SINTEF REPORT

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TITLE

The use of colour as a guide to oil film thickness - Main report

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ABSTRACT

This report gives an executive summary of the “Colour Code-project” carried out at SINTEF.

The aim of this project was to validate and if necessary calibrate present colour-thickness correlation methodology in order to improve the quantification of oil slicks with thin oil film (from sub-micron up to 100-200 microns).

The literature and experimental work was carried out in two phases, and is documented in the following three technical reports:

Phase 1 (1997/98):
- “The use of colour as a guide to oil film thickness – A literature review”
- “The use of colour as a guide to oil film thickness – Laboratory experiments”

Phase 2 (1998/99):
- “The use of colour as a guide to oil film thickness – Small scale field experiments”

Each technical report is presented as an independent document in appendices in this main report.

KEYWORDS	ENGLISH	NORWEGIAN
GROUP 1	Environment	Miljø
GROUP 2	Chemistry	Kjemi
SELECTED BY AUTHOR	Oil Spill	Oljesøl
	Oil Film Thickness	Oljefilmtykkelse
	Colour Code	Fargekode

TABLE OF CONTENTS

Executive summary

1. Literature review (Phase 1)

A literature review of the basis of current ‘colour code’ (the correlation between apparent colour and oil film thickness) used by the Bonn Agreement surveillance flights has been carried out. The aim was to collect and assess previous research data on this subject.

The following conclusions were made:
The present code consists of seven categories (regions) of colour and thickness. In the range up to 3 microns thickness (between Codes 4 and 5), the available literature and theoretical considerations strongly supports most of the colour classifications used, independent of oil type or viewing conditions. This area of the colour code is that which is most often used in assessing discharges from ships. The basis of Code 4 (blue, equivalent to 1 micron thick) and Code 5 (blue/brown, equivalent to 5 microns thick) is not totally supported by the available literature or theoretical studies.

At higher oil film thickness, the region from 5 microns and upwards, there is less evidence to support a rigorous colour/thickness correlation. Assessing the thickness of oil films that are 10 to 50 microns thick (Code 6; Brown/black, equivalent to 15 - 25 microns) by colour alone is likely to be misleading if all oil types are considered to exhibit similar characteristics. The apparent colour for a particular oil thickness will vary depending on oil type. However, a uniform colour (blue, brick red etc.) typical for this film thickness supports the conclusion that the film is beyond 5 microns.

Oil film thickness in around, or in excess of 100 microns (0.1 millimetre), Code 7 in the Bonn Agreement categorisation, cannot be determined by the colour of the film. In this thickness range the colour observed is the true colour of the oil, or emulsion formed from it, and is due to the surface colour. Oil films in this thickness range will only be observed at significant oil spills. The presence of large areas of black oil or brown emulsion will probably indicate that some response (mechanical recovery or dispersant use) is needed, while the absence of areas of these colours will indicate that the oil will probably disperse naturally, provided that it has enough time to do so before it hits the shore. However, a brown colour typical for this film thickness for the specific oil supports the conclusion that the film is beyond 50 to 100 microns.

2. Laboratory experiments (Phase 1)

Based on the findings, and particularly on the lack of scientific documentation revealed during the literature review, an extensive and systematic laboratory test program was designed and performed.

A laboratory experimental set-up allowing photographing of oil films on a water surface and a standardised procedure for this was established. Conditions were chosen to optimise the appearance of the colour of the oil films. For thin oil films /up to 5μm, including the rainbow area), a black background colour and direct light gave colour appearance. For thicker oil films (above 5-10μm) a white background and indirect light was used. A total of ten oils were investigated, including three crudes, one condensate, three fuels and three bilge water samples. Seven different oil film thicknesses were prepared of each oil type.

The following conclusions were made:
For thin oil films (rainbow area; 0.2 – 1.5µm) the apparent colour is not dependent on the oil type. Pure rainbow colours did appear for oil films with a thickness similar to the wavelength of visible light (400 – 760nm). The colour became more diffuse with increasing and decreasing oil film thickness at the edges of this thickness region.

The laboratory experiments showed that for oil films thicker than 5-10µm the apparent colour seem to depend on the intrinsic colour of the oil for the chosen experimental conditions. The intensity of the colour increases with increasing oil film thickness up to 200µm, where most oil films were black/dark brown. The colour intensity, however, varies over a wide range (decades) for the oils tested. The general colour code guide can therefore not be used for oil film thickness within this range. For quantitative determination of the total amount of oil in an oil slick of this thickness, information on the specific oil properties should be available.

The oil films of thickness 1.5 to 5-10µm appears to have no or very weak colours. The “colour” appearance is difficult to describe; metallic or homogenous could be used. This thickness region can probably be easily mistaken for the Code 1 or 2. Influence of waves on the sea surface and inhomogeneous film thickness could provoke appearance of locally areas of rainbow colours also for this thickness area.

The observations from this laboratory work constituted a basis for renaming and modification of the current Bonn Agreement Pollution Observation Log. A preliminary amending using the present oils was therefore suggested. However, it was suggested that additional work have to be done prior to preparation of a final operation field guide for quantification of oil slick by visual observations based on colour appearance. Such studies should include:

- extensive laboratory studies including more narrow film thicknesses – particularly in the band from 1 to 200 (500)µm.
- the effect of weathering (i.e. evaporation, emulsification) on oil film colour appearance
- meso-scale flumes including the effect of waves
- small-scale field (controlled out-door) experiments
- verification by large-scale field dedicated trials.

3. Small-scale field experiments (Phase 2)

Based on the recommendations made from the laboratory experiments, small-scale field experiments were performed under controlled conditions in the Trondheimsfjorden using hexagonal ring systems. The aim was to correlate laboratory data obtained in Phase 1 of the project to more realistic field situations. The effect of environmental parameters (cloud cover, direct/indirect sunlight, current and wind) and observation parameters (observation height, observation angle relative to the sea surface and sun-reflection) was studied. Six different oil types with different physical and chemical properties were used in the experimental program focusing on the oil thickness interval of 0,5-200µm.

The oil film thickness of the different parts of the oil slick was calibrated by pad sampling and analysis and was connected to photos of the same area. Based on this, colour charts for each oil were created for both blue sky and cloudy situations. The colour chart mosaic consisted of, in addition to the thin silvery/grey code and unexposed water; rainbow, metallic, discontinuous and homogenous true oil colour. The names are proposed to give the best possible description of the apparent colour of oil films. Difference between the different oil types could only be observed with the two thicker codes (50-200µm and >200µm). In the cloud cover situation, the apparent oil film colour variation was significantly less clear than under the blue sky situation.

4. Suggestion for a revised colour code

Based on results and data gained during the literature, laboratory and small-scale field studies, a new Colour Code (names and thickness intervals) is proposed:

	Thickness Interval	Litres per sq.km
Silvery	< 0,05-0,1µm >	50 - 100
Grey	<0,1-0,3µm>	100 - 300
Rainbow	<0,3 –5µm>	300 - 5000
Metallic	<5-50µm>	5000 - 50 000
Discontinuous true oil colour	<50-200µm>	50 000 - 200 000
Homogenous true oil colour	more than 200µm	more than 200 000

The scientific data obtained through these projects, proves that the correlation between apparent colour and oil film thickness in the current Bonn Agreement colour code is reasonably accurate for the thinner codes (<5µm). For oil film beyond 5µm thickness, the need for significant improvement has been identified. Both the terms and the thickness intervals have been amended in accordance with the findings of this study.

The small-scale field study indicates that the spill volume estimates made with the current Bonn Agreement Colour Code are more conservative (i.e. of lower volume) than those that would be made with the proposed new appearance/thickness correlation. The scientific work conducted during this study therefore justifies a less conservative approach in producing spill volume estimates than is currently being practised.

5. Conclusion and recommendations for further work

Based on the results obtained during this study the proposed new Colour Code should be implemented. The proposed new code is based on the best theoretical, scientific and field data available.

When known quantities of oil are released during coming surveillance exercises, ground oil film thickness measurements should be included as part of the exercise while photographs are obtained from aircraft. Valuable intercomparison data will then be obtained and this will be very useful for further training purposes.

Based on the methodology developed during this project, specific colour charts should be established for other oil types (both crudes, condensates, bunker oils and slip tank/bilge water). Such studies should be part of the documentation in connection to contingency plans required for individual oil fields, terminals and refineries).

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TITLE

The use of colour as a guide to oil film thickness; Phase 2 - Small scale field experiments

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ABSTRACT

See summary in section 1 in the report

KEYWORDS	ENGLISH	NORWEGIAN
GROUP 1	Environment	Miljø
GROUP 2	Oil	Olje
SELECTED BY AUTHOR	Oil film thickness	Oljefilmtykkelse
	Colour code	Fargekode
	Field experiment	Feltforsøk

TABLE OF CONTENTS

Page

1. Summary

Small-scale field experiments have been performed under controlled field conditions in the Trondheimsfjorden using hexagonal ring systems, to correlate laboratory data obtained in Phase 1 of the project to a “real” spill situation. The effect of environmental parameters (cloud cover, direct/indirect sunlight, current and wind) and observation parameters (observation height, observation angle relative to the sea surface and sun-reflection) was studied in particular. Six different oil types with different physical and chemical properties were used in the experimental program focusing on the oil thickness interval of 0,5-200µm.

The oil film thickness of the different parts of the oil slick was calibrated by pad sampling and analysis and was connected to photos of the same area. Based on this, colour charts for each oil were created for both blue sky and cloudy situation. The colour chart mosaic consisted of, in addition to the thin silvery/grey code and unexposed water; rainbow, metallic, discontinuous and homogenous true oil colour. These names are proposed to give the best possible description of the apparent colour of oil films. Difference between the different oil types could only be observed with the two thicker codes (50-200µm and >200µm). In the cloud cover situation the apparent oil film colour variation was significantly less clear than under the blue sky situation. In this project, significant effort was also aimed at gaining new knowledge on how the oil slick colour appearance is influenced by sky and cloud cover, sun exposure, wind and currents.

Based on results and data gained during the literature, laboratory and small-scale field studies, a new colour code (names and thickness intervals) is proposed:

	Thickness Interval	Litres per sq.km
Silvery	< 0,05-0,1µm >	50 - 100
Grey	<0,1-0,3µm>	100 - 300
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The scientific data obtained through the studies, proves that the correlation between apparent colour and oil film thickness in the current Bonn Agreement colour code is reasonably accurate for the thinner codes (<5µm). For oil film beyond 5µm thickness, the need for significant improvement has been identified. Both the terms and the thickness intervals have been amended in accordance with the findings of this study.

The small-scale field study indicates that the spill volume estimates made with the current Bonn Agreement Colour Code are much more conservative (i.e. of lower volume) than those that would be made with the proposed new appearance/thickness correlation. The scientific work conducted during this study justifies a less conservative approach in producing spill volume estimates than is currently being practised.

Based on the results obtained during this study the proposed new colour code should be implemented. The proposed new code is based on the best theoretical, scientific and field data available. When known quantities of oil are released during surveillance exercises, ground oil film thickness measurements should be included as part of the exercise while photographs are obtained from aircraft. Valuable intercomparison data will then be obtained and this will be very useful for training purposes. Based on the methodology developed during this project, specific colour charts should be established when contingency plans are required for individual oil fields.

2. Background

2.1 Introduction

Visual observation from aircraft is the most common method of identifying illegal oil discharges and oil spills. Experienced observers can achieve positive identification of an illegal discharge, but more precise volume estimation of an oil spill, based on the colour and area of different regions of the oil slick, has been identified as a complex task.

The Bonn Agreement countries undertake regular exercises in which the volume of test spills are estimated. Estimates of spill volume made by trained observers in different aircraft have shown significant differences. This is probably due to the following factors:

- The time from oil discharge to observation by each aircraft is not constant during the exercises. The amount of oil that evaporates, disperses or emulsifies changes with time and all these effects will alter the volume of oil on the sea at the time of observation. In addition, the prevailing light conditions can vary between each observation.
- Precise area estimation of the different coloured regions of the slick is critical to estimating the total oil volume. Accurately estimating the area of the different regions becomes much more difficult when the slick starts breaking up into patches. An estimate of the thickest oil area is very critical for obtaining total slick volume estimates, because this region contains a very high proportion of the total slick volume.
- The level of experience of each crew in assessing slick volumes is not identical.

The correlation between slick colour and oil film thickness according to the Bonn Agreement Colour Code appears to be a good indicator of the thickness, and therefore total volume, of thin oil films. However, based on preliminary findings a significant improvement in the understanding of this correlation is possible, and this will provide the opportunity for improving the accuracy of estimated total spill volumes.

The current colour code is based on exercises and research conducted more than 10 years ago. The significance and usefulness of the colour code has changed since it was originally developed. Illegal discharges of oil from ships can now easily be identified; any visual presence of oil on the sea surface indicates that the discharge is most probably above the maximum level permitted by current regulations.

One of the major current uses of the colour code is to classify an accidental oil spill as "combatable" or "non-combatable". Very thin oil films (containing a low total volume of oil) will require no active response because they will eventually, within hours, disperse naturally. Spills of a larger volume of oil will create thicker oil films and these may emulsify. The emulsified oil will be relatively persistent, lasting for at least several days on the sea surface. During this time it will drift and may cause some impact to the environment.

The oil film thickness within a single oil slick can vary over a very wide range - sub-micron up to several millimetres. The volume of oil within an area of the slick can therefore also vary over a very wide range, orders of magnitude. A small difference in the observed colour, which is assigned a particular film thickness in the colour code, will cause a large difference in estimated volume. Hence, colour perception - together with precise area calculation - is important for volume estimation.

2.2 Findings from Phase 1 – laboratory experiments

Phase 1 of this project involved an extensive and systematic laboratory test program to validate and calibrate the current Bonn Agreement Colour Code. An experimental procedure involving colour photography of known oil film thicknesses in trays was established. The experimental series included ten oil types with different physical and chemical properties as well as seven different oil film thicknesses in the range of 0.5µm to 200 µm. The findings were:

- For thin oil films in the range of 0.5µm to 5µm, the observed colour was independent of oil type.
- Spectrums of distinct 'rainbow' colours were observed for oil films in the range of 0.5 µm to 1µm, becoming more diffuse as the oil film thickness increased above 1 µm. For thicker oil films, substantial colour variations were observed and these appeared as a function of the intrinsic, or true, colour of the oil.
- A generally applicable colour code can therefore not be used to achieve reliable estimates of oil slick thicknesses above 1µm.
- Based on the information obtained through the experimental work and the literature review, a preliminary proposal for modifications to the Colour Code was proposed.
- The Phase 1 laboratory experiments were designed to obtain the maximum colour differentiation possible. It is believed that these will correspond to perfect viewing conditions; a sunny, bright day with blue sky. The effect of less optimum viewing conditions and viewing angles typical for field situations were not addressed.

Hence, controlled outdoor experiments under realistic viewing conditions were required prior to a Colour Code amendment proposal.

3. Objectives

The aims of the small-scale field experiments were;

- To use static field experiments to correlate laboratory data obtained in Phase 1.
- To investigate the effect observation and environmental parameters on the apparent colour of oil films of various thickness.
- To propose an amendment to the Bonn Agreement Colour Code based on scientific documentation from Phase 1 (laboratory experiments and literature study) and experimental work conducted during Phase 2.

4. Materials and methods

4.1 Materials

4.1.1 Test oils

The following test oils have been used in the small field trial experiments:

Grane crude oil
Grane crude oil is an asphalthenic, heavy North sea crude oil (density = 0.942 kg / l), and is therefore not a typical North Sea crude. It is dark, viscous oil and resembles as an intermediate bunker fuel in appearance.

Statfjord crude oil
Statfjord crude oil is a typical paraffinic North Sea crude oil of relatively low density (density = 0.835 kg / l) with a high proportion of volatile components that will evaporate with the loss of up to 40 to 45% volume when weathered for 2 to 3 days on the sea surface. The remaining oil residue rapidly forms a brown water-in-oil (w/o) emulsion with up to 80% volume water content.

Forties crude oil
Forties crude oil from the UK sector is also a paraffinic North Sea crude, and even lighter than Statfjord (density = 0.822 kg / l). It has a light brown colour. 35 to 40 % of the volume will be lost as volatile components evaporate when weathered on the sea surface for 2 to 3 days. The remaining oil residue forms a w/o-emulsion with water content of 50-70% water. The emulsion appears to be darker than the emulsified Statfjord residue.

Marine Gas oil (diesel)
Marine diesel is a refinery product; a blend of kerosine and a heavy gas oil to give a boiling point range of 150-360^{o}C. The density is 0.84 kg / l. Marine diesel oil is transparent and will spread very easily on the sea surface. About 60-80 % will evaporate after 2 to 3 days on the sea. The remaining residue does not form an emulsion and is easily dispersed naturally into the water column.

IF-30 (Low Sulphur) Intermediate bunker fuel oil
This bunker fuel came from the Esso Refinery at Slagen. IF-30 is a dark-coloured (black), high-density refinery product (density = 0.92 kg / l) consisting of about 35% volume gas oil and 65 % Bunker C heavy fuel oil.

Slop oil
Slop oils are mixtures of fuel oils and lubricating oils plus other components in a varying ratio. The slop oil sample used came from a slop oil tank at Esso storage facility in Trondheim. The detailed composition of this oil was not analysed. It has a density of 0.832 kg/l. The slop oil used in this project is from another batch than the one used in Phase 1 of the project.

4.1.2 Location of field experiments

The fieldwork was performed in a harbour owned by Fina Norge A/S located in Muruvik, about 20 km east of Trondheim. Permits were obtained from Fina Norge A/S and the County Governor of Sør Trøndelag. The latter included a number of constraints that SINTEF had to consider during the experimental period. Tankers unloading petroleum products infrequently visited the harbour. Experimental activities were halted during ship movements.

A detailed map over the experimental site is given in Figure 4.1. The harbour is located in a bay facing east. Easterly wind is therefore the only direction that could cause waves that would disturb the water surface inside the working area. The harbour facilities are located south of the working area, providing direct sunlight to the working area at noon with no shadows reaching the sea surface. In the time between falling and rising tides, an insignificant current was observed in the bay. The tidal range in this part of the Trondheimsfjord is 1-3 metres. Water depth within the harbour was in the range of 15-20 m. No seabed structures could be observed from the observation locations.

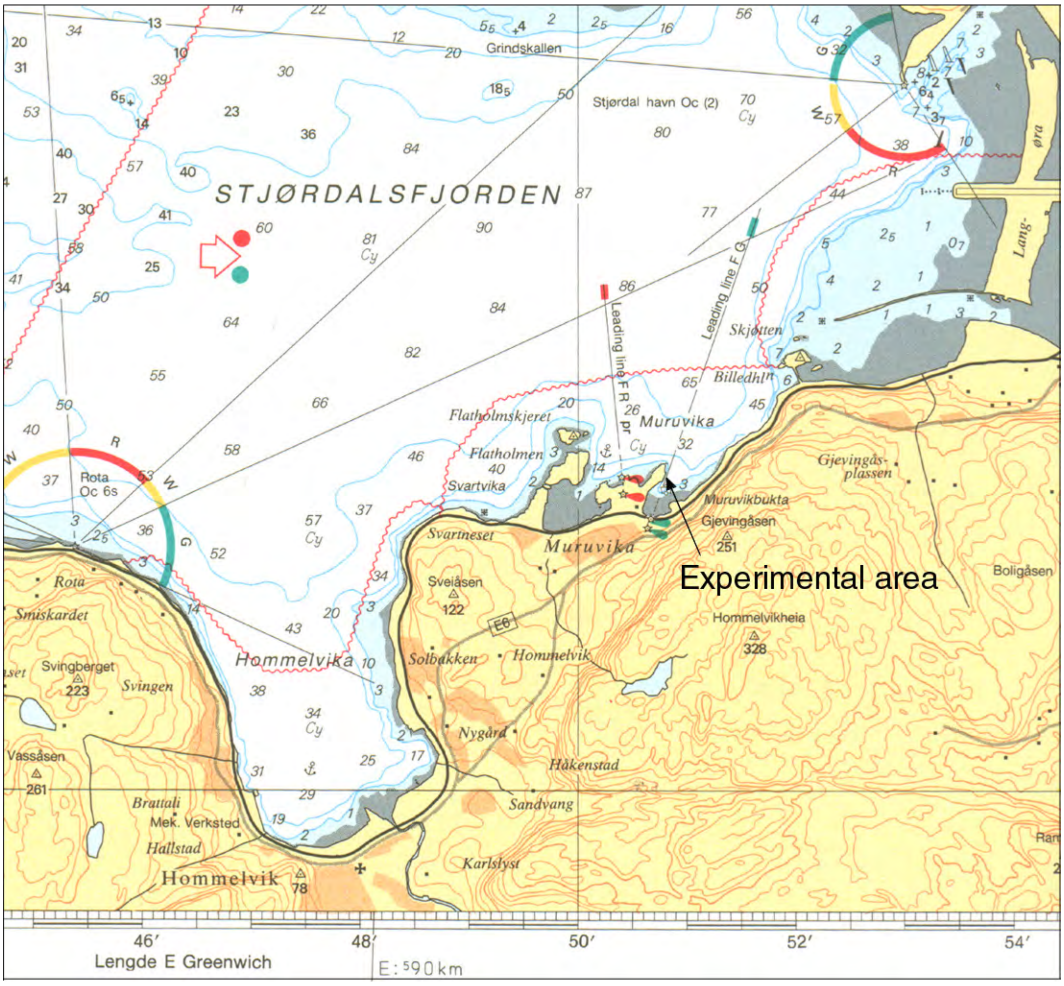


Figure 4.1 Overview map of the experimental area in Muruvik harbour

4.1.3 The experimental boom system

Based on experience from the AEAT'97 field trial, the construction of the hexagonal experimental boom system designed for this work was modified. The hexagonal booms were each made of six lengths of polyethylene (PE) tube with an outer diameter of 160 mm and wall thickness of 6.2 mm. Six lengths, each 250 cm long, were solvent-welded together to form a hexagonal floating structure. A total of five hexagonal ring systems were manufactured in this project. Preliminary testing proved that each of the hexagons was a well balanced, floating system. Approximately 4-5 cm of the ring was below the water line. Due to the strict limitations in wind exposure and wave height necessary for performing the experimental work, this shallow draft was acceptable. As a back-up solution, it was considered that holes could be drilled to allow water into the rings to reduce buoyancy. This proved not to be necessary during the experimental work. Each hexagon was connected to another by rope and the five hexagons were configured as shown in Figure 4.2.

The position of the multi-ring system was fixed by anchors and by ropes attached to the harbour construction.

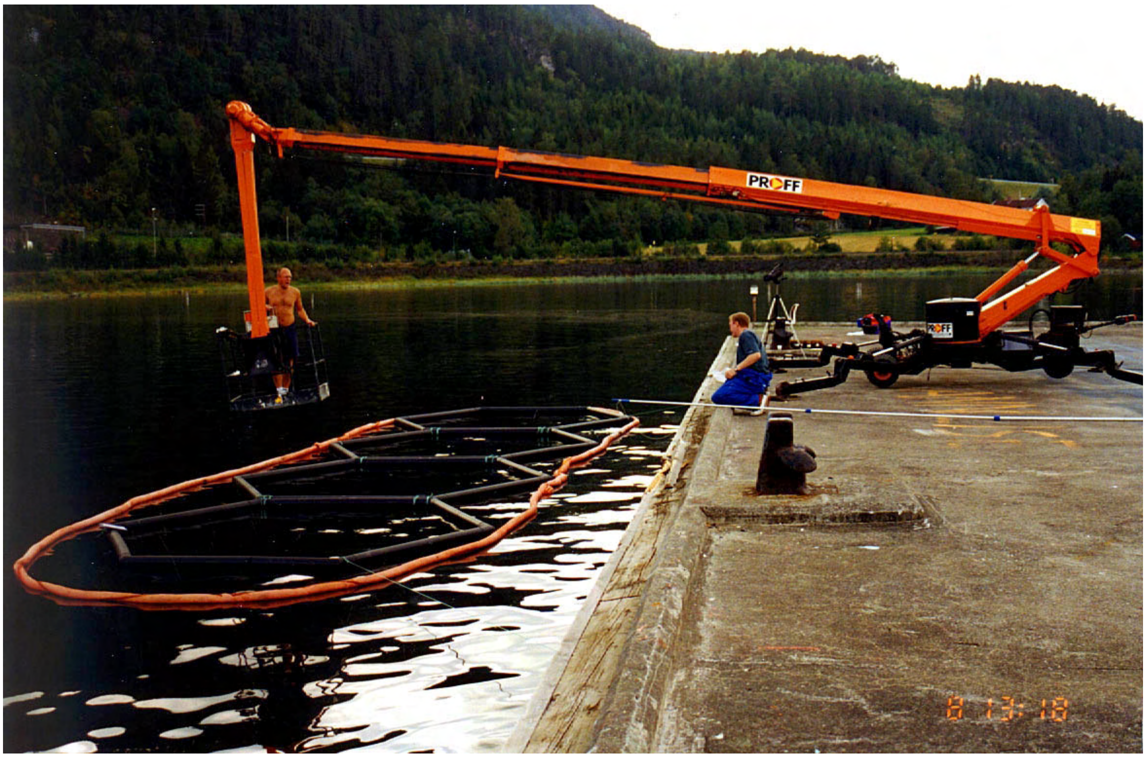


Figure 4.2 Experimental boom system.

4.1.4 Oil spill contingency

As part of the permit to use oil for experimental purposes, the "Environmental Department, County Governor of Sør-Trøndelag" forwarded several requirements.

SINTEF took full responsibility for preventing any oil from escaping from the hexagon system. The experiments were not to be performed in weather conditions that might have caused the oil to escape from the hexagons due to wind and wave action. To fulfil these requirements, the system was protected by the use of floating absorbent boom, as shown in Figure 4.2. In addition, absorbent pads were kept on shore in case oil sheen was observed outside the absorbent booms. During the experiments, no oil escaped and the pads were never put into action. When the experimental work was halted due to several days of bad weather, the absorbent booms were stored on land to better maintain their absorbing capabilities. The absorbent booms were regularly replaced when their absorbent capacity was significantly reduced by water absorption.

4.1.5 Photography equipment

The experience gained during the Phase 1 laboratory studies was used to improve photography during the Phase 2 small scale field experiments. The main differences between the two phases were natural light instead of artificial light, a dark infinite background, less flexibility in Phase 2 for performing replicate experiments, and the need in for instant processing of the exposed films. Three different photographic media were therefore used in Phase 2:

- Camera for 35 mm film - Canon F-50 with zoom lenses (35-200 mm)
- Digital camera, - Fuji MX-700
- Video camera - Sony CCD-V800E/PAL videoHi8

The Canon camera with a Kodak Gold 200 ASA negative film was used as primary photographic method. The standard 35 mm film format allowed rapid processing of pictures which was necessary to utilise the experience gained and observations made from one day to another. The video camera was used as back-up, making a reconstruction of the complete experimental log possible. All the cameras were mounted on tripods on the quay structure as well as on brackets connected to a mobile lift platform. The light intensity during photography was measured using an analogue exposure meter.

4.2 Methods

When the conditions for conducting a series of experiments were found to conform to the objectives of the experiments, the required amount of test oil was poured carefully into the experimental ring system. Time was allowed for the oil film to spread within the ring system. The oil did not spread evenly, but produced a number of different oil film thickness areas. Photographs were taken and then pad samples were taken from the different locations. Simultaneously, notes were kept in a log-book and the ongoing activities were recorded using a video camera with a time display. Photographs were taken both as overviews and as detailed pictures. The pad samples were solvent-extracted and oil film thicknesses were determined by UV/Visible spectroscopy. The photographic films were processed rapidly and photographs were available for assessment the same day. The photographs were subsequently studied in more detail and a selected number of photographs were transferred to CD-ROM format.

4.2.1 Preparation of oil films

The original plan for the small-scale field experiment was to create the same oil films thicknesses as used in the laboratory studies, by applying different oil quantities to the experimental ring system. However, observations and experience from preliminary tests clearly showed that even under ideal weather conditions this approach was not possible, as the oil did not spread evenly within the ring systems, but an oil film thickness gradient was established. Different oil volumes did, however, form oil films within different thickness intervals. The oil film thicknesses of greatest interest for this project were created by application of 1L of oil to the ring system, giving an average oil film thickness of approximately 70 microns. The oil was released carefully into the interior of the ring from a small working boat. Spreading and distribution of oil film thicknesses within the ring system was affected by the properties of oil, and environmental parameters such as wind, currents and the surface temperature. Pad sampling of the oil film and photography was initiated when the oil was sufficiently spread out within the experimental area, typically within 5-15 minutes.

4.2.2 Photography and photo processing

Al together more than eleven hundred pictures were taken during these experiments. These included photographs taken during release of the oil, during spreading and of oil film areas with similar thickness, both as overviews and as detailed pictures of various areas within the boom. Each image was obtained with three to five different camera settings to ensure a correct recording of the apparent colour of the oil film. At the end of each experimental day, the film was processed so that colour prints (working copies) were available rapidly for evaluation, and in order to design the experimental plan for the next day.

At the end of the experimental period, after all oil film thicknesses had been determined and correlated to photos and observations, approximately (>250) were transferred into CD-ROM format.

4.2.3 Oil film sampling

After the required area of the oil film had been photographed, an absorbent pad was fastened to the end of a telescopic rod. The pad was then applied onto the oil film with guidance from the operator in the mobile lift to ensure that the same area was sampled. Another set of photographs were taken of the absorbent pad on the water surface, and of the oil absorbed to the pad after removal from the oil film for visual inspection of the coverage. The absorbent pad was then carefully removed from the telescopic rod, folded carefully and placed in a “wide necked medicine bottle” (500mL) and stored until analysis.

4.2.4 Oil film thickness determination

The absorbent pad was taken out of the storage bottle and transferred into a Soxhlet extraction apparatus and extracted with 300mL DCM (dichloromethane) for 6 hours. After cooling, the solvent containing the extracted oil was dried on anhydrous sodium sulphate and transferred to a 250mL volumetric flask and solvent was added to the mark. The oil absorbance was measured, if necessary after dilution, by UV/Visible spectroscopy analysis. The oil film thickness was quantified by the use of calibration curves for each oil type. Oil quantification using the spectroscopic method cannot be used for diesel/gas oil due to very low content of coloured components in these oils. Diesel oil film thickness was determined by GC-analysis of the solvent containing the extracted oil.

4.2.5 Experimental

A total of 17 experiments were carried out on total 6 different oil types under various environmental conditions. An overview of the activities including oil type, quantity of oil used, date and time, the weather situation (sky coverage), and number of samples and photos taken is given in Table 4.1.

Table 4.1 Overview of experiments work in the small-scale field system

Oil	Quantity	Time	Weather/ Comments	Sample#	Film#
3.september					
Statfjord I	250mL		Blue sky	-	1
4. September					
Forties I	250ml	11:05- 11.57	Overcast	1 – 12	2 – 3
Forties II	1200mL	12.50 – 13.35		13 – 21	3-4
Statfjord II	1000mL	13.53		22-23	4-5
8.september					
Forties III	1000mL	09.50-10.19	Blue sky	24-30	6-7
Diesel I	250mL	10.28-10.37		31-32	7-8
Diesel II	1000mL	10.39-11.03		33	8 (7-16)
IF-30 I	1000mL	11.08-11.32		34-39,42	8-9 (29) +some10
Grane I	1000mL	11.36-13.00	More overcast	40,41, 43-45	9-11
Statfjord III	1000mL		Cloudy		
30. September					
Slop I	1000mL	10.23-11.58	Blue sky	46-59	12-16 (15)
			Height		
Forties IV	1000mL	11.34-13.18		60-65	16-18(37)
			Height		
Grane III	1000mL	13.30-14.14		66-72	19-21
Diesel III	1000mL	14.25-14.43		73-75	22
1.october					
Oil film from previous day; photos taken (blue sky)					
IF-30 II	1000mL	13.20-14.15	Sun angle (in general very little spreading of oil slicks)		23-24
Forties V	1000mL				
Statfjord IV	1000mL		Sun angle		

5. Results and discussion

During the experimental period (late August to early October), a total of only 5 days of field work was possible due to weather and logistics constraints. However, SINTEF gained valuable experience on how to conduct oil colour assessments in the field as well as identifying constraints related to the location and the facilities on site.

The main results from these Phase 2 experiments are colour charts for different oil types for two different natural light situations – overcast sky and blue sky. An assessment of how different environmental and observation parameters affected the apparent oil film colour was conducted.

5.1 Constraints related to oil film thickness measurements by oil pad extractions

Minutes after the release of oil into the hexagon, the oil slick stabilised to form a non-homogeneous oil slick of varying oil film thickness. The variation of oil film thickness within the slick area was large. It was therefore necessary to select sampling locations based on photographs. A precise link between the apparent colours and the thickness of the oil film could then be documented. A large number of samples were analysed and the data for the oil film analysis is presented in Appendix 1. Also included are comments by the scientists involved, as well as the prevailing environmental parameters, estimates on the oil film thickness and a description of the visual colour of the oil film.

For some oil types, the oil film thickness varied within a range from less than one micron to at least several hundred microns. Due to the non-homogeneous nature of the slicks, a large number of differences in microscopic and macroscopic visual appearance were observed. Under some wind/current situations, it could be difficult to find sufficient large areas of a given colour intensity to perform highly accurate pad sampling.

Oil quantification using the spectroscopic method cannot be used for diesel/gas oil due to very low content of coloured components in these oils. Diesel oil film thickness was determined by GC-analysis of the solvent containing the extracted oil.

Also, for the other oil types the analysis method used does not necessarily give the precise oil film thickness at the time of sampling, due to evaporation of volatile components that are colourless. After an oil discharge, weathering processes will take place. A significant fraction of the more volatile compounds will be lost after a short time. However, control experiments in the laboratory provided excellent correlation between the amount of oil in trays and the oil film thickness determined by solvent extraction of the pads (see example in Figure 5.1.). The film thickness determined using the analytical methods described in this report is an acceptable approach for this project. A numerical model, such as the SINTEF OWM (Oil Weathering Model) may compute the oil film thickness change as function of time. The model includes evaporation curves of the oil. The effect of evaporation will, however, not affect the conclusions in this report.

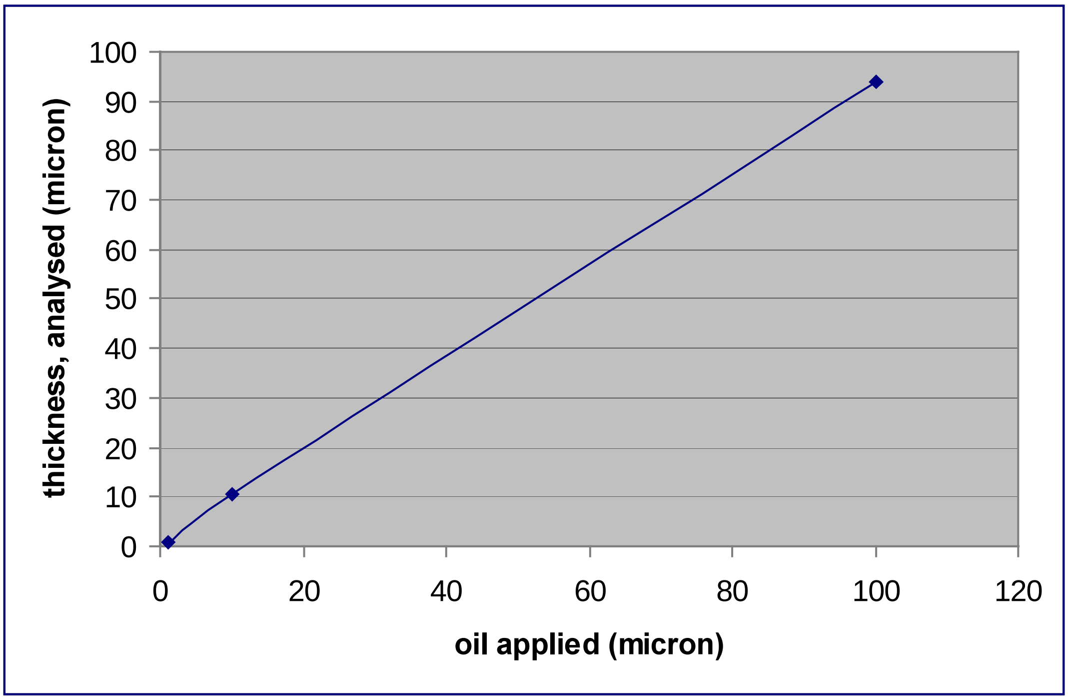


Figure 5.1 Example of oil film thickness calculation in defined laboratory systems.

5.2 Photography of oil films on water surfaces - possibilities and constraints

During the laboratory studies conducted in this project a great deal of effort was made to optimize the experimental system to maximise the apparent colour differences for oil films of different thickness. This was not practical in the experimental field situation. Early in the project period - after some trial and error - SINTEF concluded that *ad hoc* experiments were needed. Data had to be collected on site when optimal combination of environmental parameters were present. In the field, these environmental parameters cannot be controlled. Conditions will normally change during the experimental period, or during any oil spill observation period. It is therefore very difficult or impossible to reproducibly replicate the exact experimental conditions. In this project, one objective was therefore to identify how the environmental parameters affected the apparent oil film colour and to identify under which set of conditions the best results were obtained.

5.2.1 Visual effects caused by the environmental conditions

The constraints required by the Environmental Department, County Governor of Sør-Trøndelag included restrictions on the weather conditions during and after oil release, thereby minimising the risk of oil being released from the boom systems into the environment. The requirements were in accordance with our own limits for obtaining scientifically valid data from the experiments. The restrictions were related to waves on the sea surface. Hence, any wave action was avoided during the experiments.

At an early stage, SINTEF observed significant effects caused by the prevailing weather conditions on the apparent colour of oil film of a particular thickness. This was mainly related to the cloud coverage (blue sky versus cloudy, grey sky), direct sun exposure, wind and currents. In this project, significant effort was aimed at gaining new knowledge on how the oil slick colour appearance is influenced by sky and cloud cover, sun exposure, wind and currents.

Effect of cloud cover

The sky and cloud cover was identified as an important factor when observing oil film colours. This is shown in Figure 5.2, an overview of the experimental boom system during a partly cloudy sky situation. Reflections of cloud are easily seen within the visible area of the oil slick. The apparent colours in areas of identical oil film thickness are not identical in areas visible with a blue sky reflection and with a cloud reflection.

As expected, apparent colour also changes with areas of different oil film thicknesses. More detailed and distinct colour information can be observed under situations with a clear blue sky. Hence, quantification estimates will be more reliable during clear sky daylight conditions. A daylight, clear sky condition was therefore preferred when comparing different oil types and thicknesses. In addition, observations were made under different weather conditions to obtain data on differences in oil film colours caused by cloud cover variations. Colour charts for each oil type should therefore (Section 5.3) be established both for blue sky and cloudy situations. Cloud cover was, of course, not identical during the field experiment period. A rough assessment approach was therefore required.

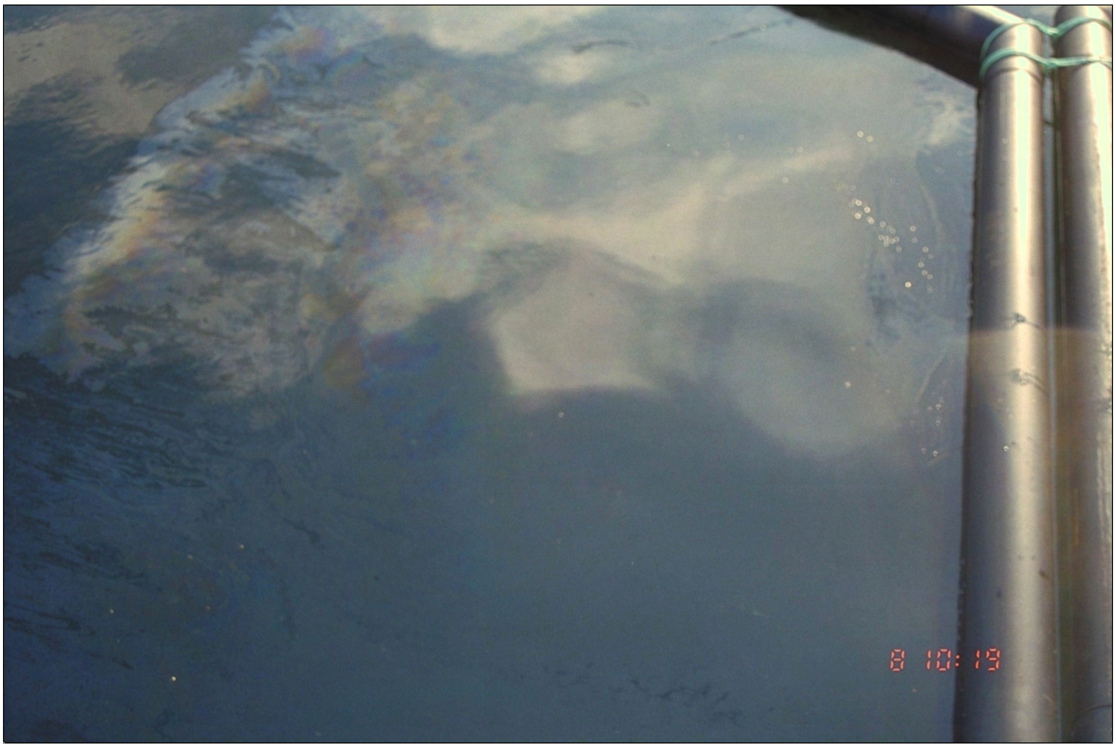


Figure 5.2 Overview picture including experiment with Forties crude oil of different film thickness under partly cloudy conditions.

Effect of direct and indirect sunlight

A range of hills is close to the experimental area. At low sun angles, they prevented direct sunlight reaching the oil slicks. However, a comparison of the oil slick colour with and without direct sunlight showed no significant colour differences. Interestingly, direct sunlight did influence the apparent colour of the clean water surface. For thin oil films, the background colour of the water is a factor. The influence of direct or indirect sunlight might therefore influence the overall colour impression when viewing very thin oil films.

Effect of wind

The behaviour of thin oil films is very sensitive to exposure to the wind. This was especially evident inside the closed boom system. An example of the effect of the wind is shown in Figure 5.3 were the oil film was concentrated to within a small "downwind" area inside the hexagon. Even at very low wind speeds, the oil film was moved by the wind and this created constantly changing oil film thickness gradients. These changes took place rapidly and it was not possible to obtain pad samples of the oil film thickness in these areas. Wind was therefore a limiting factor during field experiments.

Effect of currents

The currents in the experimental area produced a similar effect to the wind; the oil film was moved to one side of the hexagons and became concentrated there. However, this only occurred when the tide was changing. Experiments were suspended while this occurred.

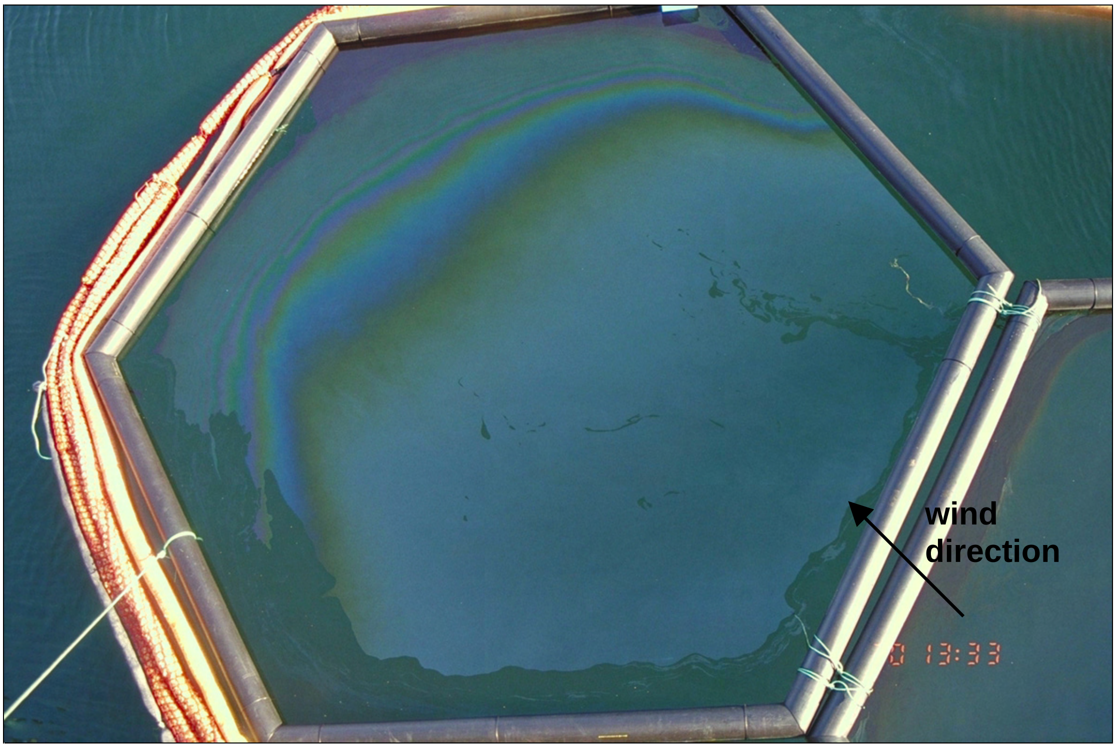


Figure 5.3 The effect of wind on the oil slick in the experimental system.

Summary of environmental effects

- The apparent colour of oil films of identical oil film thickness was not identical when viewed in an area of reflected blue sky and in areas of reflected cloud.
- Clear sky conditions produced the most distinct oil film colours. Application of any colour to thickness correlation would be most reliable under a clear sky.
- Illumination by direct or indirect sunlight was not identified as a critical factor for oil film colour assessment. However, there was difference in the observed background colour of the sea and this could influence the discrimination of oil film colour appearance.

- The effects of wind and currents are limiting factors when performing small-scale field experiments. The oil was moved to one side within the anchored hexagons and became concentrated into thicker layers.

5.2.2 Effects caused by variation in observation parameters

The design of the field experiments included the use of a movable platform from which observations could be made. This mobile lift was located on the quay structure and could be raised to a maximum height of 18 metres above quay, moved to 3 metre below the edge of the quay, and moved up to 10 metres in a horizontal direction. It was therefore possible to investigate the effect of the observation angles by altering the relative position at which the observations were made.

Effect of observation height

Each oil film was normally observed from a height ranging from 1 to 10 metres. One example (Slop oil) is presented in Figure 5.4. Overview photographs of the hexagon were taken from 2, 5 and 10 metres. Identical picture series were also taken for other oil types. The apparent colours did not change significantly within this range of observation height. Some scale/resolution effects were observed. It was possible to determine the colour of the oil film more effectively at short distances than at longer distances.

The observation height range in these tests (from 1 to 10 metres) obviously does not simulate surveillance from an aircraft that would take place from an altitude of several hundred meters. Observation from that height will cause an "averaging" effect; the distinction between small areas of different colour may not be as apparent because of the change of scale. The effect of observation altitude should be further investigated in future aerial surveillance exercises and experimental field trials.

Effect of observation angle relative to sea surface

Horizontal and vertical movement of mobile lift platform permitted the oil films to be observed from different angles relative to the water surface. Observations were made of films of several oil types. One example is presented in Figure 5.5. The observation angles were varied from close to vertical to approximately 20^{o} for a thick oil film. The picture series show no significant differences in apparent colour of the oil. The pictures were taken in bright daylight with a clear blue sky. Under such conditions it should possible to make a reasonable assessment of oil film colours from tall structures such as oil platforms, even though the observation angle will not be truly vertical.

When a similar series of photographs were taken in hazy conditions, the apparent colour of the oil film became less distinct and more grey at low observation angles. The observation angle may therefore affect the apparent oil film colour under hazy conditions and the observation should be as close to vertical as possible.

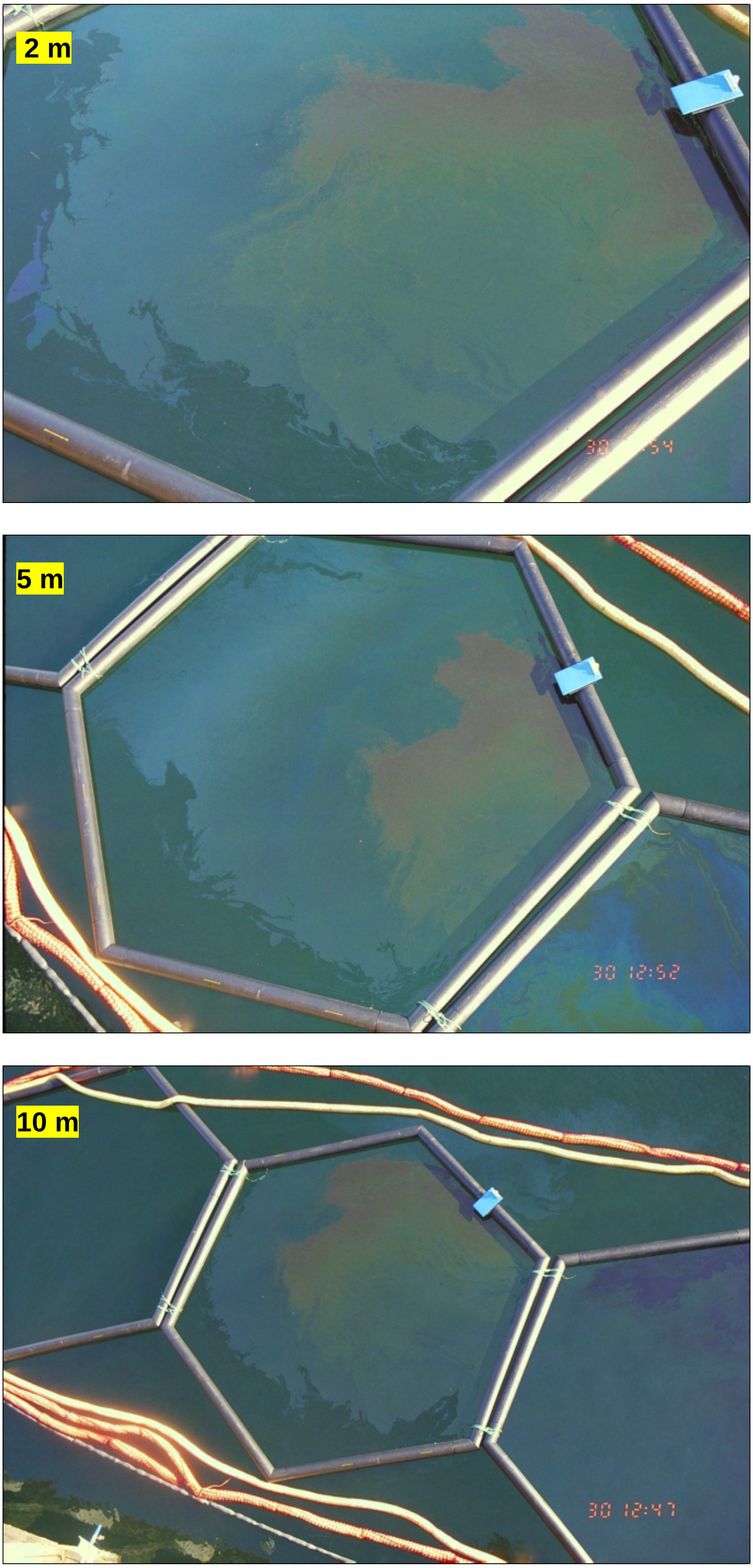


Figure 5.4 *Overview photos of oil slick in the experimental system taken from different observation heights (Forties crude oil)*

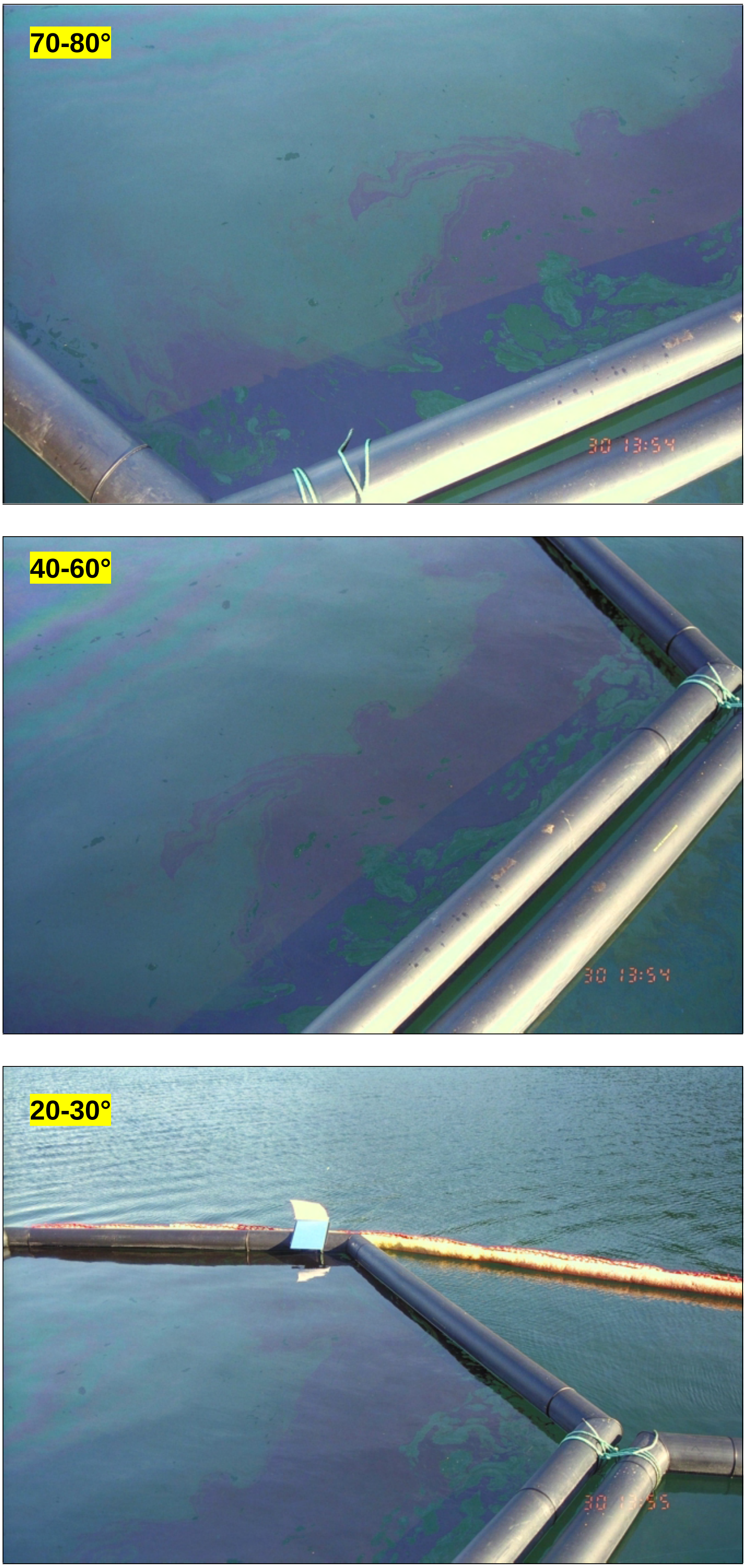


Figure 5.5 Pictures of oil slick (Grane crude oil) observed from different angles relative to the water surface.

Effect of observation angle relative to sunlight reflection

The apparent oil film colour that is observed is influenced by the direct reflection of sunlight. The magnitude of this effect is dependent on the relative angle between the reflected sunlight and the observation position. A series of photographs were taken from different angles relative to the sun by moving around the oil film in a horizontal arc. An example of the effect is shown in Figure 5.6. This photograph shows that the sunlight reflection is only significant at observation angles below approximately 30^o. These observations confirm laboratory findings in from Phase 1.

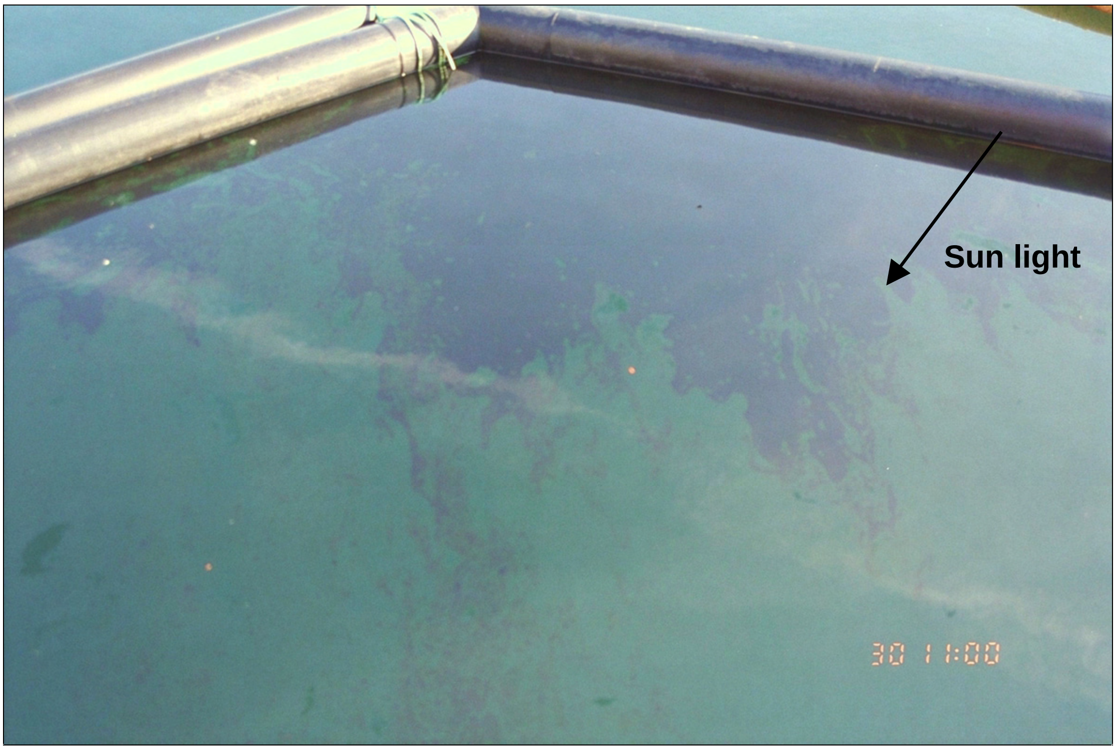


Figure 5.6 An oil slick (slop oil) observed towards the sun.

The situation will be more complex in a real spill situation. Wave action within the oil slick will create a dynamic variation in the reflection angles. It is recommended that colour assessment should be performed when the light from the sun is opposite to the observers viewing direction. This recommendation is independent of sky condition and is valid as long as the natural light is more intense in one part of the sky.

Conclusions

- The apparent colours of oil films are, for all practical means, independent of observation height within the variation of the experiments (1 to 10m). This should, however, be expanded by full/heilght field trials.
- During bright daylight and under a blue sky, the observation angle does not alter the observed apparent colour of thin oil films.
- In less ideal viewing conditions, with the presence of cloud cover or in hazy conditions, the observation angle should be as close to the vertical (straight down) as possible.

- In northern latitudes, the direct reflection of sunlight to produce 'sun glitter' and 'glare' is significant only at observation angles less than 30^o from the sun reflection pattern.

- Apparent colour assessment is best performed when the light source (the sun) is opposite to the observers viewing direction.

5.3 Assessment of the colour charts

A large number of photographs of oil films were taken and these were calibrated with oil film thicknesses measured by pad sampling and solvent extraction. Colour charts for each oil and observation condition were created based on overview and close-up photographs. An example is given in Figure 5.7.

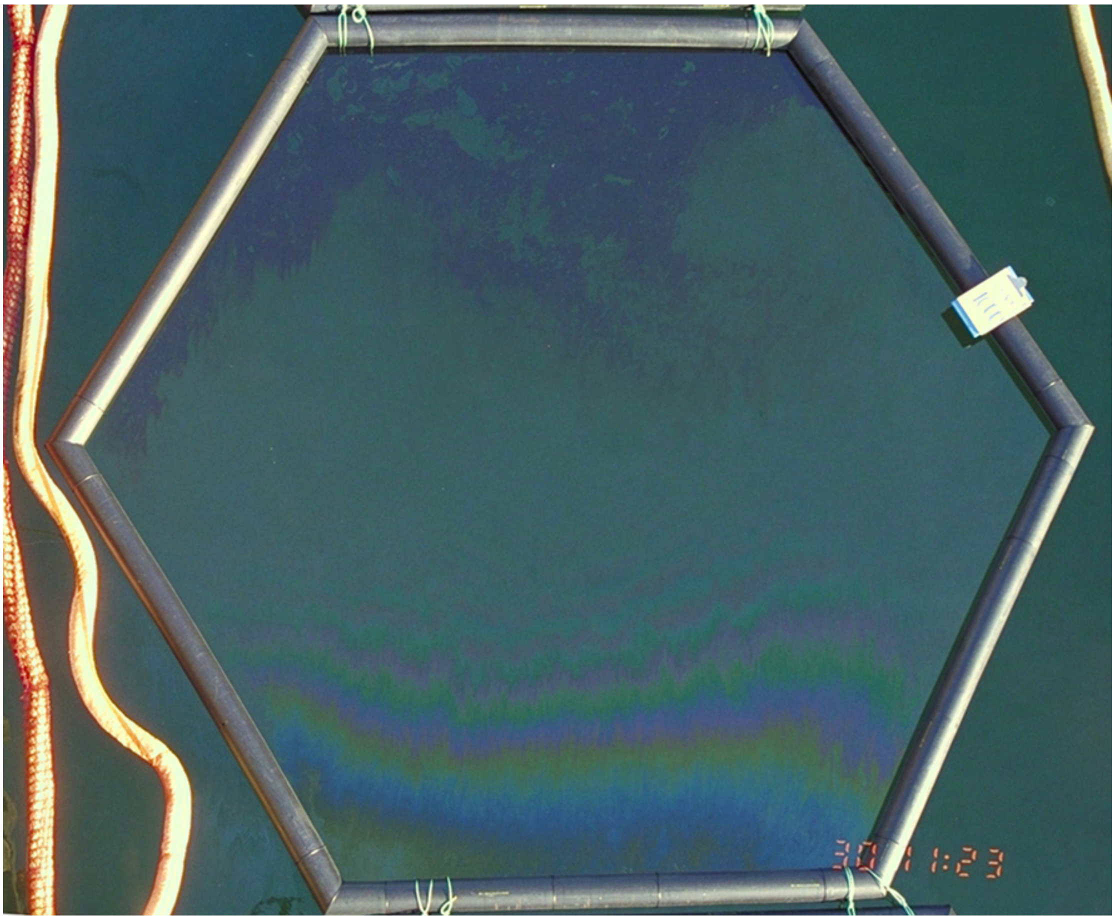


Figure 5.7 Overview picture of oil slick (slop oil) in the experimental boom system used for preparation of mosaic photos.

A slick of slop oil is shown in the overview photograph. The oil itself is easily identified as a mosaic of colours together with an area of unexposed water surface. Based on such overview photographs, close-up photographs were taken and pad sampling were made in the individual colour areas. After this three-step process, the data was analysed in detail. Each close-up photograph with apparent oil film colour that had been measured for oil film thickness by pad sampling, was compared with the same area on the overview photo. This procedure secured a reliable comparison between the oil film thickness and apparent colour for each oil type. Finally, when all the data had been collected, four main categories of apparent oil film colours were identified in addition to the silvery and grey codes. The four other categories are:

- rainbow
- metallic
- discontinuous true oil colour
- homogenous true oil colour

Each category represents one film thickness interval, which was established on the basis of:

- Colour intervals (steps) that could be easily identified by a skilled observer.

- Names that describe the apparent colour in the most precise way possible.

An individual photograph of each colour interval was not practical in the field experiments. Instead, the colour charts for each oil type have been represented as continuous colour strips created from sections within the overview photographs. The mosaic photos were manipulated using Adobe PhotoShop™ software in a way such that each colour interval covers identical areas on each chart. No manipulations of the colours themselves were performed.

Colour charts for individual oil types observed under blue sky and with overcast sky are presented in Figure 5.8 a-f. Each mosaic represents an area of approximately 0,75 x 3 metres. An image of the clear water surface is located in lower part of the mosaic. The variation in the apparent colour of the clear water area is an indication of variation in light level and effect of the cloud cover. Diesel oil has no distinct colour and has a unique spreading capability. Therefore, the diesel oil colour chart is presented only as overview photographs without any discrimination between different colour intervals.

During the fieldwork, the cloud cover varied from clear blue sky to total cloud cover with dark grey clouds. A large number of cloud cover situations, between these extremes, influenced the apparent colour of oil films, with the exception of the rainbow colours, which were always detectable. For practical reasons, it was not possible to perform the experiments with all combinations of different oil types under identical sky and lighting conditions.

5.3.1 Apparent oil film colour with respect to different oil types

During the Phase 1 laboratory experiments oil film thicknesses of 0.5µm and above were studied. Significant colour variations were observed using oil films produced from different oils. At a particular oil film thickness there were variations in oil film colour and the intensity of the colour. The experiments were designed to maximise the colour effects. In the Phase 2 field experiments, the general conclusions of the Phase 1 work were verified; there were significant differences in apparent colour of films of different oils. Experiments where the thicker oil film intervals (>200µm) were investigated in the Phase 2 work to supplement the findings of Phase 1.

The most significant differences in oil film colours were with thicker oil films (>50µm), where the true colour of the oil became an important factor. The Forties and Statfjord crude oils had a light brown colour. For Grane crude oil, the slop oil and IF-30 bunker fuel oils the oil films were darker in colour. The photographs of Grane crude oil (a heavy crude oil) and Forties crude oil (a light crude oil) in Figure 5.9 illustrates these differences. The colour of the darker oil films is very similar to that observed in the Phase 1 experiments. However, the colour of the films of the lighter-coloured oils was observed to be a brighter brown in the field, compared to the red and brown colours observed in the laboratory.

Figures 5.8 a-f

Colour charts for test oils under blue sky and cloudy sky.

Forties blue sky

Forties cloudy sky

Homogenous true oil colour

Discontinuous true oil colour

Metallic

Rainbow

Silvery/grey

Open water

Statfjord blue sky

Homogenous true oil colour

Discontinuous true oil colour

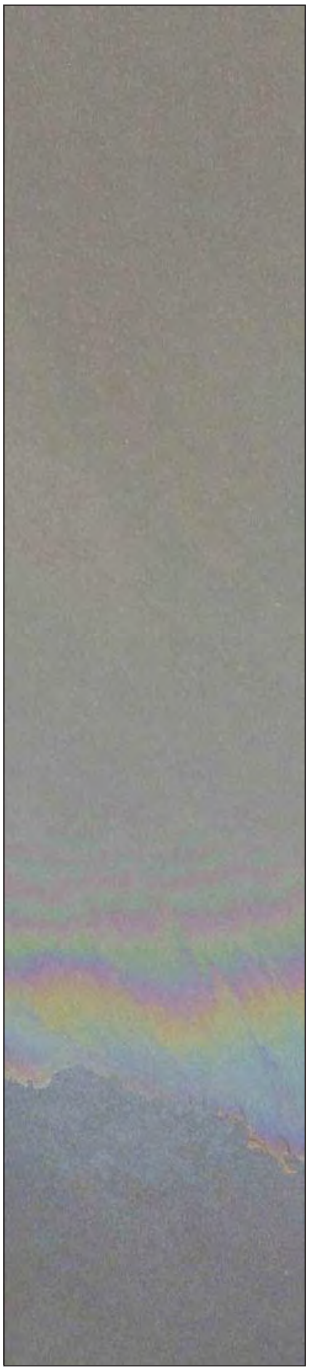
Metallic

Rainbow

Silvery/grey

Open water

Statfjord cloudy sky



IF 30 blue sky

IF 30 cloudy sky

Homogenous true oil colour

Discontinuous true oil colour

Metallic

Rainbow

Silvery/grey

Grane blue sky

Homogenous hue oil colour

Discontinuous hue oil colour

Metallic

Rainbow

Silvery/grey

Open water

Grane cloudy sky

Slope blue sky

Homogenous true oil colour

Discontinuous true oil colour

Metallic

Rainbow

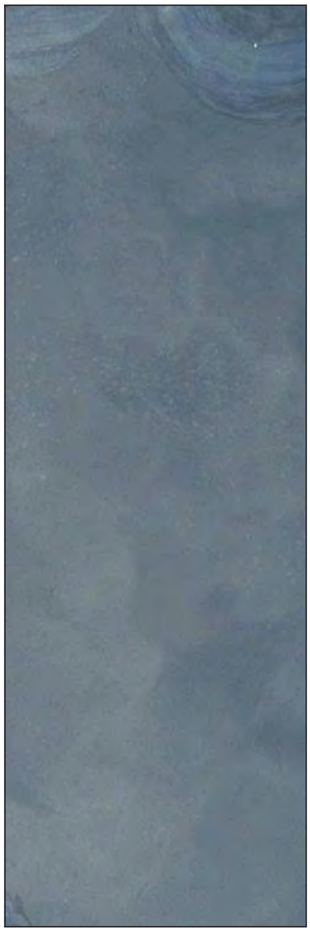
Silvery/grey

Open water

Slope cloudy sky

Diesel blue sky

Diesel cloudy sky



The large differences in colour intensity observed in the laboratory were not observed in the field experiments. The true colour of the oils, as opposed to an apparent colour that depended on film thickness, appeared at around the same oil film thicknesses for all oil types tested. This indicates that the degree of surface coverage by oil is more important for visual observation by aerial surveillance observation than the actual colour of the oil.

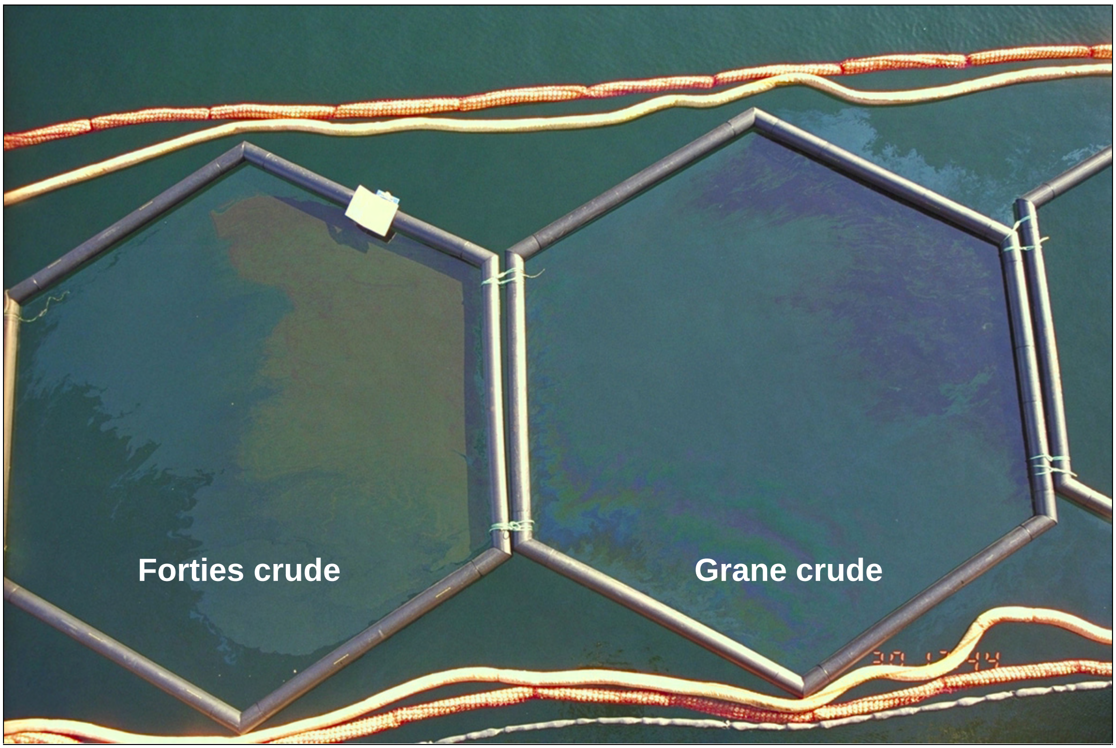


Figure 5.9   Overview photo of two different crude oil types.

The colour charts for the different oil types presented in Figure 5.8 were produced under two different sky conditions; blue sky and a partially cloudy sky.

<u>IF-30 bunker fuel oil</u>

Photographs were taken over a period of two days in two different weather situations - overcast and blue sky. In the chart recording the colours observed with overcast sky, no colour differences associated with oil film thickness, other than that of the rainbow region, were observed. It may therefore be difficult to quantify the volume of spilled IF-30 bunker fuel oil on the basis of apparent colour during overcast conditions. This will likely be the situation also for other heavy bunker fuels. With a blue sky, the colour chart shows the reflection of the blue sky on either side of the rainbow colour thickness region (i.e. silvery/grey and metallic). In both charts it is difficult to identify the location of the open water area.

<u>Grane crude oil</u>

Observations were made with an overcast sky, with thin haze situation and with a blue sky. The apparent colour of the different thickness regionswithin the oil film was easily observed. For Grane crude oil the oil film thickness produced a ‘metallic’ thickness region that was slightly brown. The appearance of thicker oil films was influenced by the reflection of the blue sky, creating a blue-brown colour.

Slop oil

During overcast weather, the slop oil colour was intermediate to those observed with the Grane crude oil and IF-30 bunker fuel oil. The colours were more diffuse. Apparent colour differences with oil film thickness were identified. With observations carried out under a blue sky, significant colour variations with oil film thickness were easily identified.

Forties crude oil

The colour chart produced with blue sky shows significant sky reflection creating blue-green colours. Even for the thickest oil film regions, the blue sky reflection was observed. The appearance of thick oil films, under a blue sky, of Forties crude oil resembles those observed with Statfjord crude oil. During a hazy day the true colour of the oil could only be observed in the thickest oil film regions.

Statfjord crude oil

The colour chart produced with an overcast sky shows that there were insignificant differences between the colours observed for different oil film thicknesses, apart from those produced in the rainbow region. With a blue sky, the apparent oil film colour is much brighter than those observed with heavier oil types.

Marine diesel fuel oil

Marine diesel fuel oil is transparent and has very little true colour. It is not possible to differentiate between the different oil film thicknesses on the basis of colour observations. This is independent on sky cover. The photographs presented in Figure 5.8f are overviews taken under different weather situations. The oil film reflects the sky and clouds and the appearance gives no indication of oil film thickness.

5.4 Assessment of oil film thicknesses – colour appearance

Based on all information obtained in Phases 1 and 2, SINTEF believes that the best possible description of the apparent colour of oil films can be described with the following terms;

- silvery
- grey
- rainbow
- metallic
- discontinuous true oil colour
- homogenous true oil colour

The first 3 terms - grey, silvery and rainbow - are described in the literature study and the relationship between apparent colour and oil film thickness is well supported by theory.

5.4.1 Silvery and grey

No specific testing was done to verify that the silvery/grey appearance of an oil film corresponded to a particular oil film thickness.

During release of the oils into the hexagons, the oil gradually spread to cover most of the available water surface. The rate and kinetics of this process were dependent on the spreading coefficient of the different oil types. For most oil types, the spreading process was slow and this allowed observation of the dominant and easily-observable rainbow area. The very thin oil film that appears grey and silver was located between the open water and the rainbow area. The appearance of the grey/silver area was influenced by the reflection of the sky off of the water surface underneath this extremely thin oil film. Pad sampling of this thickness interval was outside the scope of this project. Theoretical considerations indicate that the silver/grey oil film would have a thickness from 0.05 to 0.3µm.

The colour charts for the different oils show that the silver and grey colour areas of a slick may be difficult to distinguish in low wind conditions from the much thicker oil film that appears to be ‘metallic’ in colour. However, there are two possible methods that may aid discrimination between these two areas:

- In windy conditions, the wave-damping effect of the ‘metallic’ appearing area will be much more significant than that of the much thinner silver/grey area.

- The ‘metallic’ area will be located between rainbow and the true oil colour area, while the silver/grey is located between the slick edge and rainbow area, in a spreading oil slick

Confusing the silver/grey and metallic areas within a spreading oil slick will cause the volume estimation to be in error by a factor of two orders of magnitude.

5.4.2 Rainbow

The rainbow area is a reliable and easily identified thickness interval as described in the literature and laboratory experiment reports. The rainbow colours are independent of sky coverage. As demonstrated in the colour charts presented, the intensity of the rainbow colours are only slightly influenced by the sky reflection. With an overcast sky, the rainbow colours become more diffuse. With a blue sky, the reflection may interfere with some of the rainbow colours.

Multiple rainbow colour areas can be observed in some light conditions. These are due to constructive and destructive interference as described in Phase 1 and in the literature study. Rainbow colours may therefore be observed at film thicknesses above the wavelength of visible light (>800nm).

The experimental evidence confirms that the thickness of oil films that exhibit rainbow colours is from 0.3µm to 5µm.

5.4.3 Metallic

The term ‘metallic’ has been found to be more precise than the present term ‘blue’ for describing the appearance of oil films that are somewhat thicker than those describe that exhibit rainbow colours.

For this thickness interval, the apparent colour is not caused by true colour of oil or by interference. The apparently ‘metallic’ colour has been identified as a mirror effect dependent of light- and sky conditions. A wide range of colours can be observed, blue, purple, red and greenish (Figure 5.8). The ‘metallic’ appearance is the common factor. The term ‘blue’ is valid in daylight blue sky situations only, but blue was never observed during overcast conditions.

Pad samples measurements revealed that the thickness interval for metallic appearance was from 5µm to 50µm. This is significantly thicker than the present Bonn Agreement "blue" code classification.

5.4.4 Discontinuous (broken) true oil colour

For oil slicks that are greater than 50µm thick, the true colour of the specific type of oil will gradually dominate the colour that is observed when viewing the slick. Brown oils appear brown and black oils appear black. The broken, or discontinuous, nature of the colour is due to thinner areas within the slick. The spreading behaviour of the oil under the effects of wind and current will cause this

The colour variations observed for oil films in this region of thickness are due to;

- Thickness variations within the interval (each experimental spill formed a discontinuous true oil colour area of unequal thickness although always within the same thickness interval)
- Sky reflection caused variations.
- True oil colour variations.

Based on the observations done that the term “discontinuous true oil colour” describes the apparent colour more accurately than the old term “blue/brown” of the present Bonn Agreement Colour Code.

Based on photographs and thickness measurement of oil films all oil types, the “discontinuous true oil colour” has been defined as a thickness interval from 50µm to 200µm.

5.4.5 Continuous true oil colour

For oil slick thickness greater than 200µm the true colour of the specific oil type will be the dominant effect on observed colour.

Colour variations observed for continuous true oil colour are due to;

- The true oil colour.
- The true oil colour is more diffuse in overcast weather.
- Oil types with a very dark colour may appear slightly bluish in blue sky conditions.

The colours of thicker slicks of IF-30 bunker fuel oil, slop oil and Statfjord crude oil varied little, making thickness assessments more difficult in overcast weather.

Based on photographs and thickness measurements of oil films of all the oil types, the “continuous true oil colour” thickness has been defined as greater than 200µm.

5.5 Comparison between laboratory and outdoor field experiments

The following differences between results obtained in the laboratory (Phase 1) and from small-scale outdoor field experiments (Phase 2) have been identified;

- The outdoor field observations are more representative of aerial surveillance situation because the laboratory experiment conditions were devised to obtain maximum colour differences. In general, the oil film colours were more diffuse in outdoor field situations, in particular during overcast and haze.

- In the field experiments, the apparent oil film colour was independent of oil type for film thicknesses below 50µm.

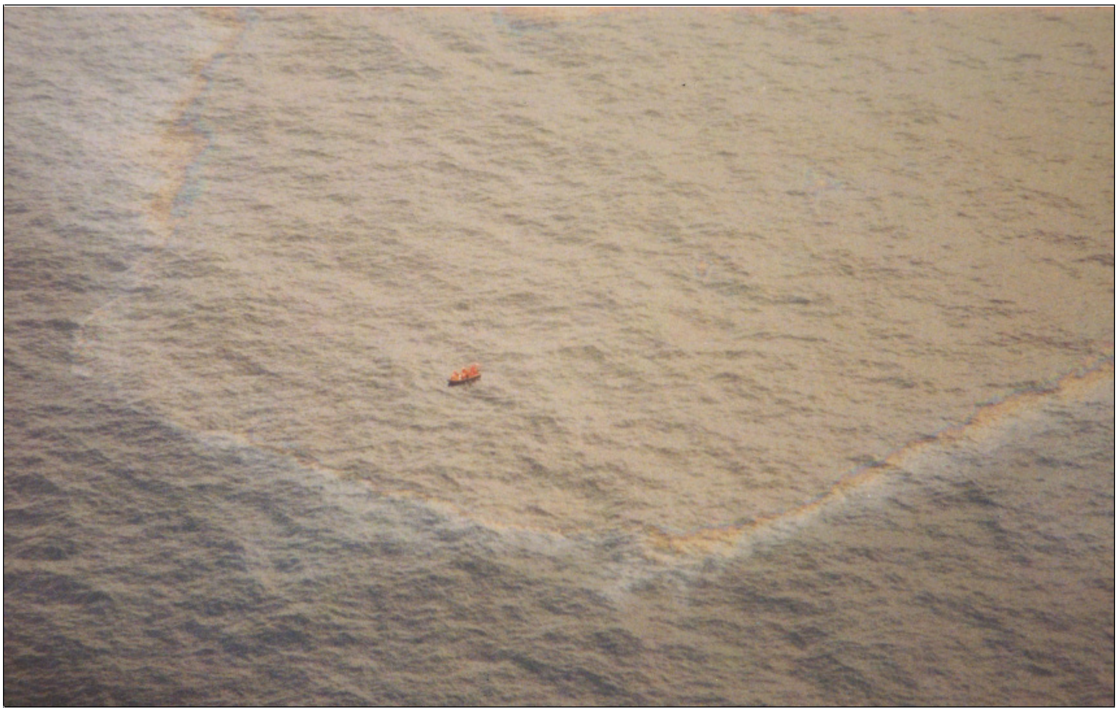
- Based on these field experiments, the colour code classification "metallic" is proposed to replace the current classification of "blue" in the Bonn Agreement Colour Code. This classification has, in addition to those of 'silver', 'grey' and 'rainbow', been identified as being independent of oil type in defining a particular range of oil film thickness.

SINTEF Applied Chemistry has been involved in a number of experimental field trials and oil on water exercises in the North Sea during the last twenty years. Several of these experimental oil slicks have been co-ordinated with surface pad sampling. Most of these studies have been focused on the thick oil film regions consisting of evaporated/emulsified oil in the millimetre range. However, some documentation exists also for the thinner non-emulsified range (<100-200µm), e.g. the two photos in Figure 5.10. These photographs, taken during the NOFO field experiments in 1995 and 1996, are presented as examples of field observations of oil slicks

The photo from 1995 is from a surface released experimental oil slick of Troll crude, and is taken during pad sampling in the "Metallic" region of the slick. The picture clearly shows the "Rainbow" area in the edges of the oil slick and a small area outside this with the "Silvery" region.

The photo from 1996 is from an underwater blowout simulated release with Troll crude. This release generated a fairly homogenous oil film that was quantified by pad sampling to be in the range of 10-50µm ("metallic" colour).

A)



B)

Figure 5.10 Photos taken by survaillance aircraft of experimental oil work during NOFO exercises. A) 1995 surface releace, B) 1996 underwater release.

5.6 New and old colour code comparison

All scientific data obtained in Phase 1 and Phase 2 studies proves that the correlation between apparent colour and oil film thickness in the current Bonn Agreement Colour Code is reasonably accurate for the silver, grey and rainbow thickness regions. Only minor adjustments are proposed. For oil films beyond 5µm thickness, the need for significant improvements has been identified.

SINTEF therefore recommends a revised Colour Code as presented in Table 5. Both the terms and the thickness intervals have been amended in accordance with the findings of this study.

SINTEF recommend that thickness intervals, a range of oil film thickness instead of one average value is introduced. This will indicate the overall accuracy of the volume assessments made on the basis of the colour code. Minimum and maximum volume estimates could then be made.

New Colour Code

	Thickness Interval	Litres per sq.km
Silvery	< 0,05-0,1µm >	50 - 100
Grey	<0,1-0,3µm>	100 - 300
Rainbow	<0,3 –5µm>	300 - 5000
Metallic	<5-50µm>	5000 - 50 000
Discontinuous true colour	<50-200µm>	50 000 - 200 000
Homogenous true colour	more than 200µm	more than 200 000

Notes:
Colour Code have not been calibrated for emulsified oils.
Colour assessments should be made vertically for best results.
In overcast weather colours are more diffuse compared to a blue sky situation.
Silvery, Grey, Rainbow and Metallic are oil-type independent.

Current Bonn Agreement Colour code

	Thickness	Quantity (cub/km^2)
Silvery	0,02µm	0,02
Grey	0,1µm	0,1
Rainbow	0,3µm	0,3
Blue	1µm	1
Blue/brown	5µm	5
Brown/black	15-25µm	15-25
Dark brown/black	>100µm	>100

Colour code comparison:

Bonn colour code	New colour code
Silvery (0,02µm)	Silvery <0,05-0,1 µm>
Grey (0,1µm)	Grey <0,1-0,3µm>
Rainbow (0,3µm)	Rainbow <0,3-5µm>
Blue (1µm)	Metallic <5-50µm>
Blue/brown (5µm)	Discontinuous true colour <50-200µm>
Brown/black 15-25 µm Dark brown/black (>100µm)	Homogenous true colour >200µm

Advantages:

- The proposed new terms (category names) are valid for all oil types.
- The new terms are more easily identified in real-life situations.
- The re-defined 'rainbow' thickness interval takes into account the theoretical effects of constructive and destructive interference at multiple wavelength of visible light.
- The proposed thickness intervals reflect the accuracy of the colour assessment method.
- Each term and thickness interval is based on the best possible theoretical and scientific documentation (literature study, theory, laboratory and field trials).
- Each term and thickness interval is explained by photographic examples. This can improve training of professional observers.

Disadvantages:

- A range (interval) of estimated spilled oil volume, from a minimum to a maximum, is recommended as a result of colour code assessments. This may cause additional workload on crew. However, for minor spills a conservative or middle estimate may only be needed.
- Quantification of oil spill volume during haze or with overcast skies will be difficult. Operational guidelines for the use of colour codes in different weather and viewing situations are recommended. This should include definitions of viewing conditions, such as the minimum sun elevation requirement for using the colour code.
- The use of a range of different brown shades (dark brown, yellow, and light brown) should be discontinued. The presence of *homogenous true colour* should be quantified by the lower limit. Only knowledge of the specific colour properties of the oil, identification of emulsions or significant wave damping effects within the slick should justify the use of oil film values beyond 200µm

The small-scale field study indicates that the spill volume estimates made with the current Bonn Agreement Colour Code are more conservative (i.e. of lower volume) than those that would be made with the proposed new appearance/ thickness correlation. The scientific work conducted during this study justifies a less conservative approach in producing spill volume estimates than is currently being practised.

6. Conclusions and recommendations for future work

- The proposed new colour code should be implemented. The proposed new code is based on the best theoretical, scientific and field data available.

- When known quantities of oil are released during surveillance exercises, ground oil film thickness measurements should be included as part of the exercise while photographs are obtained from aircraft. Valuable intercomparison data will then be obtained and this will be very useful for training purposes.

- Based on the methodology developed during this project, specific colour charts should be established when contingency plans are required for individual oil fields

Appendix 1

Pad extractions

Resultater Grane

prøve ID	absorbans	absorbans	absorbans	snitt absorbans	fortynning	oljemengde	dekning	filmtykkelse	Beskrivelse
40	0,586	0,586	0,587	0,586	125	66,75	100	1,31	metallic
41	0,474	0,474	0,473	0,474	125	182,91	100	3,60	metallic
42	0,396	0,396	0,396	0,396	250	305,84	100	6,01	metallic brunlig
43	0,374	0,374	0,374	0,374	250	288,85	100	5,68	metallic
44	0,25	0,25	0,25	0,250	25000	19308,00	90	421,75	tykk olje
45	0,273	0,273	0,273	0,273	1000	843,37	100	16,58	metallic
66	0,519	0,52	0,523	0,521	250	402,12	95	8,32	metallic
67	0,436	0,437	0,437	0,437	10000	13489,86	80	331,49	middels tykk
68	0,316	0,316	0,316	0,316	250	244,05	50	9,60	tykt,brunt område
69	0,419	0,42	0,412	0,417	1000	1288,23	100	25,32	tykk metallic / svak brun
70	0,577	0,577	0,577	0,577	10000	17825,15	100	350,42	relativt tykk olje
71	0,438	0,439	0,439	0,439	1000	1355,16	100	26,64	metallic
72	0,553	0,554	0,553	0,553	1000	1709,40	80	42,01	metallic / tynt brun

Resultater IF-30

prøve ID	absorbans	absorbans	absorbans	snitt absorbans	fortynning	oljemengde	dekning	filmtykkelse	Beskrivelse
34	0,483	0,479	0,478	0,480	25	8,69	100	0,17	rainbow
35	0,197	0,197	0,196	0,197	250	35,60	100	0,72	metallic
36	0,419	0,422	0,423	0,421	40000	12201,95	100	245,77	mørk brun tykk olje
37	0,301	0,302	0,303	0,302	1000	218,65	100	4,40	brun farge
38	0,512	0,51	0,51	0,511	250000	92431,70	100	1861,76	mørk brun meget tykk olje
39	0,362	0,362	0,362	0,362	125	32,76	100	0,66	

Resultater Forties

prøve ID	absorbans	absorbans	absorbans	snitt absorbans	fortynning	oljemengde	dekning %	filmtykkelse	Beskrivelse
24	0,339	0,339	0,339	0,339	1000	1047,26599	100	23,59	metallic
25	0,541	0,542	0,543	0,542	250	418,597467	100	9,43	metallic(tynnere)
26	0,312	0,314	0,314	0,313	1000	967,974462	100	21,81	tykkere
27	0,366	0,367	0,366	0,366	10000	11317,0631	100	254,96	tykk brun
28	0,38	0,381	0,382	0,381	1000	1177,01576	90	29,46	tynnere brun olje
29	0,517	0,516	0,516	0,516	1000	1595,09834	100	35,94	blass brunfarge
30	0,248	0,248	0,248	0,248	100000	76614,1489	100	1726,01	brun meget tykk
60	0,323	0,324	0,325	0,324	250	250,231696	90	6,26	tynn metallic med brune flekker
61	0,632	0,632	0,632	0,632	250	488,106271	100	11,00	noe tykkere metallic m/flekker
62	0,765	0,765	0,766	0,765	2500	5910,82278	80	166,45	brunt ujevnt
63	0,384	0,384	0,384	0,384	10000	11862,836	100	267,25	meget tykt
64	0,532	0,532	0,536	0,533	250	411,904026	100	9,28	metallic med brune flekker
65	0,382	0,382	0,382	0,382	100	118,010504	100	2,66	tynn metallic med brune flekker

Resultater Slop-olje

prøve ID	absorbans	absorbans	absorbans	snitt absorb	fortynning	oljemengde	dekning %	filmtykkelse	Beskrivelse
46	0,372	0,372	0,372	0,372	1000	1228,534	90	30,37	tykk metallic/brunt
47	0,321	0,323	0,323	0,322	1000	1064,509	100	23,69	tykk metallic/svakt brunt
48	0,695	0,696	0,696	0,696	10000	22974,46	100	511,18	tykk/brunt
49	0,266	0,266	0,268	0,267	250	220,1673	100	4,90	tynn metallic
50	0,528	0,531	0,53	0,530	250	437,3074	70	13,90	
51	0,817	0,817	0,818	0,817	1000	2699,251	100	60,06	overgang metallic-brunt
52	0,226	0,226	0,227	0,226	4000	2989,872	100	66,52	overgang metallic-brunt ,mest brunt
53	0,686	0,689	0,694	0,690	250	569,4077	100	12,67	metallic, tykkere
54	0,466	0,466	0,466	0,466	50	76,94848	80	2,14	metallic , tynnere
55	0,271	0,272	0,273	0,272	250	224,5707	100	5,00	metallic , tykkere
56	0,678	0,679	0,68	0,679	1000	2242,404	100	49,89	metallic/tynt brunt
57	0,367	0,367	0,367	0,367	10000	12120,21	100	269,67	brunt område (middels tykt)
58	0,4	0,4	0,401	0,400	1000	1322,105	100	29,42	transient område , lyst brunt
59	0,603	0,603	0,604	0,603	250	498,1286	100	11,08	svakt brunt