpha") weathered for 2.5 days at sea prior to treatment of
  1.0 m^3 Corexit 9500

..

Due to lack of ground truth sampling of oil weathering data of the Forties and the HFO slicks, only weathering data and predictions of the Alpha slick is presented in this report.

The primary purpose of the experiments was to measure the changes in oil properties during weathering at sea, and to determine the period of time during which Corexit 9500 can be considered as a viable response option for these oils.

In order to have a better understanding and documentation of the likely weathering properties and chemical dispersibility with Corexit 9500 on the oils planned to be used in the field, it was decided to perform some laboratory experiments prior the field trial.

Summary

During a laboratory study prior the field trials, the weathering properties and the "dispersibility properties" for weathered ANS crude and IFO-180 heavy fuel oil were defined. The experimental data from this laboratory study were used as input to the SINTEF Oil Weathering Model to improve the validity of the predictions of the weathering properties and in estimating the "time window" for effective use of Corexit 9500 on the oils to be used in the field trial.

Compared to earlier studies carried out with Corexit 9527 at SINTEF, Corexit 9500 shows an improvement in the dispersibility up to a viscosity of 20.000 cP on the ANS emulsions. This gives a significant increase in the "time window" for effective use of dispersant on the ANS crude.

In addition to the ANS testing, some limited chemical dispersibility testing with Corexit 9500 on two different batches of IFO-180 HFOs was carried out in SINTEFs laboratories. Also for the bunker fuels, the dispersant dosage seem to be very critical to the effectiveness results (dosages up to 1:10 is required). More systematic investigation is also needed in order to better establish the "viscosity areas" for dispersibility for different bunker oil qualities and their w/o-emulsions.

The viscosity data obtained in the laboratory and by the model predictions generated prior the trials corresponded well with the weathering and dispersant performance that took place in the field. These field trials therefore confirmed laboratory studies carried out at SINTEF indicating

that it is possible to disperse ANS crude oil emulsions up to a viscosity of 20,000cP and IFO-180 emulsions to viscosities of 20,000 to 30,000 cP. Emulsions weathered to viscosities above these values seem to disperse slowly / poorly when treated with dispersant. Such available data of the "viscosity area" the dispersibility are crucial information for the OSC during spraying operations.

The ground truth data of the water content in the surface emulsion gave fairly good correlations to the model predictions for the first half day after release. However, over the next days, a reduction in the water content was obtained in the field. This may be explained by an evaporation of the emulsified water in the surface emulsion probably took place, due to high sea-temperature and extremely sunny conditions during the experiment period. Temperature in the oil was measured up to 5°C higher than sea temperature. This needs further investigation because this process in not reflected in present weathering models. Algorithms for evaporation of water in surface emulsions should therefore be developed. This is particularly relevant when predicting more long-term weathering (several days at sea) and under more temperate / tropical conditions.

The results from the field experiment in 1997 are further described by Daling, 1998 and also discussed by Daling and Strøm, 1999 and Lewis *et al*., 1998.

Predicted water uptake and emulsion viscosity from SINTEF OWM is presented together with field data in Figure 7.1 and Figure 7.1, respectively.

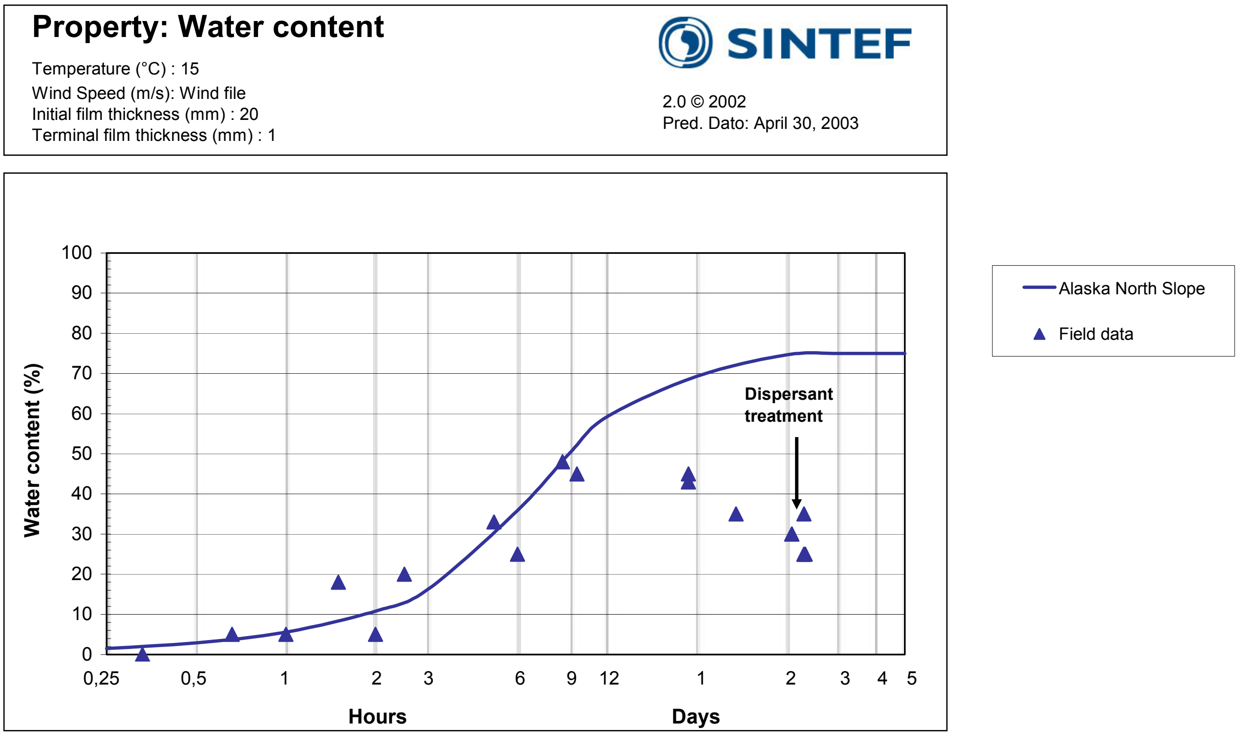

Figure 7.1 Predicted water uptake and field data Alaska North Slope 1997.

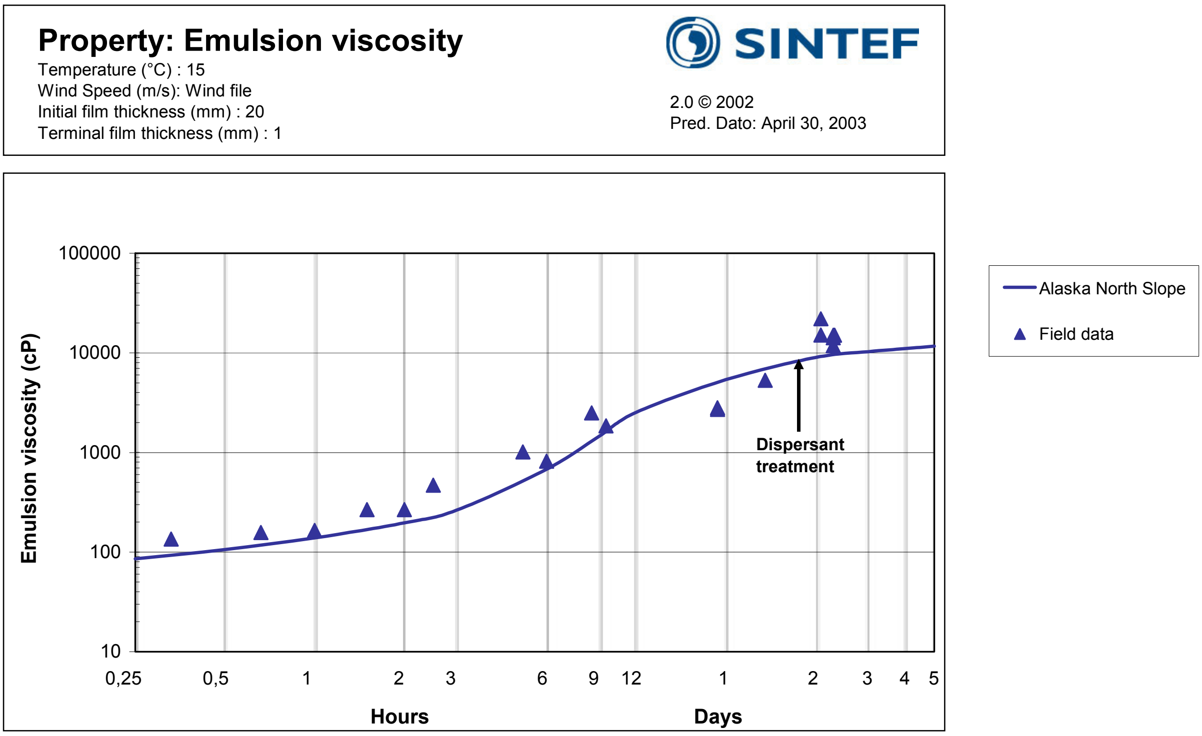

Figure 7.2 :Predicted emulsion viscosity and field data Alaska North Slope 1997

7.2 Field and input data 1997

The data from samples taken of the oil slick is given in the tables described here.

Table 7.1 Physico-chemical properties and "field check" of dispersant and demulsifier effectiveness of Alaska North Slope crude ("Alpha slick") at sea. UK Trials, 20. - 23. September, 1997."

Table 7.2 Wind conditions (average wind in m/s) during the AEA'97 field trial used as input to the SINTEF Oil Weathering Model.

Table 7.3 : Input data for predictions of Alaska North Slope crude oil behaviour at sea.

Table 7.1 Physico-chemical properties and "field check" of dispersant and demulsifier effectiveness of Alaska North Slope crude ("Alpha slick") at sea. UK Trials, 20. - 23. September, 1997."

Sample / Time at Sea	***Date / Time***	***AEA ID-no***		***Water (vol.%)***	***Viscosity (cP, at 15^{o}C, at AEA)***	***Dispersibility (DER = 1 : 25)***	***Emulsion stability and Demulsifier effectiveness (fraction dehydrated at 15^{o}C)***			
				(Alcopol-method)	***(at shear rate = 10s^{-1})***	***Field test (Concawe, 1988)***	***Dosage: DER = 500 ppm***	***D_{2min}***	***D_{1h}***	***D_{24h}***
Saturday, 20. Sept.										
Release	**0837-0900**	**31 Tons of Alaska North Slope released**						**-**	**-**	**-**
A0 / (fresh crude, analyzed at SINTEF (0.883 kg/L)					20 (100 s^{-1}) !!			-	-	-
A1 / 20 min.	0920	AA00167		<1	135 (100 s^{-1}) AEA	Good		-	-	-
A2 / 40 min.	0920	AA00171		<5	157 (100 s^{-1})	Good		-	-	-
A3 Pos A / 1 h.	1000	AA00175		<5	165 (100 s^{-1})	Good		-	-	-
A3 Pos B / 1.5 h.	1030	AA00185		18	266 (100 s^{-1})	Good	Stability Alcopol O 60 Corexit 9500	0 0 0	0.2 0.4 0.3	0.8 1.0 1.0
A4 Pos A / 2 h.	1100	AA00189		<5	266 (100 s^{-1})	Good		-	-	-
A4 Pos B / 2 h.	1100	AA00193		<5	182 (100 s^{-1})	Good		-	-	-
A5 / 2.5 h.	1230	AA00197		20	469 (10 s^{-1})	Good	Stability Alcopol O 60 Corexit 9500	0 0 0	0.3 0.7 0.5	0.8 0.8 1.0
A6 Pos A / 5 h.	1350	AA00206		33	1010	Good	Stability Alcopol O 60 Corexit 9500	0.1 0.3 0.2	0.2 0.6 0.3	0.4 0.6 0.6
A6 Pos B / 6 h.	1500	AA00212		25	818	Good	Stability Alcopol O 60 Corexit 9500	0 0 0	0.2 0.6 0.6	0.5 0.6 0.8
A7 Pos A / 8.5 h.	1720	AA00214		48	2491	Good	Stability Alcopol O 60 Corexit 9500	0 0 0	0 0.2 0.1	0.1 0.5 0.4

Sample / Time at Sea	***Date / Time***	***AEA ID-no***		***Water (vol.%)***	***Viscosity (cP, at 15^{o}C, at AEA)***	***Dispersibility (DER = 1 : 25)***	***Emulsion stability and Demulsifier effectiveness (fraction dehydrated at 15^{o}C)***			
				(Alcopol-method)	***(at shear rate = 10s^{-1})***	***Field test (Concawe, 1988)***	***Dosage: DER = 500 ppm***	***D_{2min}***	***D_{1h}***	***D_{24h}***
A7 Pos B / 9.5 h.	1820	AA00220		45	1849	Good	Stability Alcopol O 60 Corexit 9500	0 0 0	0 0.1 0.1	0.4 0.8 0.7
Sunday, 21. Sept.										
A8 Pos A / 22.5 h.	0730	AA00225		45	2703	Good	Stability Alcopol O 60 Corexit 9500	0 0 0	0 0.2 0.2	0.2 0.5 0.4
A8 Pos B / 22.5 h.	0739	AA00231		43	2812	Good	Stability Alcopol O 60 Corexit 9500	0 0 0	0 0.1 0.1	0.2 0.3 0.4
A9 / 32.5 h.	1720	AA00320		35 (36% KF)	4948 (AEA) 5300 (SINTEF)	Good / Reduced	Stability Alcopol O 60 Corexit 9500	0 0 0	0 0 0	0 0.1 0.1
Monday, 22. Sept.										
A10 / 54.5 h.	1525	AA00363		30	15076	Reduced	Stability	0	0	0
A11 / 54.8 h.	1540	AA00367		30 (35% KF)	19700 (AEA) 22000 (SINTEF)	Slowly / Reduced	Stability Alcopol O 60 Corexit 9500	0 0 0	0 0 0	0 0.1 0.2
Treatment	**1552-1600**	**400 liters of Corexit 9500, spray runs 1-3**								
A12 / 55 h. Non-treated area (?)	1555	AA00371		25	14200	Reduced	Stability	0	0	0
A13 / 55 h. Treated area	1610	AA00375		25 (22% KF)	10839 (AEA) 11800 (SINTEF)	Reduced / Good	Stability Alcopol O 60 Corexit 9500	0 0 0	0.1 0.1 0.1	0.22 0.7 0.4
A14 / 55 h. Non-treated area (?)	1625	AA00379		35 (37% KF)	8863 ?? (AEA) 15000 (SINTEF)	Reduced	Stability Alcopol O 60 Corexit 9500	0 0 0	0 0 0	0 0.2 0.1

Sample / Time at Sea	*Date / Time*	*AEA ID-no*		*Water (vol.%)*	*Viscosity (cP, at 15^{o}C, at AEA)*	*Dispersibility (DER = 1 : 25)*	*Emulsion stability and Demulsifier effectiveness (fraction dehydrated at 15^{o}C)*			
				(Alcopol-method)	*(at shear rate = 10s^{-1})*	*Field test (Concawe, 1988)*	*Dosage: DER = 500 ppm*	D_{2min}	D_{1h}	D_{24h}
Treatment	**1628-1638**	**600 liter, spray runs 4-9. →Total 1000 liters of Corexit 9500, now applied.**								
A15 / 55.5 h. Non-treated area (?)	1645	AA00383		25	15027	Reduced	Stability	0	0	0

*: *D is fractional dehydration of emulsion. After 2 min, 1hour and 24 hours settling after demulsifier addition in the vials*

Table 7.2 Wind conditions (average wind in m/s) during the AEA'97 field trial used as input to the SINTEF Oil Weathering Model

Time after release (hours)	***Wind speed (m/s) ANS-slick Release: Sept. 20. 0840 – 0900***
0	4
2	4
4	5
6	6
8	6
10	6
12	6
16	5
20	3
24	4
28	5
32	6
36	5
40	4
48	5
56	6
72	6
120	6

Table 7.3 : Input data for predictions of Alaska North Slope crude oil behaviour at sea.

Fresh oil properties	
Specific Gravity (60 F/60 F)	0.908
Pour Point (°C)	-31.666
Reference temperature #1 (°C)	13
Viscosity at ref. temp.#1 (cP)	76
Vanadium (ppm wt.)	-
Nickel (ppm wt.)	-
Asphaltenes (wt. %)	-
n-Pentane Insolubles (wt. %)	-
Flash Point (°C)	-
Wax Content (wt. %)	-
Dispersable for visc. <	4000
Poorly/not dispersable for visc. >	>20000
Maximum water uptake (%) at 5°C/13°C	75

-: *Data missing*

True boiling point curve	
Temperature (°C)	**Cumulative volume (%)**
30	3
82	7
166	19
193	23
288	38
343	49
510	74

Film thickness (mm)	
Initial	20
Terminal	1

Weathering properties (laboratory data)				
	Fresh	**150°C+**	**200°C+**	**250°C+**
Boiling temperature (°C)	-	197	255	320
Volume topped (%)	0	20	26	32
Residue (wt %)	100	84	78	67
Specific gravity (g/l)	0.908	0.919	0.93	0.947
Pour point (°C)	-30	0	3	9
Flash point (°C)	-	43	78	127
Viscosity at 13°C (cP)*	76	109	287	853
Viscosity of 50% emulsion (cP)*	-	676	1776	4991
Viscosity of 75% emulsion (cP)*	-	1819	10000	22000
Viscosity of max water (cP)*	-	3059	10000	22000
Maximum water content (%)	-	75	75	75
Halftime for water uptake (hrs)	-	0.28	0.22	0.43
Stability ratio	-	1	1	1

- : *Not measured*
* : *Viscosity measured at shear rate $10s^{-1}$.*

8 Deep Spill JIP 2000

In order to increase the understanding of how oil and gas from subsea leaks or blowouts will behave in deep water. The DeepSpill Joint Industry Project was established with the aim of determining the fate of oil and gas released in deepwater by performing full-scale field experimental releases.

Objectives
The main purposes of these experiments were:

- to obtain data for verification and testing of numerical models for simulating accidental releases in deep waters;
- to test equipment for monitoring and surveillance of accidental releases in deep waters;
- to evaluate the safety aspect of accidental releases of gas and oil in deep waters.

Verified numerical models combined with improved surveillance of the releases should then provide a better basis for oil spill contingency planning and environmental impact assessments in conjunction with future deep water exploration, development and production.

Releases
The experiments were conducted at 844 m depth in the Helland Hansen region in the Norwegian Sea. 60 m^3 marine diesel and 60 m^3 Sture blend together with 18 m^3 liquefied natural gas (LNG) equivalent to 10 000 m^3 of gas at atmospheric pressure were released from a discharge platform lowered down to the seabed.

The results from the DeepSpill JIP 2000 are presented in Johansen *et al*., 2000.

Figure 8.1- Figure 8.3 predictions of evaporation, water content and viscosity of emulsion of Sture Blend compared to sample data from the deep spill experiment. The data from the deep spill experiment is in good accordance to the predictions made by the SINTEF OWM (Johansen *et al*., 2001).

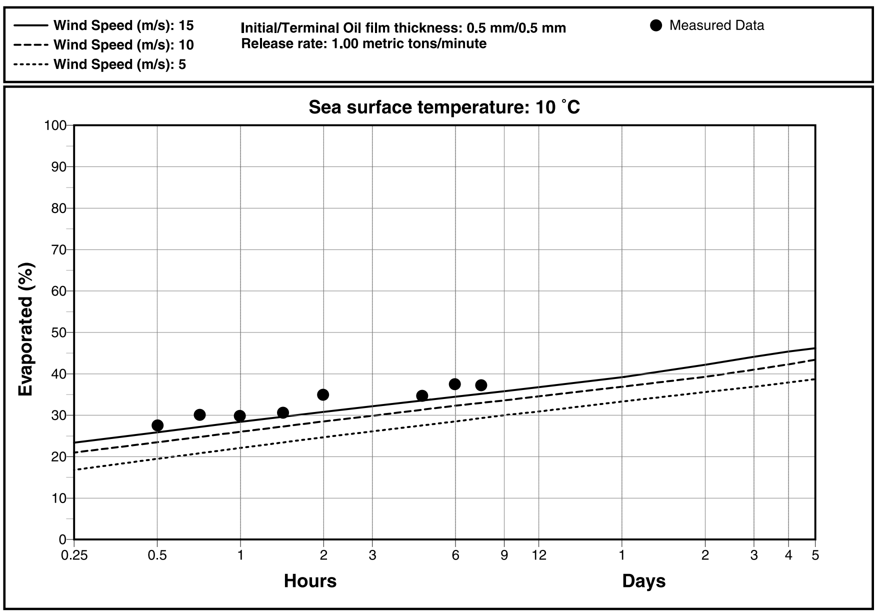

Figure 8.1 Evaporative loss of crude oil after resurfacing. Measured values compared with predictions based on laboratory data obtained from Sture Blend (2000). Note that this is essentially the same blend of crude oils as the Sture blend used in the experiment, but previously marketed with another name.

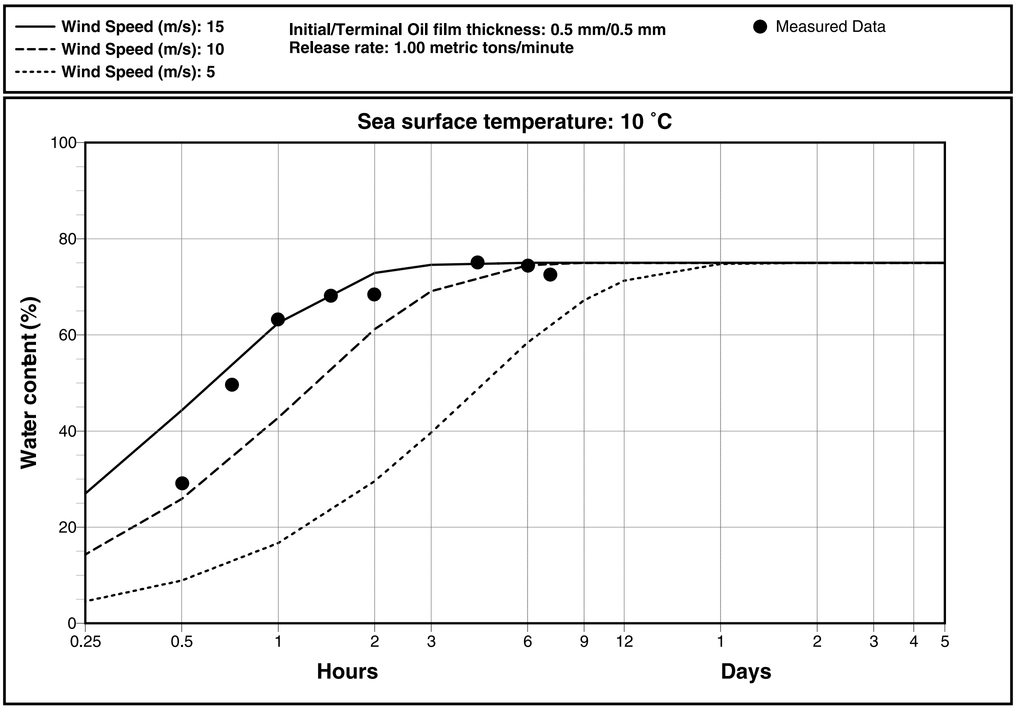

Figure 8.2 Water uptake of Sture Blend crude oil after resurfacing. Predicted and measured values.

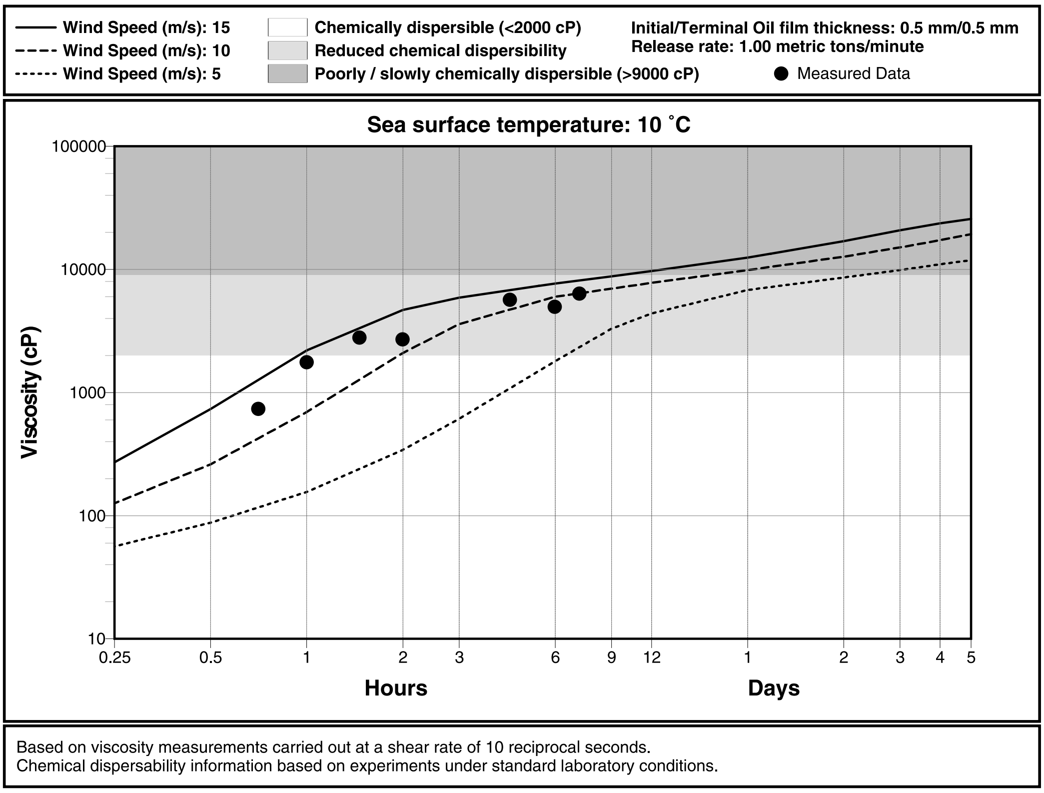

Figure 8.3 : Viscosity of emulsion, Sture Blend crude oil after resurfacing. Predicted and measured values

8.1 Field data 2000

The data from samples taken of the oil slick are given in the tables described here.

Table 8.1 : Emulsion film thickness (μm) – Sture Blend crude oil

Table 8.2 : W/o emulsion properties

Table 8.3 : Wind data 2000

Table 8.4 : Model input – weathering data Sture blend

Table 8.1 : Emulsion film thickness (μm) – Sture Blend crude oil

Sampling time (local time)	Water content.[1]	Emulsion Film thickness (μm)	Position [1] Lat	Long	Comments (sampling technique / Visual observations)
0902	29	19	65 00.037	4 50.775	PP-Pad, spot sampling / metallic
0904	29	171	65 00.034	4 50.775	PP-Pad, spot sampling / Thick oil (Discontinuous / continuous true)
0908	29	38	65 00.009	4 50.772	PP-Pad, spot sampling / thick oil (Discontinuous)
0909	29	7	65 00.001	4 50.719	PP-Pad, spot sampling / metallic
1035	29	15	65 00.150	4 51.517	PP-Pad, spot sampling / 4 samples
1036	29	101	65 00.146	4 51.500	in thick (discontinuous) oil and
1037	29	27	65 00.139	4 51.496	metallic. In an area with relatively
1038	29	36	65 00.130	4 51.487	fresh oil
1100	66	676	64 59.635	4 51.091	PP-pad, spot sampling from emulsified patches
1105	66	1983	64 59.588	4 51.156	PP-pad, spot sampling from thick emulsion
1110	63	1187	64 59.433	4 50.971	Thick emulsion, estimated > 1-3 mm
1116	63	1008	64 59.398	4 50.989	PP-Pad, spot sampling from thick emulsion
1116	63	1902	64 59.398	4 50.989	PP-pad, spot sampling from thick emulsion
1617	69	1264	[2]		PP-pad in thick emulsion, 3
1617	69	1204			parallel samples
1617	69	777			

[1]) Position given in geographical degrees followed by decimal minutes
[2]) Samples taken in the southern front of the slick (Position not recorded)

Table 8.2 : W/o emulsion properties

Sampling station	Tentative Weath. time	Density (g/ml)	Viscosity at 10(s^{-1}) (mPas)	Water cont (vol%)	[2]Emulsion breaker efficiency [1] D_{4h}	[1] D_{24h}	Stability [1] D_{4h}	[1] D_{24h}	Water free residue properties [3] Density (g/ml)	Evap loss (wt%) [5]
906	0.5	0.9259	- [4]	29.2	- [4]	- [4]	- [4]	- [4]	0.8852	28.2
920	0.75	0.9550	706	51.5	1.00	1.00	0.50	0.78	0.8806	31.7
1010	1	0.9810	1935	65.8	0.53	0.53	0.16	0.61	0.8962	32.3
1055	1.5	0.9841	3400	67.6	0.82	0.82	0.00	0.27	0.8987	33.5
1116	2	0.9822	3100	66.7	0.83	0.83	0.08	0.41	0.8967	36.2
1427	5	0.9910	7600	75.1	0.61	0.61	0.00	0.00	0.8885	35.6
1506	6	0.9928	5000	72.1	0.69	0.69	0.00	0.24	0.9096	39.3
1620	7	0.9840	6700	68.5	0.73	0.73	0.00	0.00	0.8950	39.3
Fresh crude	-	0.8423	84	-	-	-	-	-	0.8423	-
200°C+	-	0.8903	477	-	-	-	-	-	0.8903	-

1) *D is fractional dehydration of emulsion. D_{4h} is effect after 4 hours, D_{24h} is the effect after 24 hours. D=0: no water settled. D = 1: all water settled.*
2) *Effect of 500 ppm concentration of the emulsion breaker Alcopol O60%, relative to the oil volume*
3) *Properties of the oil residue after the water has been drained off by 0.5% emulsion breaker Alcopol at 60°C*
4) *The sample volume was too small to perform the analysis.*

Evaporative loss quantified by GC – SINTEF Evap-program)

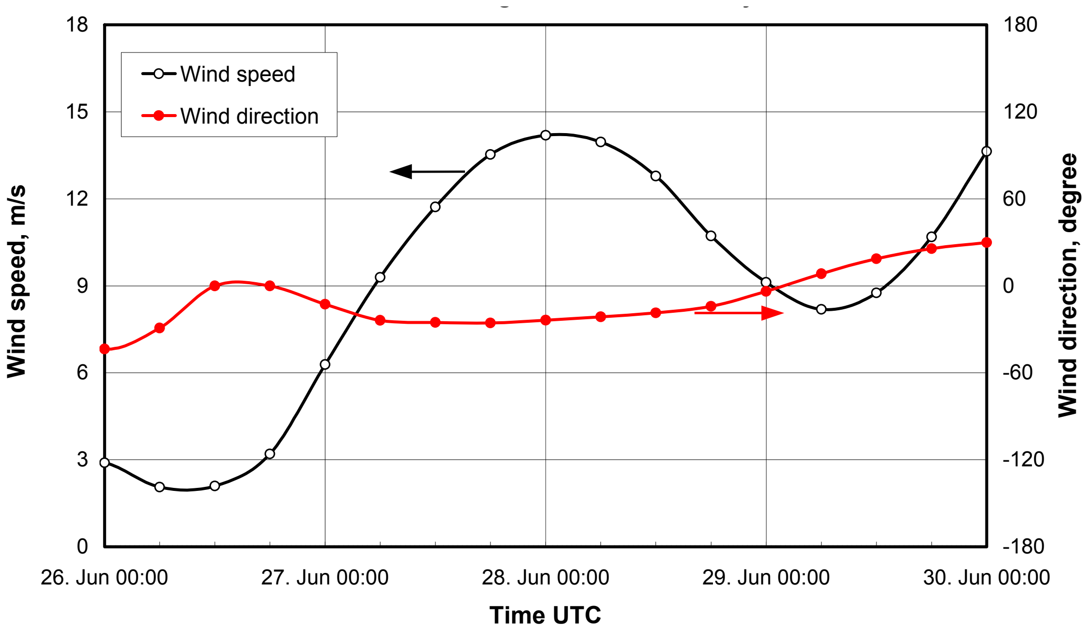

Figure 8.4 Plot of wind speed and direction at the Helland Hansen site during the DeepSpill sea trial. Based on smoothed data as shown in Figure 6.1.

Table 8.3 : Wind data 2000

Start date :	25.06.2000	00 UTC
Time from start (h)	**Wind speed (m/s)**	**Direction (°)**
0	10,4	15
6	9,3	10
12	4,9	6
18	2,8	337
24	2,9	316
30	2,1	331
36	2,1	0
42	3,2	0
48	6,3	347
54	9,3	336
60	11,7	335
66	13,5	334
72	14,2	336
78	14,0	339
84	12,8	341
90	10,7	346
96	9,1	356
102	8,2	8
108	8,8	19
114	10,7	26
120	13,6	30

Table 8.4 : Model input – weathering data Sture blend (2000)

Fresh oil properties	
Specific Gravity (60 F/60 F)	0.847
Pour Point (°C)	-3
Reference temperature #1 (°C)	13
Viscosity at ref. temp.#1 (cP)	10
Vanadium (ppm wt.)	-
Nickel (ppm wt.)	-
Asphaltenes (wt. %)	-
n-Pentane Insolubles (wt. %)	-
Flash Point (°C)	-
Wax Content (wt. %)	-
Dispersable for visc. <	2000
Poorly dispersable for visc. >	9000
Maximum water uptake (%) at 5°C/13°C	75

-: *Data missing*

True boiling point curve	
Temperature (°C)	**Cumulative volume (%)**
90	10.62
120	16.74
145	21.48
160	24.23
205	32.29
250	40.62
295	50.27
350	61.09
420	70.84
565	89.12

Film thickness (mm)	
Initial	0,5
Terminal	0,5

Weathering properties (laboratory data)				
	Fresh	**150°C+**	**200°C+**	**250°C+**
Boiling temperature (°C)	-	185	250	303
Volume topped (%)	0	16	28	39
Residue (wt %)	100	86	76	65
Specific gravity (g/l)	0.847	0.877	0.892	0.907
Pour point (°C)	0	9	18	21
Flash point (°C)	-	38	80	119
Viscosity at 13°C (cP)*	10	25	65	350
Viscosity of 50% emulsion (cP)*	-	190	480	2800
Viscosity of 75% emulsion (cP)*	-	-	2600	6300
Viscosity of max water (cP)*	-	-	-	-
Maximum water content (%)	-	80	80	78
Halftime for water uptake (hrs)	-	0.130	0.100	0.180
Stability ratio	-	0.200	0.705	1

- : *Not measured*
* : *Viscosity measured at shear rate $10s^{-1}$.*

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