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Revision of the OCS-Weathering Model: Phases II and III"

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TITLE

Final Report

Revision of the OCS Oil-Weathering Model: Phases II and III

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ABSTRACT

This project was composed of the following tasks:

- A teleconference with potential users of the SINTEF Oil Weathering Model (OWM)within MMS;
- Delivery and training in the use of the SINTEF OWM;
- Weathering studies of selected crude oils for inclusion in the OWM library;
- Development and delivery of Version 3.0 of the OWM;
- Preparation of test data sets for calibration and validation of oil weathering models;
- Preparation of this final report, a publication, and summary slides describing the project.

This final report summarizes the results of these tasks. Written deliverables, with the exception of the publication, which is in preparation, and the model software, are included in appendices on an accompanying CD-ROM.

KEYWORDS	ENGLISH	NORWEGIAN
GROUP 1	Marine Technology	Marinteknikk
GROUP 2	Modelling	Modellering
SELECTED BY AUTHOR	Oil	Olje
	Petroleum Technology	Petroleumsteknikk

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1 Introduction

The purpose of this study has been to provide and augment information needed to support development of environmental risk assessments, Environmental Impact Statements, review of contingency plans, and oil-spill response for offshore gas and oil leasing.

The MMS OCS Oil-Weathering Model (OWM) is a heavily used tool in the environmental assessment process for MMS. In the Alaska OCS Region, numerous estimates of oil-spill fate and behavior are derived from the OWM. The model provides analysts with a common, quantitative set of spill scenarios. The OWM is used to estimate whether State and Federal water quality standards and criteria would be exceeded by a spill, over what area, and for how long. The model calculates the area covered by a slick through time and the persistence of a slick. The model calculates how long the lighter, but most toxic components remain in the oil slick. The model is used to distinguish the effects of larger and smaller spills, for example between the effects of an average tanker spill versus an average pipeline spill. The *in situ* viscosity and degree of emulsification provided by the model are used in assessing the mitigation by and effectiveness of oil spill countermeasures such as mechanical recovery, dispersants, and *in situ* burning.

In the Gulf of Mexico Region, the OWM is more frequently used in environmental assessments to evaluate oil-spill contingency plans and the reliability of associated oil-spill models. The OWM is critical to the latter evaluation because, unlike most oil-spill models, the OWM incorporates specific chemistry of individual crude oils and petroleum products.

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.

The primary objectives of Phases II and III of this study have been:
1) to 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 algorithms and weathering models.

2 Teleconference

The teleconference to kick off the project took place in October, 1999. Participants were:

MMS Alaska: Dick Prentki, Caryn Smith
MMS Gulf of Mexico: Gail Rainey, George Guillen, and Darice Breeding
MMS Herndon: Betty Estey
SINTEF: Mark Reed, Per Daling, Janne Resby

The meeting started with a brief overview of the project, and a discussion of the trade-offs between performing more detailed weathering analyses for fewer oils or less detailed analyses for a layer variety of oils.

There were 4,731 producing oil wells in the GOMR as of Dec 1998 from multiple reservoirs, and over 26,000 miles of offshore pipeline, carrying oil mixed from production at approximately 4,000 platforms. The question of how to select one or two oils to study was raised. SINTEF suggested that one could either choose oils that are typical of a large number of others, or select those which are or will be shipped in largest quantities. In general, MMS does not have crude assay data on oils, so that comparison of oil types is difficult. It was decided to carry out limited weathering studies (no meso-scale runs) for 2 GOM oils. The GOMR may work with industry in developing a final determination.

It was asked whether SINTEF can use weathering data developed by others (e.g. Environment Canada) in the OWM. The answer was a reserved yes, given knowledge about what methods are used, how the results from those methods compare with those from SINTEF's, and given the possible necessity of additional information to fill any gaps. For example, the methodology for emulsification testing is very sensitive to energy input, and the kinetics of this process are key in determining both spill lifetime and the window of opportunity for dispersant application.

Minimum inputs to the SINTEF OWM are True Boiling Point curve, density, viscosity at some reference temperature, and pour point of the fresh crude. Beyond that, the actual weathering data becomes important for reliable predictions.

The Alaskan oils are much more limited in number. Priority oils are Liberty and North Star, but they were not available at the start of the project in the quantity needed (20 liters for bench scale, 10 liters for dispersant testing, 20 liters for meso-scale testing). One Cook Inlet oil was also to be selected.

After some discussion, it was agreed that 10°C would be a reasonable test temperature for the North Slope oils. The representative temperature for the Gulf of Mexico oils was eventually set at 25 C.

Each of the project tasks was then discussed in some detail, resulting in a set of action items at the conclusion of the teleconference.

3 Delivery and Training in the Use of the SINTEF Oil Weathering Model

The SINTEF Oil Weathering Model Version 1.6 was delivered to MMS at project start in 1999, and served as the basis for the training course in February 2000. The OWM Version 1.8 was delivered in April 2000, followed by Version 2.0 in April 2001.
The training workshop took place on February 8-9, 2000, at MMS facilities in Denver, Colorado. A number of desired changes and improvements were noted during the workshop, and subsequently incorporated into Versions 1.8 and 2.0 of the OWM.

4 Weathering Studies

4.1 Introduction

In Environmental Impact Assessment (EIA) studies and when planning the most effective response, it is important to have reliable predictions of how specific oil properties will change during an oil spill event. The efficiency of various oil spill combat methods (e. g. mechanical, dispersion and/or burning) depends greatly on the physical-chemical properties of the oil at the time of action.

The weathering behaviours of Alaskan and Gulf of Mexico crude oils were investigated at SINTEF. The results of the weathering studies were incorporated into the SINTEF OWM weathering library, and supplied to MMS with the OWM and Oil Database Editor.

4.2 Oils investigated

The following six crude oils were received and investigated in the laboratory at SINTEF :

- Alpine Composite
- Endicott
- Milne Point Unit
- North Star
- High Island Composite
- Neptune Field Composite

The Neptune Field and High Island oils are Gulf of Mexico oils, the rest are Alaskan oils. Gulf of Mexico oils were tested at 23°C and Alaskan oils at 10°C.

Endicott, Alpine Composite, Neptune Field Composite and North Star were analysed following the SINTEF standardised weathering methodology. Due to too high water contents, Milne Point Unit and High Island Composite were not analysed using standard procedures. Meso-scale flume test were performed of the High Island Composite in order to establish a dataset for the OWM. The water content of Milne Point Unit was too high for performance of weathering analysis.

4.3 Brief summary of the oils weathering properties

A brief summary of the oil and weathering properties of the crude oils is given below. For further details about oil properties see Table 4-1 and for discussion of weathering behaviour related to oil spill response see Leirvik *et al*., 2002.

<u>Alaskan crude oils :</u>

Alpine Composite is a paraffinic crude oil, with a density of 0,834 g/mL. The Alpine Composite contains a relatively large amount of lower molecular weight compounds and approximately 25% of its original volume will be evaporated 24 hours after the spill at both summer and winter temperatures. Alpine Composite will form w/o-emulsions with a maximum water content of 80 % at both winter and summer temperatures, yielding approximately five times the original spill volume. The w/o-emulsion formed after one day of weathering at sea is stable.

Endicott is an asphaltenic crude oil, with a density of 0,913 g/ml with a relatively low evaporative fraction. Endicott will form w/o-emulsions with a maximum water content of approximately 60 % at winter temperatures and 65 % at summer temperatures, more than doubling the original spill volume. The w/o-emulsions formed are very stable.

Milne Point Unit oil is a heavy naphthenic, biodegraded crude oil with an approximate density of 0.95 g/ml. The oil seems to be highly biodegraded (i.e. no paraffinic components are present in the Gas Chromatogram). The emulsion is extremely stable and can only be dehydrated at high temperatures and with the addition of a high dosage of demulsifier (approximately 10%).

North Star oil is a light paraffinic crude oil, with a density of 0.816 g/mL. The North Star oil contains a relatively large amount of lower molecular weight compounds and approximately 30 % of its original volume will evaporate 24 hours after the spill at both summer and winter temperatures. North Star also forms stable emulsions.

Gulf of Mexico crude oils :

High Island is a naphthenic, biodegraded crude oil, with a density of approximately 0.85 g/mL. The High Island oil contains a medium amount of lower molecular weight compounds; over 20 % of its original volume will evaporate 24 hours after the spill at both summer and winter temperatures. Results from the meso scale flume study show that High Island oil forms unstable emulsions with low viscosity. Maximum water content is high at 70%, but observations from the meso scale flume show that emulsions dehydrate almost completely within an hour when left at rest (e.g. in a recovery storage tank).

Neptune Field Composite is a paraffinic crude oil, with a density of 0,869 g/mL. The Neptune Field Composite contains a relatively large amount of lower molecular weight compounds and over 30 % of its original volume will be evaporated 24 hours after the spill at both summer and winter temperatures. The experimental results showed that the Neptune Field Composite did not form stable w/o-emulsions. One normally would expect that a crude oil with a wax and asphalthene content similar to the Neptune Field Composite will form stable w/o-emulsions. SINTEF suspects that production/process chemicals are present in the oil sample thereby reducing the w/o-emulsion process. This suspicion is supported by the un-normal low interfacial tension value measured for the fresh crude (6 mN/m).

A comparison of the evaporation and emulsion viscosity of the Alaska and Gulf of Mexico oils is shown in Figure 4-1, Figure 4-2 and Figure 4-3, Figure 4-4 respectively. The evaporation of the Alaska oils is very different, from approximately 20 to 50% after 5 days at 10°C and 10 m/s wind. The emulsion viscosities of these oils vary from approximately 8000 to 40000 cP under the same conditions. The two Gulf of Mexico oils has evaporation and emulsion viscosity in the same range at 20°C and 10 m/s wind, however, the development is some different.

Table 4-1: A summary of the physical and chemical variables for Endicott, the Alpine Composite and the Neptune Field Composite, The High Island Composite and the North Star. The viscosities for Endicott, the Alpine Composite, the North Star, the Neptune Field Composite and the High Island Composite and the were measured at 10℃, 10℃ , 10℃, 23°C and 23°C respectively.

Oil type			Evaporated [vol%]	Residue [wt%]	Density at 15,5°C [g/mL]	Pour point [°C]	Viscosity at $10\ s^{-1}$ [cP]	Flash point [°C]	Interfacial tension [mN/m]	Wax content [wt%]	Asphaltenes "hard" [wt%]
Alaskan North Slope	Endicott	Fresh	0	100	0,913	6	510	<20	24	5,5	1,6
		150°C+	6	95	0,923	9	840	56	24	5,7	1,7
		200°C+	12	89	0,931	15	1630	85	25	6,1	1,8
		250°C+	19	84	0,940	18	5150	121	25	6,5	1,9
	Alpine Composite	Fresh	0	100	0,834	-18	103	<20	18	3,2	0,06
		150°C+	22	81	0,867	-3	118	38	20	3,9	0,07
		200°C+	34	69	0,885	9	839	82	27	4,6	0,09
		250°C+	44	60	0,898	18	1160	123	16	5,3	0,1
	North Star	Fresh	0	100	0.816	-39	10	<20	20	5,8	0,016
		150°C+	24.7	78.5	0.850	-9	45	37	21	7,3	0,021
		200°C+	38.5	65.3	0.866	3	380	77	23	8,8	0,025
		250°C+	50.2	53.8	0.881	18	2272	119	24	10,7	0,030
Gulf of Mexico	Neptune Field Composite	Fresh	0	100	0,869	-9	10	<20	6	3,7	0,3
		150°C+	11	90	0,887	0	50	46	6	4,1	0,4
		200°C+	22	81	0,900	3	110	93	7	4,6	0,4
		250°C+	30	73	0,911	9	300	128	8	5,0	0,4
	High Island Composite	Fresh	0	100	0,847	-15	23	-	14	1,6	0,03
		150°C+	-	-	-	-	-	-	-	-	-
		200°C+	-	-	-	-	-	-	-	-	-
		250°C+	33	70	0,879	0	83	-	16	2,3	0,04

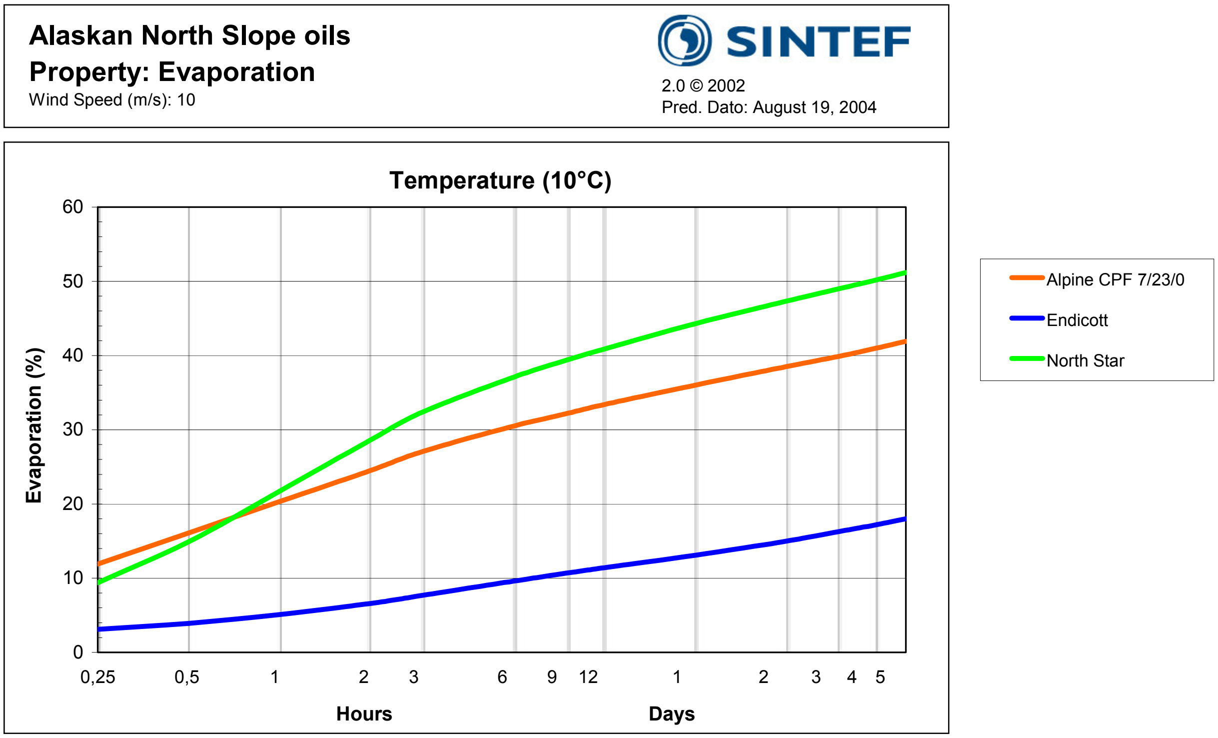

Figure 4-1 : Evaporation of the Alaska oils.

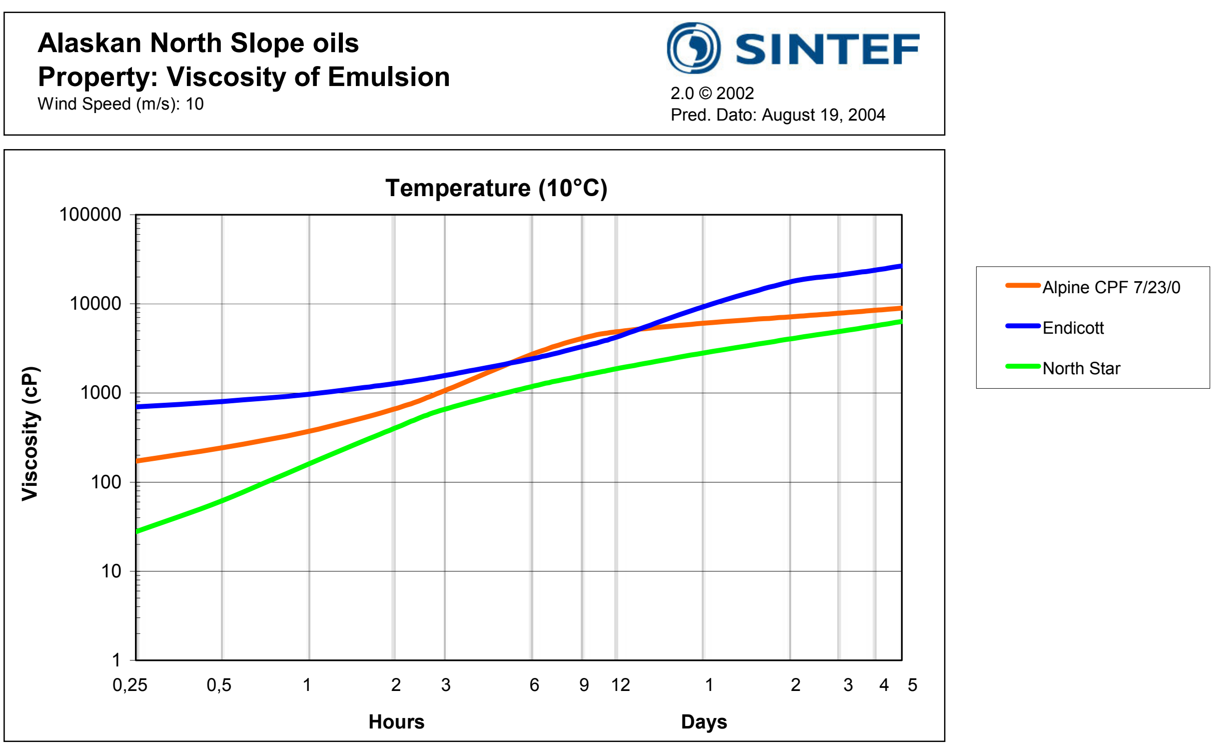

Figure 4-2 : Viscosity of emulsion of the Alaska oils.

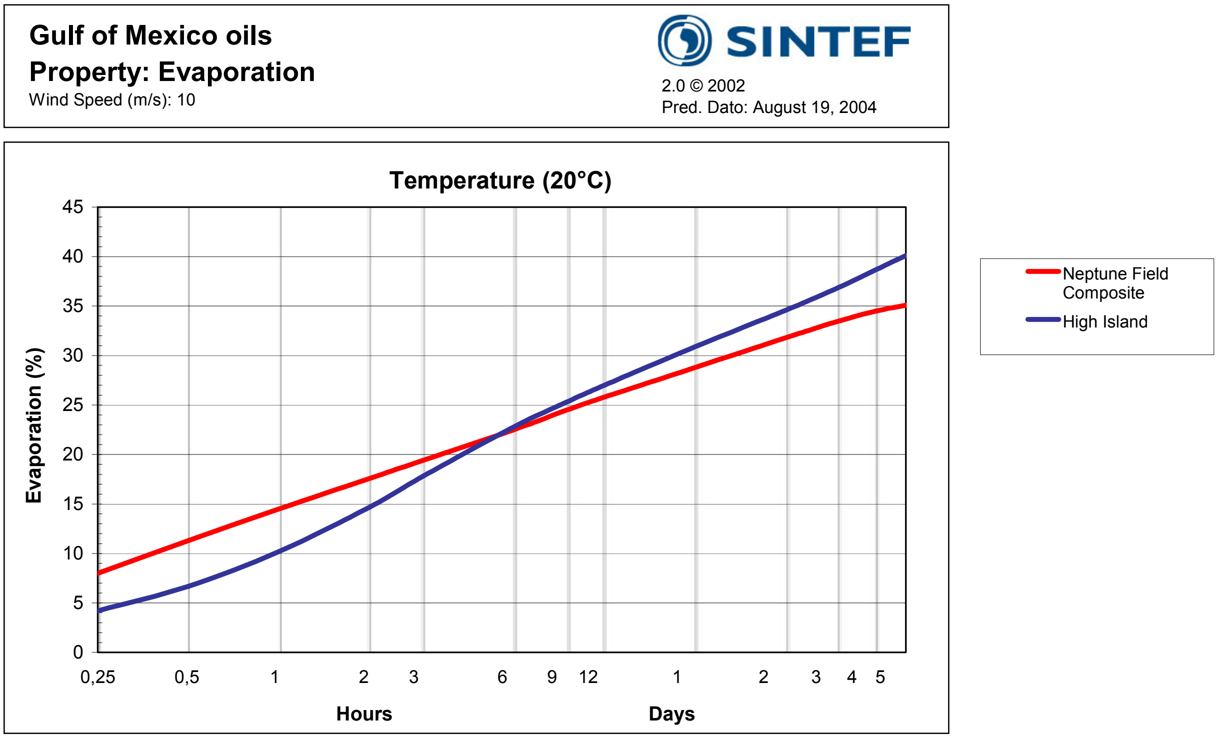

Figure 4-3 :Evaporation of the Gulf of Mexico oils.

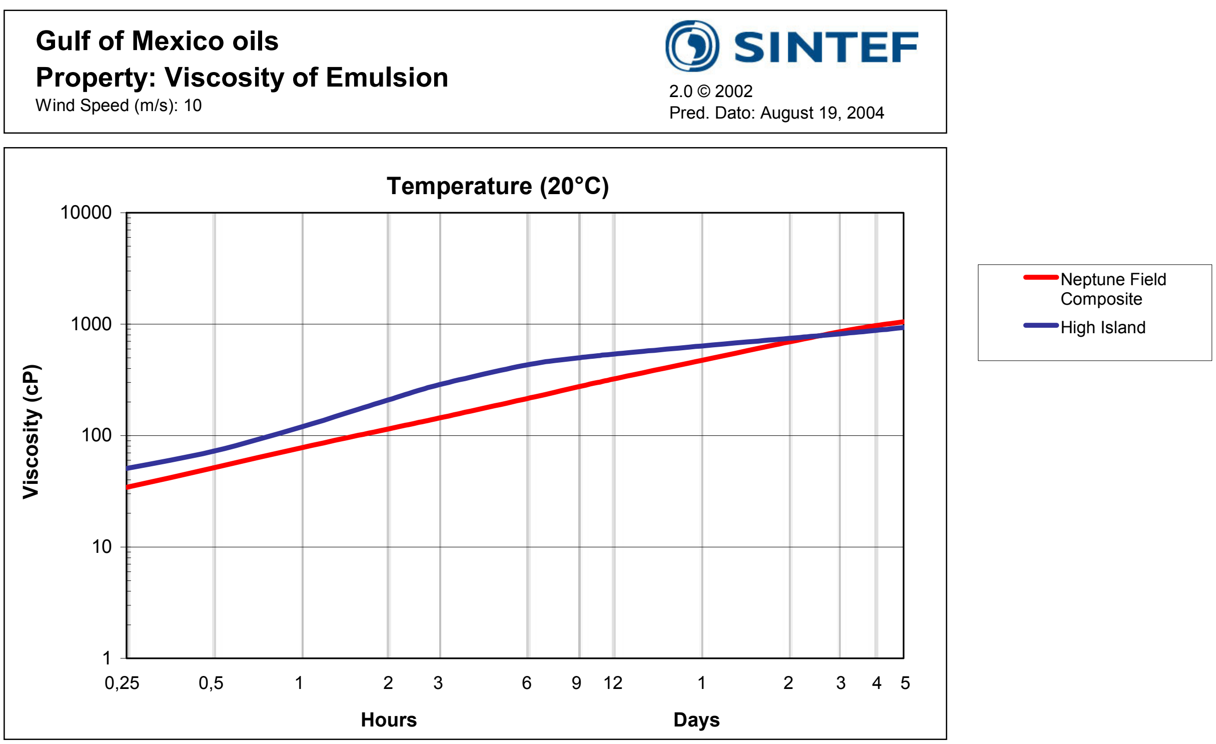

Figure 4-4 : Emulsion viscosity of the Gulf of Mexico oils.

5 Oil Weathering Model Version 3.0

Version 3.0 of the OWM was delivered at the end of June, 2004. In addition to numerous improvements in the user interface, this version includes the following improvements over 2.0:

- possibility for surface and subsurface releases;
- internal computation of initial film thickness, based on release rate and duration;
- New spreading algorithm supporting both surface and underwater releases, with improved stability and better detection of erroneous input values;
- New oil type query filters in both OWM and the Oil Database Editor, allowing filtering on ranges of values for API gravity, specific density, and pour point;
- Capability to add/delete Data Source, Geographical Area, and Product in the Editor as documented in the User Manual how to achieve this during editing of oil information;
- New *.TX2 data results file for easy EXCEL import;
- Enabled multi-selection capability in temperature and wind lists, and made Add and Delete buttons more dynamic to facilitate clearing the entire list at once;
- Revised User's Manual for Version 3.0.

The spreading mechanisms for instantaneous releases and continuous releases are different. Instantaneous releases will spread radially, while oil released continuously will spread laterally (i.e. cross-current). This difference in spreading behaviour will affect other weathering properties e.g. evaporation and natural dispersion. Version 2.0 of the model only accounts for lateral spreading (i.e. all releases are treated as continuous), but in Version 3.0, the spreading of instantaneous and continuous spills is treated differently. Also, a calculation of the surface spreading for sub surface releases in shallow to moderate water depths (depth less than e.g. 300 m) is included. This calculation requires input of gas-to-oil ratio (GOR) and depth in addition to release rate.

The spreading algorithms are documented in detail in Appendix D.

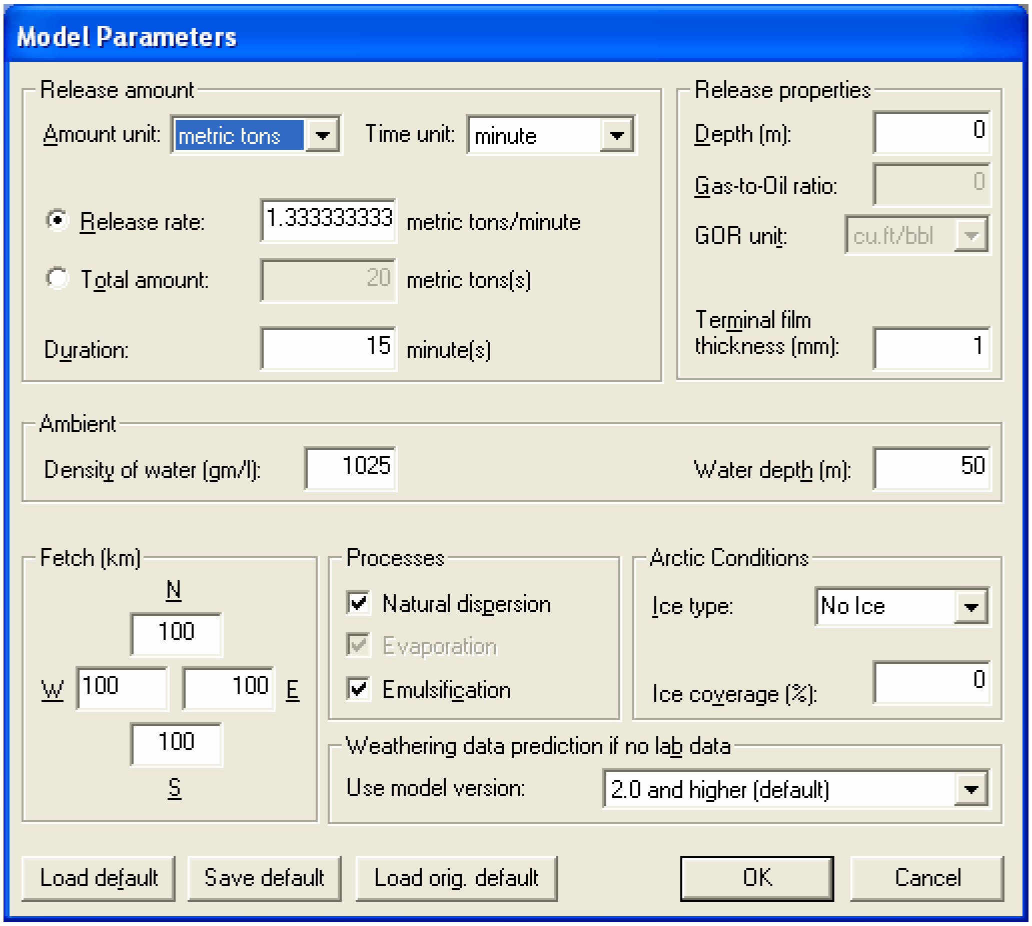

Figure 5-1. New Model Parameter dialog in Version 3.0, allowing for underwater releases, and with initial thickness computed internally depending on release type, rate, and duration.

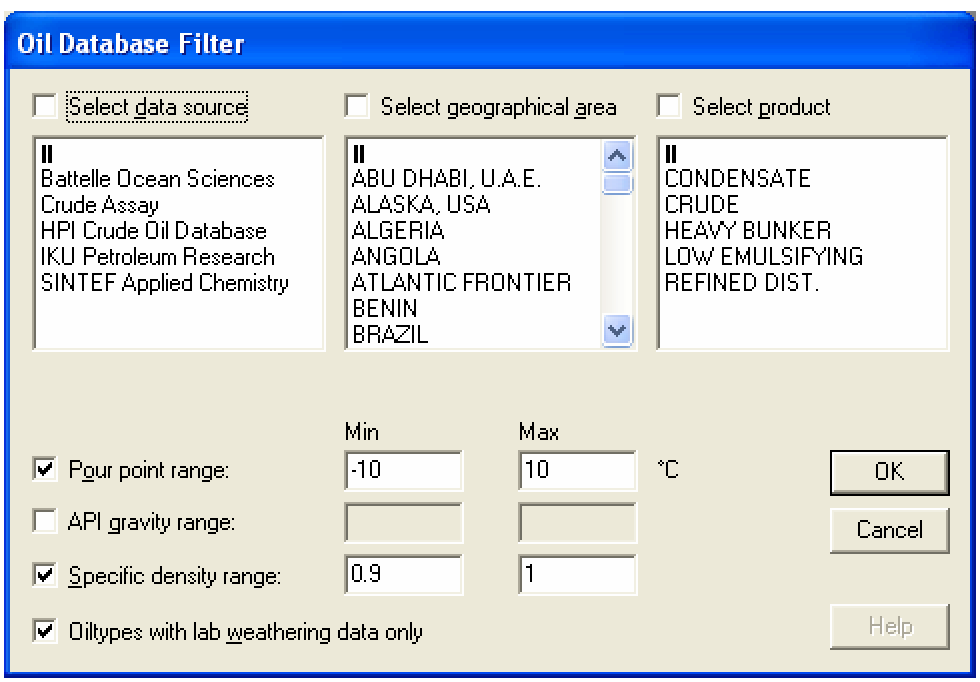

Figure 5-2. New Oil Database Filter query options include selected oil properties.

MMS has an unlimited internal use license for the model.

6 Test Data Preparation

6.1 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 the compilation of oil spill data sets that would be suitable for model testing and validation.

A framework for this task 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 joint industry program to address model sensitivity testing, preparation and archival of specified data sets, and testing of model algorithms.

Many data sets of potential interest were identified in the Phase I Report (OCS Study MMS 98-0058). SINTEF investigated the possibility of developing a joint industry program developed to facilitate the data collation, but without success. We therefore agreed with MMS to proceed alone in this task with the limited budget from MMS allocated to address the two last scopes/goals: i.e. preparation of available oil spill data sets, and 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.

6.2 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 was identified and preliminary evaluation of data sets was performed. None of the field trials satisfied the strict criteria for an “ideal data set”, with respect to both methodology and data-documentation. We therefore selected best available data sets for calibration/validation of oil weathering models. Many of the older data sets from experimental trials had a limited potential for model calibration-/validation, because of varying quality of data due to lack of consistent procedures for sampling and analytical methodology.

Some recent field trials had better documented and suitable procedures for field sampling and analysis. The preliminary conclusion from this review was that data from recent field trials in the UK and Norway (see below) had a potential for calibration/verification of oil weathering models, and an effort in collecting relevant data from these series was given priority.

UK: Field trials in the North Sea from the period 1992-97: These experiments were 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 AMOP publications by AEA Technology, but more extensive environmental data from the field test is needed to use them in model tests.

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 the late 70's, but only some of the trials were considered to be relevant for our purpose. The SINTEF-89 and MIZ-93 trials produced 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 procedures for sampling and 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.

6.3 Datasets collected

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 the 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 extensive search to obtain 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 thickness 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.

The full report is included as Appendix B: Development of Data Sets from Experimental Oil Spills for OWM Algorithm and Model Testing and Validation.

7 Final Report, Publication, and Summary Slides

The Final Report is a self-reference to this document.

A publication with the working title "The MMS Oil Weathering Model: Further Developments and Applications" is in preparation. It is intended that the paper will be presented at the International Marine Environmental Modelling Seminar (IMEMS) to be held in Washington DC in October, 2004.

A set of summary overheads has been prepared in PowerPoint format, and is include on the CD-ROM as an Appendix to this report.

Separate documents on CD-ROM:

Appendix A: Overheads Summarizing the Project

Appendix B: Weathering Properties of Endicott, Milne Point Unit, High Island Composite, the Alpine Composite, the Neptune Field Composite, and North Star Oil Samples

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

Appendix D: Users Manual for SINTEF OWM Version 3.0

Appendix E: Manuscript submitted to Journal of Environmental Software and Modelling: "The MMS/SINTEF Oil Weathering Model, Further Development and Applications" by R. Prentki, C. Smith, Ø. Johansen, P. Daling, M. Moldestad, K. Skognes, and M. Reed.