

REPORT

Oil in Ice - JIP



SINTEF Materials and Chemistry
Marine Environmental Technology

Preface

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

The objectives of the program were;

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

The program consisted of the following projects:

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

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

Stein Erik Sørstrøm
Program Coordinator
(stein.e.sorstrom@sintef.no)

Funding Partners



R&D Partners



Cooperating Partners





SINTEF Materials and Chemistry

Address: NO-7465 Trondheim,
NORWAY
Location: Brattørkaia 17C,
4. etg.
Telephone: +47 4000 3730
Fax: +47 930 70730

Enterprise No.: NO 948 007 029 MVA

SINTEF REPORT

TITLE

Establishing, Testing and Verification of a Laboratory Burning Cell to Measure Ignitability for In-Situ Burning of Oil Spills. P2 In Situ Burning, Task 1 Mapping Burnability. Oil in ice JIP report no: 20.

AUTHOR(S)

Per Johan Brandvik, Janne Fritt-Rasmussen, Roger Daniloff, Frode Leirvik and Janne Lise Resby

CLIENT(S)

Shell, Statoil, ConocoPhillips, Chevron, Total, Agip KCO

REPORT NO. SINTEF A15550	CLASSIFICATION Unrestricted	CLIENTS REF. Gina Ytteborg, Hanne Greiff Johnsen, Eimund Garpestad, Marine Julliand, Ulf-Einar Moltu, and Mark Shepherd	
CLASS. THIS PAGE Unrestricted	ISBN 978-82-14-04771-4	PROJECT NO. 80053200	NO. OF PAGES/APPENDICES 26/0
ELECTRONIC FILE CODE Report-burningcell-final.doc		PROJECT MANAGER (NAME, SIGN.) Per Johan Brandvik <i>J. Brandvik</i>	CHECKED BY (NAME, SIGN.) Per S. Daling <i>P.S. Daling</i>
FILE CODE	DATE 2010-04-20	APPROVED BY (NAME, POSITION, SIGN.) Tore Aunaas, Research director <i>T. Aunaas</i>	

ABSTRACT

For removal of oil spilled in ice-infested waters, in-situ burning (ISB) is one of the response techniques with the highest potential for Arctic conditions especially in snow and dense ice. In order to make in-situ burning an operational tool there is a need to better define the potential and limitations for ignition of oil spills with regard to oil type and weathering degree.

SINTEF has constructed a small scale laboratory burning cell to perform controlled experimental burn on a 100 ml scale (weathered and emulsified oil). This laboratory cell is a complete unit with a cooling water, exhaust system, full temperature control and protection of the operator against fumes or hot oil/water. All relevant temperatures (cooling water, oil, flame temperature) are monitored and logged continuously during the experiment. After flame-out the residue is collected and quantified to calculated ISB burning effectiveness.

The system have been built, tested and modified at SINTEF laboratories in Trondheim. An extensive test program (ISB ignition and burning effectiveness) has been performed closely coordinated with a meso scale weathering study. These data are reported together with the weathering results (Brandvik et al., 2009).

The laboratory cell has been verified against field ISB experiments performed at SINTEFs field station on Svalbard. The results from the large scale experiments (approx. 600L of emulsified oil) with respect to the limit of burnability (water content/flash point) correlated well with the results from the laboratory cell experiments.

This work show that the new burning cell can be used together with the meso scale weathering concept to map the operational "window of opportunity" for use of ISB as a function of weathering. The algorithms developed from this data will be implemented in SINTEF Oil Weathering model.

KEYWORDS	ENGLISH	NORWEGIAN
GROUP 1	In-situ burning	Brenning
GROUP 2	Oil spill	Olje søl
SELECTED BY AUTHOR	Arctic	Arktis
	Ice	Is
	Contingency	Beredskap

TABLE OF CONTENTS	PAGE
1 Introduction	5
2 Objective.....	6
3 Experimental.....	7
3.1 Basic design of laboratory burning cell	7
3.2 Construction of laboratory burning cell.....	8
3.3 Initial testing and redesign/modification	9
3.4 Laboratory use of burning cell.....	9
3.4.1 Preparation	9
3.4.2 Ignition	10
3.4.3 Collection of residue for quantification	10
3.4.4 Calculating burning effectiveness	10
3.5 Oil type.....	11
3.6 Ignitability Testing of Oil Samples Weathered in the Laboratory.....	11
3.7 Field experiments to verify the laboratory burning cell.....	11
3.7.1 Oil weathering.....	11
3.7.2 Oil sampling and analysis	12
3.7.3 Meso scale in situ burning (ISB) of weathered oil.....	12
3.7.4 Burning of weathered oil using the laboratory cell.....	12
4 Results and discussion.....	16
4.1 Initial laboratory testing.....	16
4.2 Laboratory testing of samples from the meso scale weathering (SeaLab)	18
4.3 Field verification on Svalbard 2007 (lab experiments versus field experiments)	18
4.4 Meso scale weathering experiments performed at Svalbard 2008.....	21
5 Conclusions	22
6 Acknowledgements.....	22
7 References	23
Appendix A: Data from field experiments on Svalbard in 2007	25

1 Introduction

For removal of oil spill, in situ burning is one of the response techniques with the highest potential for Arctic conditions, especially in snow and dense ice. Experiments with in situ burning the recent years have shown removal efficiencies of up to or in some cases even more than 90% (Brandvik and Faksness, 2009; Brown and Goodman, 1986; Buist, 2003; Buist et al., 1999; Dickins, 2008; Dickins and Buist, 1999; Guenette and Sveum, 1995; Guenette, 1997; Guenette et al., 1995). The suitability of in situ burning depends on the initial oil characteristics and the weathering state of the oil. Several factors are important for a successful burning:

- Slick thickness. A minimum slick thickness is required to secure the burning. Different minimum thicknesses are reported: 2-5 mm in loose pack ice (Buist et al., 2008; Fingas, 1998) reports the prime rule of thumb as at least 2-3 mm and C. C. Guenette, (1997) have found that 1-3 mm is at least required for fresh crude oils but more for weathered and heavier oils.
- Heat transfer and flame temperature. A typical flame temperature is about 900 – 1200°C, the slick surface typically 350 – 500°C and at the oil – water interface close to ambient (Buist et al., 1999).
- Oil type and weathering characteristics:
 - Evaporative loss. The oil/emulsion must contain light components that can easily evaporate and be ignited, this is important since it is the gas that burn. It is stated in the literature that evaporative loss should not exceed 30% (Guenette, 1997) to be ignitable. However, it is the composition (the content of light components) of the residual oil which is important for ignition.
 - Emulsification. Heat is used to break the emulsion and thereby remove water or boil off the water. Until this has been done the temperature in the emulsion will not exceed 100°C (Buist et al., 1999). Hence the stability of the emulsion is of great importance for a successful burning. If the water content in the emulsion is too high and the emulsion is very stable, ignition of oil can be very difficult.
 - Drift and spreading of the oil slick. Thick oil layers and continuous slicks increase burning effectiveness. Ice limits the spreading of the oil, resulting in a thick oil film and thereby low evaporation and attenuated wave formation resulting in low oil in water emulsion (Brandvik and Faksness, 2009).
- Wind speed and general weather conditions. The wind speed should not exceed 10-12 m/s (Buist, 2003; Guenette, 1997), but even 9-10 m/s tend to have a negative effect on the burning (Guenette et al., 1995). Moderate winds on the other hand tend to act as a herding agent for the oil (Guenette, 1997) and enhance upwind flame spreading (Guenette and Sveum, 1995).

In order to make in situ burning an operational tool there is a need to better define the potential and limitations for ignition of oil spills with regard to oil types and weathering degree. A significant improvement over the more rule of thumbs listed over should be possible.

This project is aiming at establishing a better basis for decision on when to use or not to use in situ burning by improving the algorithms in oil weathering models for more accurate predictions of the “window of opportunity” for ISB.

2 Objective

The main objectives with in situ burning activities within the Oil-in-ice joint industry program (JIP) have been to:

1. Establish, test and verify a small scale laboratory burning cell to measure ignitability and burning effectiveness of weathered oil samples.
2. Perform small scale laboratory burning experiments with the new burning cell to create data describing ignitability/burning effectiveness versus oil type and weathering degree.
3. Perform large scale in situ burning (ISB) experiments to create calibration data for SINTEF oil weathering model regarding in situ burning effectiveness versus weathering time.

This report describes the work performed to fulfil the first objective above. The work related to the other two objectives is described in another report (Brandvik et al., 2010a and Brandvik et al., 2010b).

3 Experimental

3.1 Basic design of laboratory burning cell

The work described in this report is performed with a modified laboratory burning cell constructed and operated at SINTEF SeaLab in Trondheim. Initial work was performed in 2006-07, prior to the oil-in-ice JIP, as cooperation between SINTEF and the Norwegian University of Technology (NTNU). The construction and testing of this first version of the laboratory cell was performed as a Master Degree project (Daniloff, 2007). This early version was the starting point for further development and testing performed in the JIP. See Figure 3.1 below for details on the initial version.

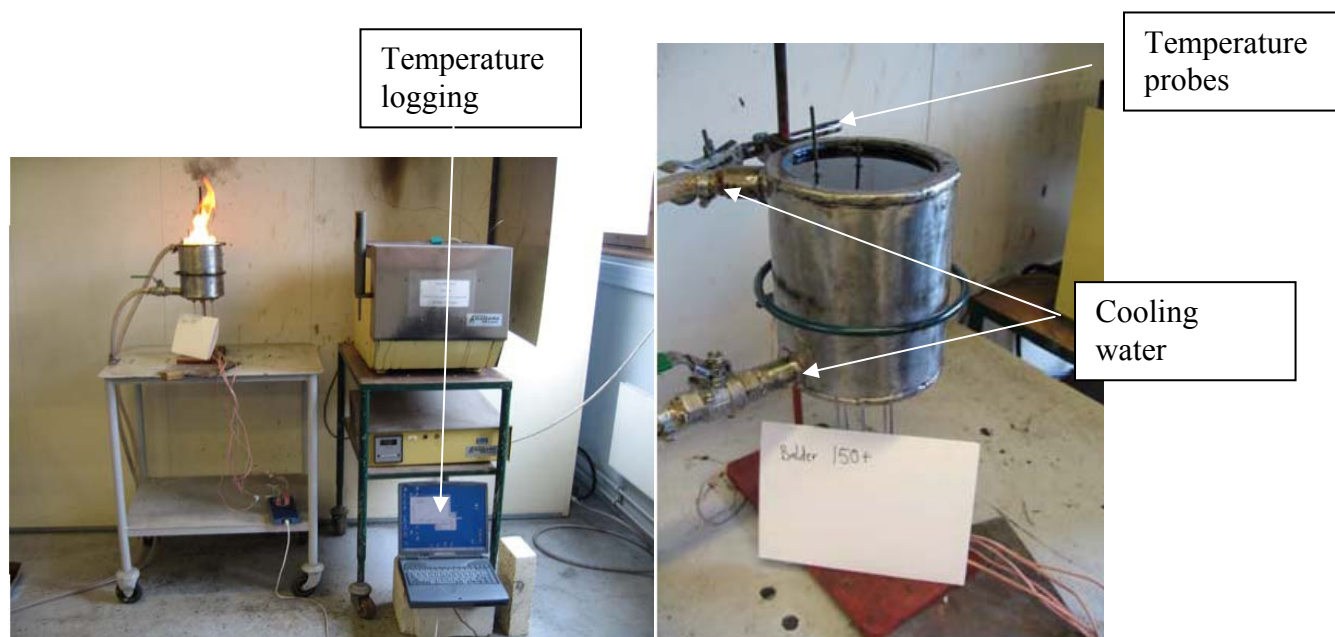


Figure 3.1 The early version of the laboratory cell which were used at SINTEF Fire research laboratory since special facilities for handling burning experiments were needed (from Daniloff, 2006).

Initial testing of the burning cell confirmed that cooling was necessary to avoid over-heating of the system during burning causing boiling of water and water shooting high up in the air. This situation removed oil from the cell and sometimes caused secondary fires in the vicinity of the cell. When burning oil in situ at sea, the water column is only to a minimal degree heated by the burning oil on top of the water column (Buist, 2003), hence adding the cooling system to the burning cell provides a more realistic system. When testing the cell with a minimum of flow through the cooling system, the temperature in the water in the cell increased slightly, but stayed well below boiling temperature of water. Flow rate was adjusted to ensure that the combustion was not inhibited and to avoid boiling of the water in the cell. With a rate of 500 ml/min the returning cooling water from the cell started at 10°C and ended around 15°C for the longest experiments.

The main functions which needed improvements in this early version were:

1. Better handling of the exhaust fumes so it can be operated in an ordinary laboratory
2. Better system for temperature measurements and logging
3. More reproducible ignition system
4. More stable and reproducible system for cooling water
5. Better protection of the operator against accidental busts of hot water and oil
6. All functions built into one unit – a “burning cell trolley”

3.2 Construction of laboratory burning cell

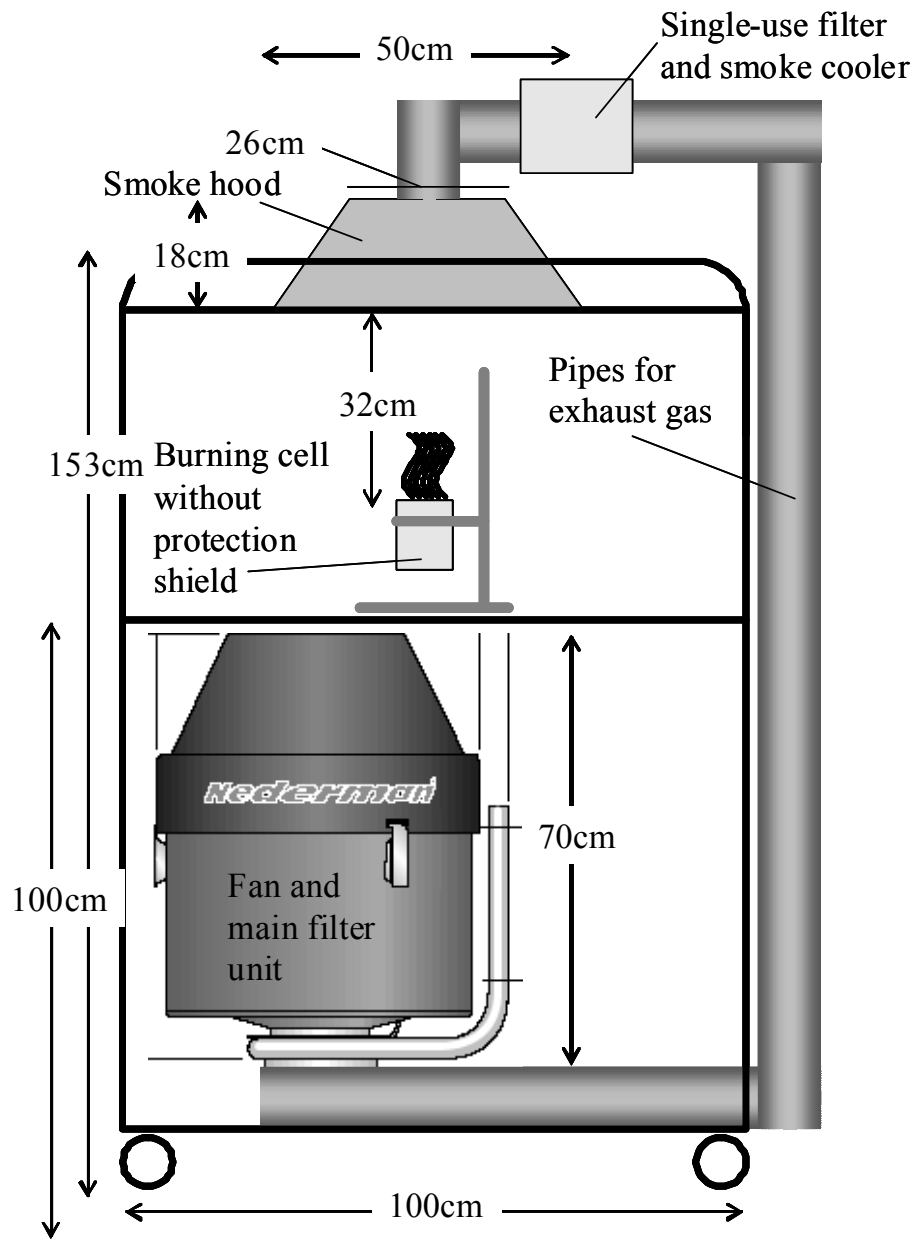


Figure 3.2 Conceptual figure of the laboratory burning cell

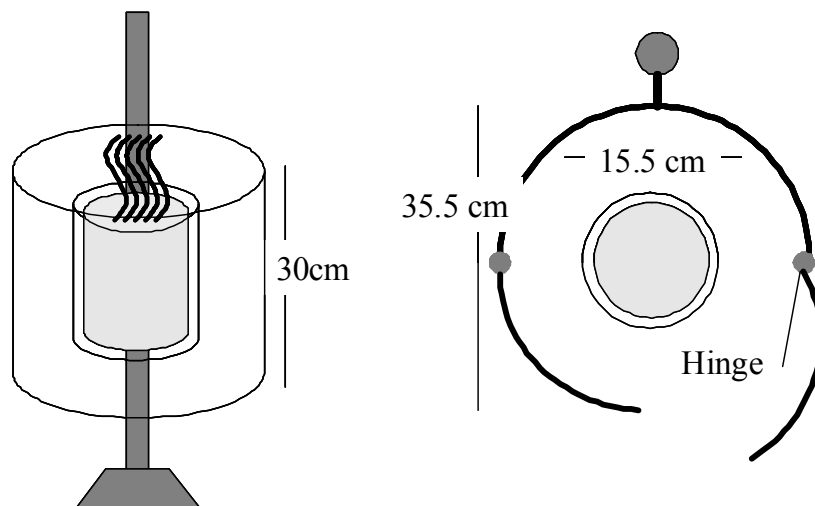


Figure 3.3 Details of the new safety shield around the burning cell



Figure 3.4 The new burning unit during initial testing. Left: SINTEF engineer Frode Leirvik, being responsible for the construction, right: Janne Fritt-Rasmussen, PhD-student (Technical University of Denmark - DTU/University centre at Svalbard - UNIS) which have done most of the ISB work.

3.3 Initial testing and redesign/modification

The smoke exhaust system had initially limited capacity and the expensive filters in the fan had to be changed rather frequently. The high temperature of the smoke also raised the temperature in the fan/filter unit above 120 °C, which we found disturbing. To deal with this a cooling unit (tap water circulation) was mounted. This had capacity to lower the exhaust temperature to under the air temperature during the whole burning experiment. The drawback was the soot which was captured in the cold cooling ribs. However, the size of the cooling system made cleaning in an ordinary laboratory sink manageable. To capture some of the soot before it entered the cooler and the main (and expensive) filter in the fan unit, we mounted a filter holder in front of the cooler. This can be used for “single-use” paper filters or filters of stainless steel mesh.

3.4 Laboratory use of burning cell

The burning cell was operated according to a laboratory procedure at SINTEF which were developed during the initial testing. A short version of this procedure is given below. The full laboratory procedure for the operation of laboratory burning cell is implemented as a part of the laboratory procedures at SINTEF.

3.4.1 Preparation

1. A fixed amount (approximately 120 g; the exact amount was found for each experiment) of fresh oil, evaporated oil or water-in-oil emulsion from the meso scale flume was added to the water surface in the cell.
2. The temperature probes adjusted (in the water, in the oil layer and in flame)
3. Temperature logger turned on
4. Water flow adjusted to 500 mL/min
5. Water temperature set to 10°C and controlled.
6. Check exhaust fume filters and fan motor

3.4.2 Ignition

Propane Torch: A propane or butane torch was used as ignition source. The torch was held in a 30° angle to the oil for 10 seconds. If the oil did not ignite this procedure was repeated 2 times. If no ignition was recorded after the third attempt the oil was declared as “not ignitable”.

Gelled gasoline: It is planned to also develop a procedure to use gelled gasoline (or crude oil) with added emulsion breaker (Alcopol O 60). Experiments to study the correlations between these two ignition procedures will also be performed. This will be performed as a part of the PhD work of Janne Fritt-Rasmussen (Fritt-Rasmussen, 2010).

3.4.3 Collection of residue for quantification

After termination of the burn, the residue was collected by adding a circular piece of (pre weighted) 3M adsorption pad matching the inner diameter of the burning cell. The warm residue usually soaked into the 3M pad and could easily be removed with the pad after cooling. The amount of water adsorbed to the 3M pad was usually marginal (<10%). The amount of oil residue left in the cell was usually also marginal (<10%).

After each burn the cell was usually sufficiently cleaned by the removal of residue. However, for more viscous or sticky residues e.g. from burning heavy bunker fuels a more thorough cleaning procedure might be needed. The water level was adjusted dependant on the amount of water in the emulsified samples. This water is usually separated from the emulsion during the experiment and sometimes caused in a rise in the water level.

3.4.4 Calculating burning effectiveness

The burning effectiveness (BE%) was calculated as given below:

$$\text{Burning Effectiveness (BE\%)} = 100 \cdot \left(1 - \frac{\text{mass of residue}}{\text{mass of initial oil}} \right) \quad (1)$$

Since the “mass of initial oil” in Equation 1 could contain a different amount of water due to the varying degree of weathering, the absolute number of BE% could vary significantly (between 50 – 90%) for a successful burn. Because the emulsions break and water is separated during a successful burn, the BE% for emulsified samples could be higher than for less weathered samples. To allow for an easier comparison, samples with varying water content and BE% can be corrected for the varying water content (see Equation 2).

$$\text{Burning Effectiveness Corrected (BE\% - Corr.)} = 100 \cdot \left(\frac{1 - (100 - \text{BE\%})}{(100 - \text{WC\%})} \right) \quad (2)$$

Chapter 3.4 presents the burning efficiencies and BE%-Corr is used for this purpose. Nevertheless, the absolute value of both the BE% and BE%-Corr are of less importance since the main use of this laboratory cell is to study the ignitability of the weathered oil as a function of weathering in order to estimate the time window for in situ burning.

The absolute value of BE% is also dependent on the scale of the laboratory equipment. Large scale burns will usually produce a higher BE% due to the generation of more heat and higher temperatures.

3.5 Oil type

Statfjord, Troll B and Balder were used for the initial laboratory testing with the burning cell, while Troll B and Grane were used for the large scale experiments on Svalbard. Relevant properties for the fresh crudes are given in Table 3.2.

3.6 Ignitability Testing of Oil Samples Weathered in the Laboratory

The initial testing of the burning cell was conducted on samples weathered by small scale equipment. With these samples, the light components are removed by evaporation and then emulsified to simulate different weathering stages at sea. This was done by using a stepwise weathering approach used by SINTEF to study the weathering properties of oils and for preparing an “oil weathering manual” for the oil companies. The weathering procedures are described by Daling et al., 2003, and will not be discussed any further here.

Nevertheless, in an oil spill situation at sea, the weathering processes occur simultaneously and affect each other. It is therefore of great importance that the oils are weathered under realistic conditions when studying their behaviour when spilled on the sea surface. A meso scale flume basin (Singsaas et al., 1992) located at SINTEF is routinely used to simultaneously study the weathering processes under controlled conditions. Testing with the burning cell was performed on a series of weathered oil samples from the meso scale flume. Samples were taken from the emulsified surface oil for a series of physical and chemical analyses. The surplus, free seawater in the collected sample was immediately drained off using a separation funnel before the sample was homogenized and divided into aliquots for further analysis. The analysed physical and chemical properties are given in Table 3.1. Weathering experiments were performed using different oil types and ice conditions, and the details regarding these experiments are described in Brandvik et al., 2010b.

Table 3.1 Physical/chemical properties, units and methods

Property	Unit	Method
Viscosity of weathered oil	cP (or mP) at shear rate 10 or 100 s ⁻¹ at 3-6 °C	Daling et al., 2003
Water content of w/o-emulsion	volume %	Daling et al., 2003
Density of water free oil	g/ml at 15.5 °C	ASTM D4052-91
Chemical dispersibility of weathered oil	weight %	Concawe, 1988
Evaporative loss	weight %	Daling et al., 2003
Flash point of water free oil	°C	ASTM D93-90
Pour point of water free oil	°C	ASTM D97-87

3.7 Field experiments to verify the laboratory burning cell

The field experiments were performed on the ice in Van Mijenfjord close to SINTEF’s field research station on Svalbard (Spitsbergen) in April 2007 and 2008. The field station is located at the mining community Sveagruva approximate 70 km from Longyearbyen, the administrative centre on Svalbard.

3.7.1 Oil weathering

A flume with circulating sea water was used to study weathering of the oil at different ice conditions. The flume dimensions and principal layout are given in Figure 3.5. The depth of the flume was 50 cm and it was not cut completely through the fjord ice (total ice thickness 110 cm). Two propellers were used to control circulation, and a wave generator to introduce wave energy. Two heat generators were used to control the ambient air temperature and prevent the sea water in the flume from freezing. More details concerning the experimental set-up are given in Brandvik et

al., 2010b. Compared to related experiments performed in 2005 (Brandvik and Faksness, 2009) the experiments performed in 2007 were larger in scale with 200 litres of oil per experiment. The weathering experiments were coordinated and terminated with ISB experiments. The duration of the six large scale experiments varied (2-8 hours.) to obtain emulsified oil with different degree of weathering (evaporative loss, water content, flash point etc.).

3.7.2 Oil sampling and analysis

A comprehensive sampling program was carried out during the period each experiment lasted. Initially, 200 liters of crude was very gently applied on to the surface of the flume. Samples were taken from the emulsified surface oil for a series of physical and chemical analyses. Surplus, free sea water in the collected sample was immediately drained off using a separation funnel, before the sample was homogenized and divided into aliquots for further analysis. The analyses of the physical and chemical properties of surface emulsified oil were performed in a laboratory container on the ice close to the flume immediately after sampling. The two last analyses (pour- and flash point) were performed later at the SINTEF laboratories in Trondheim. Details regarding the analysis above are described in Daling et al., 2003.

3.7.3 Meso scale in situ burning (ISB) of weathered oil

The meso scale verification of the ignitability measured with the laboratory cell (100 mL) was performed on a 300-600L scale (dependant on emulsification). After each weathering experiment the emulsion was lead to the burning chamber (see Figure 3.7) by a simple boom arrangement assisted with some shovelling of the surface weathered oil. The film thickness in the 9 m² burning chamber varied from 15 to 25 mm. The igniter was applied to the middle of the weathered oil and lit by a propane torch. The igniter used consisted of gelled crude (1L) added 4% emulsion breaker (Alcopol O60). If no sufficient flame spreading and initial burning of the weathered oil started during the burn time of the igniter (10 min), the weathered oil was classified as “Not ignitable”. In the cases where the weathered oil ignited, the residue was collected with adsorption pads and quantified gravimetrically (see Figure 3.8).

3.7.4 Burning of weathered oil using the laboratory cell

The laboratory burning cell was operated outside the laboratory and all samples collected from the flume were tested with the laboratory cell. The same procedure as described earlier (Chapter 3.4) was used for the operation of the laboratory burning cell. The core unit of the burning cell was operated in “Field mode”. Only the cell itself, the propane ignitor, the cooling unit (pump, coolant and thermos), and the flame temperature unit/logger were operated in the field, see Figure 3.9 for details.

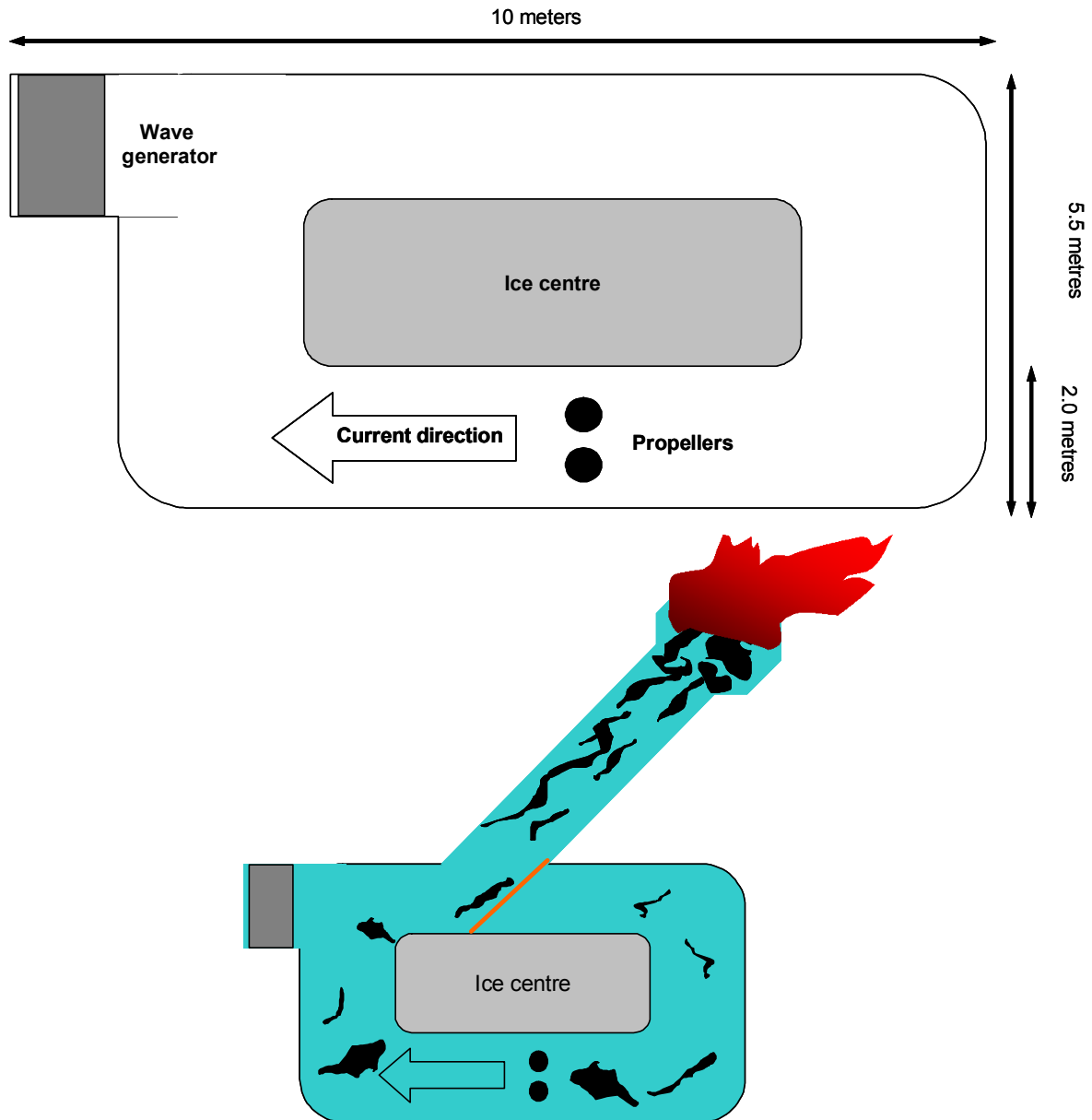
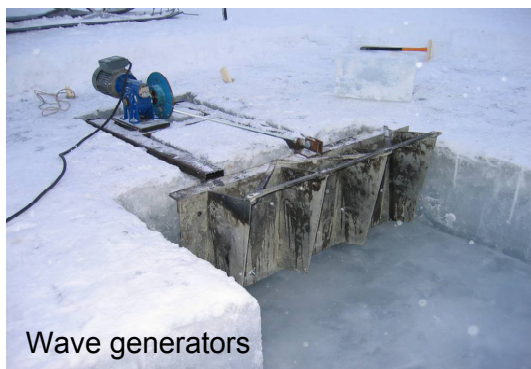
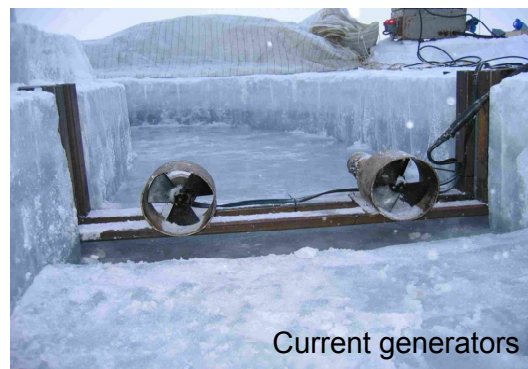


Figure 3.5 An overview showing the flume and the relationship between the weathering flume and the connected channel to the basin used for in situ burning experiments. After the weathering period the channel was opened and the oil was lead to the in situ burning basin.



Wave generators



Current generators

Figure 3.6 Close up of the wave generator and the current propellers used for controlling the circulation. See prior figure for an overview



Figure 3.7 In situ burning of weathered oil. The system consisting of a burning basin connected to the weathering basin with a channel (see earlier figure) in operation.



Figure 3.8 Collection of residue. After cooling the residues were easy to remove/collect with 3M adsorption pads. Quantitative collection of residues was important for determining burning effectiveness.



Figure 3.9 The core unit of the laboratory burning cell operated in “Field mode”. Only the cell itself, the butane ignitor, the cooling unit (pump, coolant and thermos), and the flame temperature unit/logger were operated in the field.

Table 3.2: Main relevant properties for Staffjord, Grane, TrollB and Balder crudes

Property	Staffjord 2008-0047	Grane 2007-1060	Troll 2007-0287	Balder 200-0654
Wax content (wt. %)	4.3	3.2	0.9	2.1
Viscosity (cP, shear rate 100 s ⁻¹ , 13 °C)	7.0	640	27	219
Asphaltene content (wt. %)	0.1	1.4	0.04	1.1
Density (g/ml)	0.834	0.941	0.900	0.914
Flash point (°C)	<-39	26	3	15
Pour point (°C)	-3	-24	-36	-30
Loss at 150 °C (vol. %)	25.2	3.1	9.6	7
Loss at 200 °C (vol. %)	34.2	4.7	19.5	11
Loss at 250 °C (vol. %)	43.6	12.7	26.5	17

4 Results and discussion

Four different types of experiments have been performed in the development and verification of this laboratory burning cell. First initial testing was performed with weathered oil samples (evaporative loss and emulsification) prepared with small scale lab apparatus (see chapter 4.1). Then samples for burning experiments were generated using the meso scale weathering flume at SINTEF SeaLab in Trondheim (chapter 4.2). Finally, two different series of field experiments were performed at SINTEF's field station at Svalbard during spring 2007 and 2008 (chapter 4.3 and 4.4).

4.1 Initial laboratory testing

The strategy for the experimental testing of the laboratory burning cell was based on the initial testing performed using the prototype. This initial work showed that the measured burning efficiencies (BE%) varied as expected. The BE% varied as a function of weathering (evaporative loss) mainly due to the increased amount of heavier components and increasing amount of residue (higher terminal film thickness) at end of burns (flame out). This can be seen in Figure 4.1.

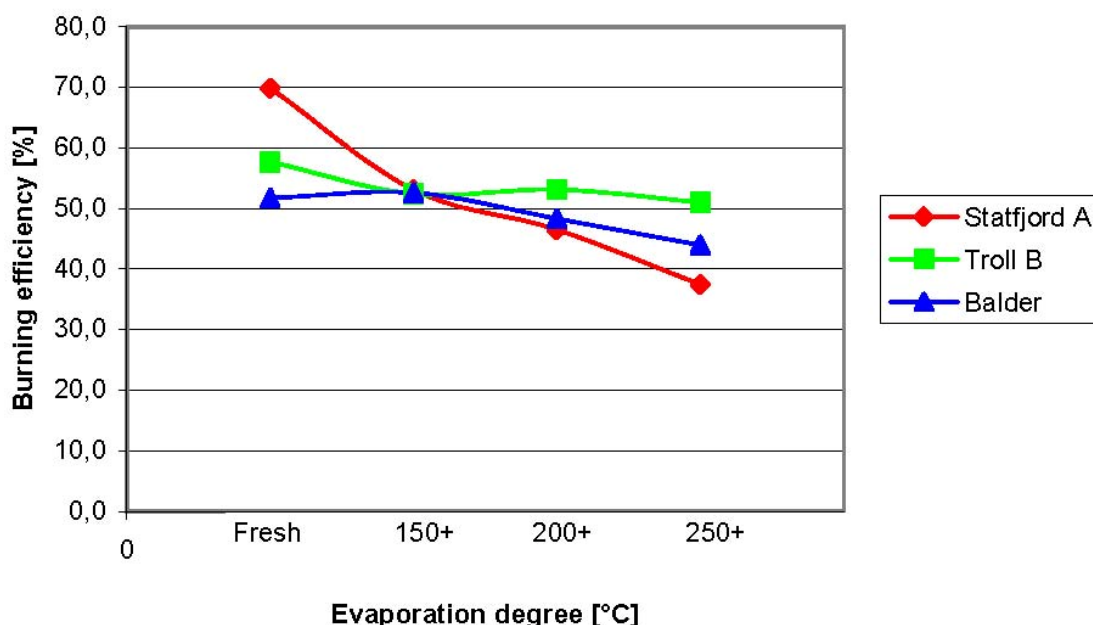


Figure 4.1 Initial testing of the laboratory cell on weathered samples (only evaporative loss) with three different oil samples (Statfjord, Troll and Balder), from Daniloff 2007.

Samples were then prepared taking both emulsification and evaporation into account. This was done using the stepwise weathering approach used by SINTEF to study weathering properties of oils and preparing “Oil weathering manual” for the oil companies (Daling et al., 2003). Samples were prepared using evaporation and corresponding levels of water content simulating realistic weathering of the three crudes Statfjord, Troll and Balder at 10 m/s wind. The BE% with the experimental cell are given in Figure 4.2.

Figure 4.2 shows how BE% vary as a function of weathering time for these three very different oil types. The naphthenic Troll form stable water-in-oil emulsions with very high water content and show a very marked drop in BE% due to the stable emulsions and high water uptake. The asphaltenic Balder show similar behaviour, while the waxy Statfjord have much longer time window for ISB. The Statfjord emulsion is still ignitable after two days of weathering with a high water content, evaporative loss and flash point, due to the wax-stabilisation of the emulsion. Heat

is very efficient to break emulsion where waxes are the main mechanism to stabilise water droplets in the emulsion.

The heat from the ignitor has to break the emulsion so water free oil can be heated above the flash point for ignition of the oil. This process must also continue after ignition, so heat from this burning oil can further break emulsion and expand the burning area. This is a larger challenge for Troll and Balder emulsions (stabilised by a combination of wax, naphthenic and asphaltenic components) which are not so easily broken by heat.

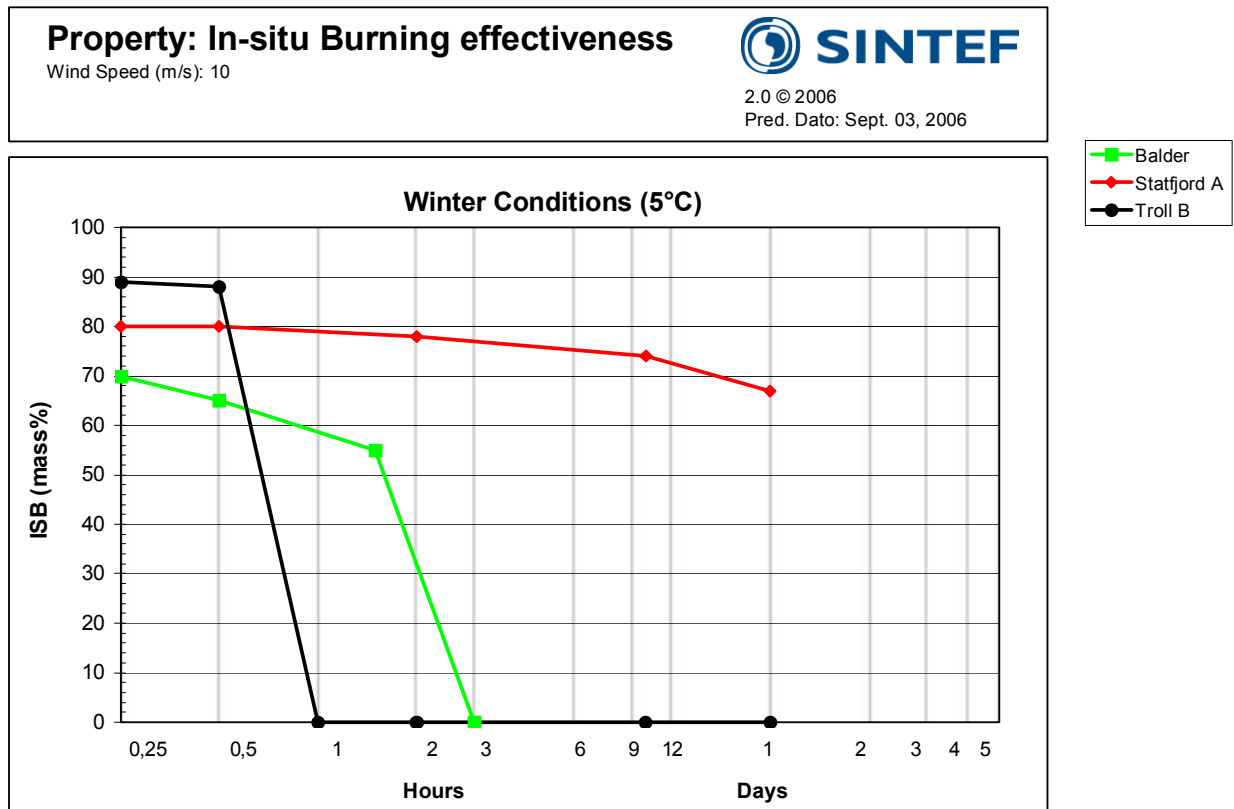


Figure 4.2 Burning effectiveness of the laboratory cell. Burning effectiveness as a function of weathering (evaporative loss and emulsification) with three different oil types (Statfjord, Troll and Balder), data from Daniloff 2007.

Table 4.1: Comparison of oil properties and in situ burning efficiencies for three oil types

Oil type	Weathering time (approx. hours)	Water content (vol. %)	Evaporative loss (vol. %)	Flash Point (°C)	BE%
Statfjord	24	75	44	150	70
Troll	1-2	67	10	70	0
Balder	2-4	50	7	60	0

When the meso scale weathering started as a part of P1 and P2 in the oil-in-ice JIP, this was used to generate samples for the burning cell instead of the initial approach using stepwise weathering. The main advantage with this approach is that many weathering processes act on the oil simultaneously giving a more realistic weathering. This was documented by sampling and measurements of a broad range of physical/chemical properties were also measured on these samples as a part of Oil in Ice JIP, P1 Oil weathering and P4 Dispersants (see Brandvik et al., 2010b for details).

4.2 Laboratory testing of samples from the meso scale weathering (SeaLab)

Samples from the meso scale weathering experiments were also used in the new burning cell. The samples were burned as soon as possible after collection and for the early and unstable samples they were burned within an hour for more stable samples they could be stored to the next day. Figure 4.3 shows the BE% from three series of meso scale weathering experiments with open water, 50% ice cover and 90% ice cover (See Brandvik et al. 2010b, for details). The Norne crude is a very vaxy crude with a high water uptake rate. In open water (0% ice) the water uptake is fast and the ignitability drops during the first hour due to the high water content and the very stable emulsions. As the amount of ice increase and weathering (especially evaporation and emulsification) are retarded the drop in ignitability is delayed (or the window of opportunity for ISB is expanded) to 48h (50% ice) and still ignitable after 72 hours (90% ice).

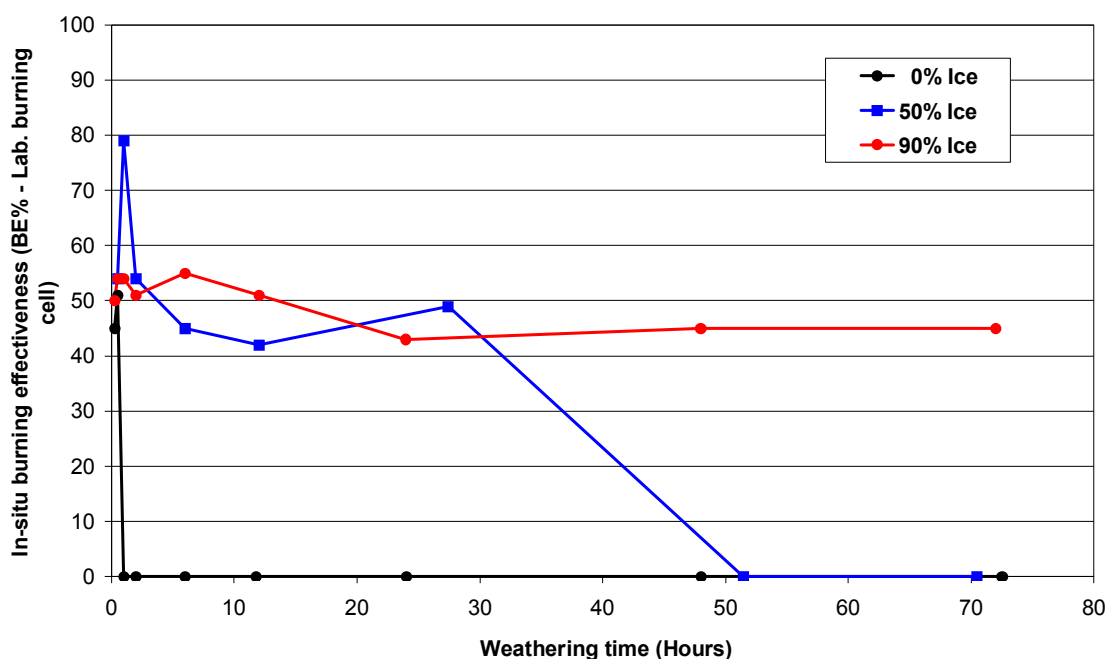


Figure 4.3 SINTEF SeaLab meso scale results 2008: Burning effectiveness as a function of weathering time for the three different experiments (0%, 50% and 90% ice coverage) with Norne crude.

A complete selection of burning results are presented in a common report from the meso scale experiments covering weathering, dispersants and ISB, (Brandvik et al., 2010b). Figure 4.3 was included here to show how the laboratory burning cell can be used to produce data for predicting a time window for use of in situ burning as a function of weathering and ice conditions.

4.3 Field verification on Svalbard 2007 (lab experiments versus field experiments)

The main purpose with the field work on Svalbard in April 2007 was to generate field data to verify the modified laboratory burning cell. A series of six meso scale experiments were performed with varying weathering time from 2 – 8 hours, see Figure 4.4.

When planning this series of experiment the aim was to spread the experiments with respect to weathering so most of them were burnable, a few should show reduced burnability and one or two should be not burnable. To keep the needed weathering time as short as possible, the asphaltenic Grane crude were selected for these experiments. This crude form stable emulsions and becomes difficult to ignite after 6-8 hours of weathering.

To compare the burnability (BE%) from the laboratory cell and the meso scale basin burnings the BE% from both these tests are plotted together as a function of water content in the emulsion (Figure 4.5) and flash point of the emulsified oil (Figure 4.6). In both figures the experimental data is smoothed with an S-function to visualise the trends.

In both Figure 4.5 (BE% versus water content) and Figure 4.6 (BE% versus flash point) we clearly see that both the meso scale burning tests and the laboratory burning cell gives the same trends with respect to drop in BE% (shaded green area). In Figure 4.5 the correlations between the experimental data and the smoothed S-functions are very good ($r= 0.71$ and 0.99) and the lines are close to overlapping in the zone of interest indicating the same drop in BE% as a function of weathering.

In Figure 4.6 (BE% versus flash point) the correlations between the experimental data and the smoothed S-functions are not so good ($r= 0.27$ and 0.45) as in the previous figure. However, also in this figure the lines are showing the same trend and are indicating a zone with a sharp drop in BE% as a function of weathering (flash point).

This strongly indicates that the data from the laboratory cell can be used to predict a zone of sharp drop in BE% as a function of weathering. This zone also represents the end of the operational window of opportunity for use of in situ burning.

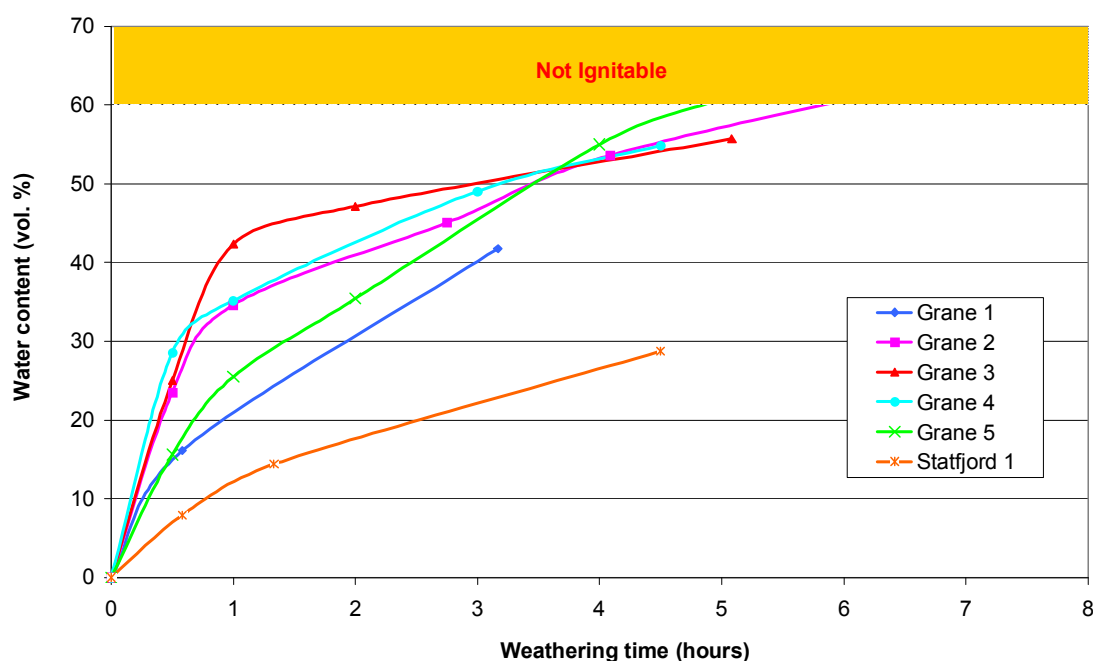


Figure 4.4 Weathering of Grane and Statfjord crude visualised by the water content in the emulsified oil for the six experiments performed at SINTEF's research station in Svea, April 2007.

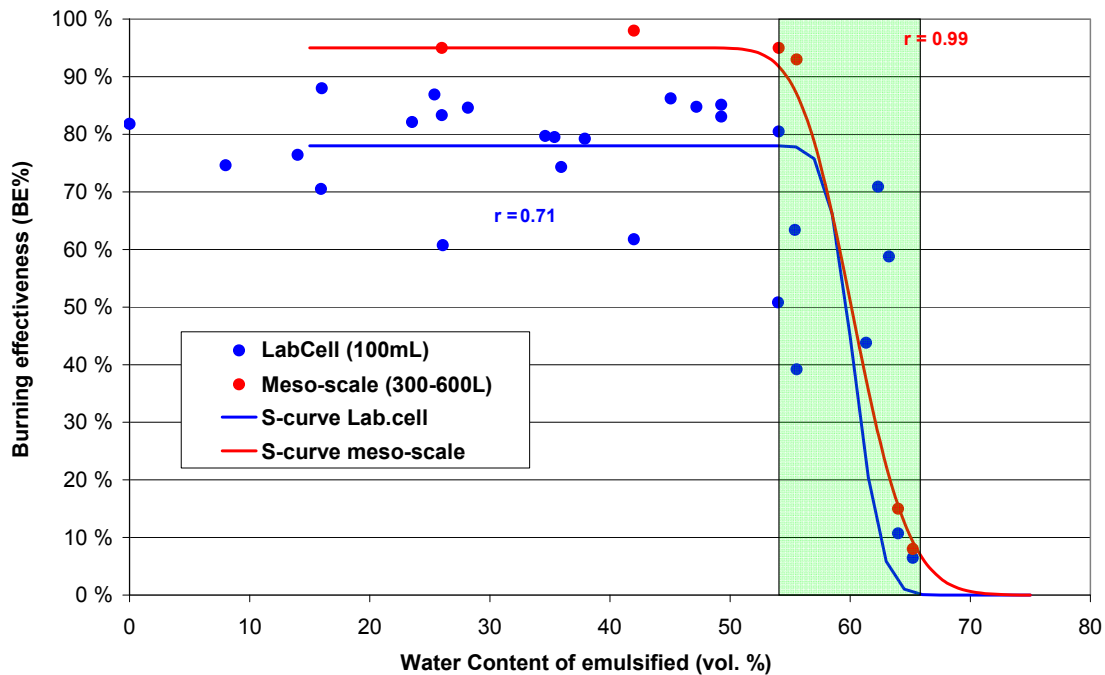


Figure 4.5 Comparison of burning effectiveness measured simultaneously with the laboratory burning cell (100 ml) and the meso scale weathering and ISB-basin (4-600 litres) on Svalbard using Grane crude oil. Effectiveness is given as a function of the water content in the emulsified oil. The smoothed functions are S-functions fitted to the data and the correlation between the measured data and the functions are given on the figure (r).

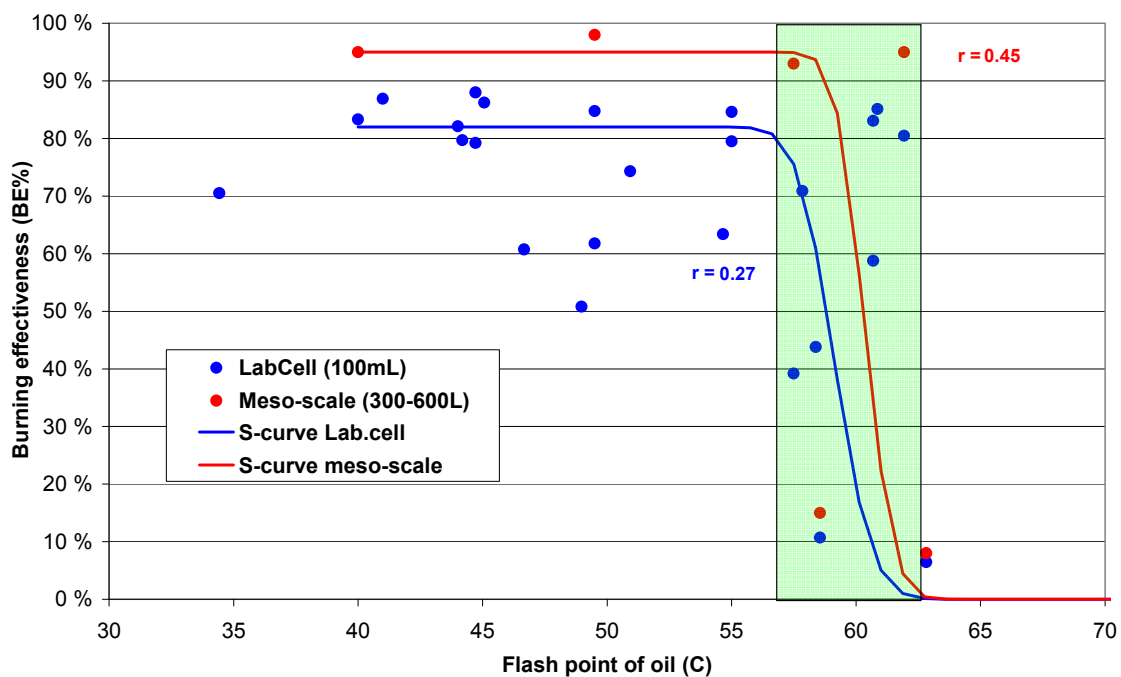


Figure 4.6 Comparison of burning effectiveness measured simultaneously with the laboratory burning cell (100 ml) and the meso scale weathering and ISB-basin (4-600 litres) on Svalbard with Grane crude oil. Effectiveness is given as a function of the flash point of the oil. The smoothed functions are S-functions fitted to the data and the correlation between the measured data and the functions are given on the figure (r).

4.4 Meso scale weathering experiments performed at Svalbard 2008

Field work was also performed on Svalbard in April 2008. The main topic for this field work was oil weathering at different ice conditions (0, 50% and 90% ice coverage). The experiments were performed as described in this report (using 200L of oil), and further details are available in other reports (Brandvik et al., 2010b). All samples collected for physical/chemical properties were also immediately tested with the Laboratory burning cell as described in this report (see Figure 3.9).

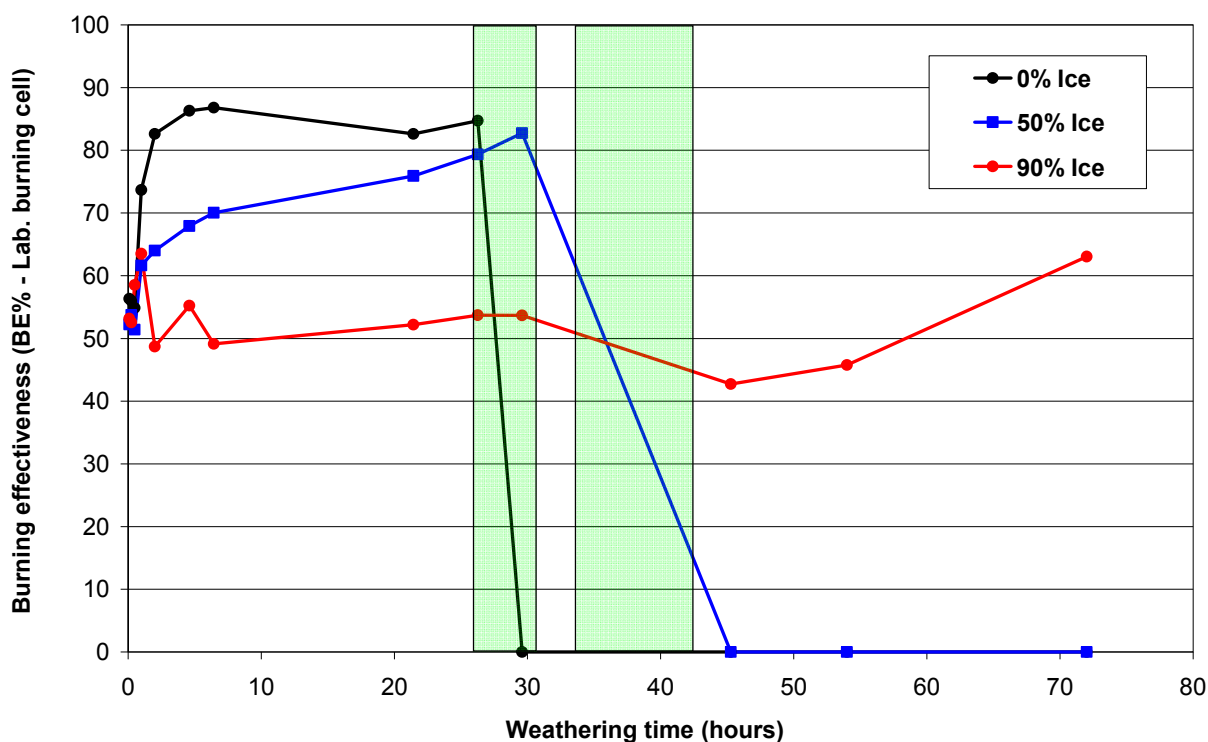


Figure 4.7 Svalbard meso scale results 2008: Burning effectiveness measured with the laboratory burning cell as a function of weathering time for the three different experiments (0%, 50% and 90% ice coverage) with the naphtenic Troll crude.

Figure 4.7 shows the burning effectiveness (BE%) measured with the laboratory burning cell from the 2008 field work. The same sharp drop in BE%, as seen earlier, can also be seen for this meso scale weathering experiments. At open water the limit for ignitability is reached after approximate 30 hours, while at 50% ice coverage the oil is ignitable up to approximate 40 hours. At 90% ice coverage the weathering of the oil is lowered due to wave dampening and the weathered oil is ignitable when the experiment is terminated after 3 days. This figure shows that the laboratory cell generates data which can be used to predict the operational window for use of in situ burning.

The laboratory cell has been used to generate similar data with samples from the meso scale weathering basin at SINTEF SeaLab in Trondheim for 5 different oil types (see example in Figure 4.3). These results are reported in a separate report (Brandvik et al., 2010b).

5 Conclusions

The laboratory burning cell has in been modified and upgraded to satisfy modern Health-Safety-Environmental (HSE) standards. The laboratory cell is now fully operational at SINTEFs oil weathering lab in Trondheim and will be used to map in situ burning properties (ignitability/burning effectiveness) of different oil types as a function of weathering.

A similar burning cell is later also built and is now operational at the Arctic centre, Danmark Technical University. This laboratory burning cell is used as a part of Janne Fritt-Rasmussens PhD work (Fritt-Rasmussen, 2010).

The new laboratory burning cell has been used to measure burning properties as a function of weathering. The relevance of this data has been verified by comparison with meso scale burning experiments (300-600 L) performed at Svalbard. The predicted time windows for use of in situ burning were identical for the data from the laboratory burning cell and the field experiments.

The laboratory cell has been used to map burning properties of weathered oil from SINTEFs meso scale oil weathering facilities in Trondheim. These data will be used to generate algorithms to predict the operational window for use of in situ burning on oil spills in ice. These algorithms will be implemented in the SINTEF Oil Weathering Model. This work is performed in a separate task in P2 – In situ burning in the oil-in-ice JIP (Brandvik et al., 2010c).

6 Acknowledgements

The University Centre at Svalbard (UNIS) and Store Norske Spitsbergen Kullkompani (SNSK) are thanked for their valuable logistical support during the field work on Svalbard.

7 References

- Brandvik, P.J., and L. Faksness, 2009: "Weathering Processes in Arctic Oil Spills: Meso-Scale Experiments with Different Ice Conditions", *Cold Reg. Sci. Technol.*, 55,1: 160-166.
- Brandvik, P.J., P.S. Daling, L-G Faksness, J. Fritt-Rasmussen, R.L. Daae and F. Leirvik. 2010a: *Experimental oil release in broken ice - a large-scale field verification of results from laboratory studies of oil weathering and ignitability of weathered oil spills*. Oil in ice JIP Report no 26, pp. 40. SINTEF Materials and Chemistry, Marine Environmental Technology, Trondheim, Norway.
- Brandvik, P.J., Myrhaug J.L., Daling, P.S., Leirvik, F. and Fritt-Rasmussen, J. 2010b: Meso-scale weathering of oil as a function of ice conditions, oil properties, dispersibility and in situ burnability of weathered oil as a function of time. Oil in Ice JIP Report no: 19. SINTEF, Trondheim, Norway.
- Brandvik, P.J., J. Fritt-Rasmussen and N.R. Bodsberg: 2010c: "Predicting Ignitability for Oil Spills as a Function of Oil Type and Weathering. Laboratory Studies Verified by Field Experiments". in *Proceedings of the Thirty-third AMOP Technical Seminar on Environmental Contamination and Response*, Environment Canada, Ottawa, Ontario (in Press).
- Brown, H.M. and R.H. Goodman, 1986: "In Situ Burning of Oil in Ice Leads", Proceedings of the Ninth Annual Arctic and Marine Oilspill Program - Technical Seminar, Environment Canada, Ottawa, ON, Canada, pp. 245-256.
- Buist, I., S. Potter, T. Nedwed and J. Mullin, 2008: "Herding Agents Thicken Oil Spills in Drift Ice to Facilitate In Situ Burning: A New Trick for an Old Dog", International Oil Spill Conference Cold Region Response, pp. 673-679.
- Buist, I., 2003: "Window-of-Opportunity for In Situ Burning", *Spill Science & Technology Bulletin*, 8:4:341-346.
- Buist, I., J. McCourt, S. Potter, S. Ross and K. Trudel, 1999: "In Situ Burning", *Pure Appl. Chem.*, 71:1:43-65.
- Daling P.S., M.Ø. Moldestad, Ø. Johansen, A. Lewis and J. Rødal, 2003: "Norwegian Testing of Emulsion properties at Sea - The importance of Oil Type and Release Conditions", *Spill Science & Technology Bulletin*, 8:2: 123-136.
- Daniloff. R., 2007: "In situ Burning of Oil Spills", Master Thesis at The Norwegian University of Science and Technology (NTNU), Trondheim, Norway.
- Dickins, D., P.J. Brandvik, J. Bradford, LG. Faksness, L. Liberty and R. Daniloff, 2008: "Svalbard 2006 Experimental Oil Spill under Ice: Remote Sensing, Oil Weathering under Arctic Conditions and Assessment of Oil Removal by In-Situ Burning", American Petroleum Institute, 1220 L Street NW, Washington DC 20005 USA.
- Dickins, D.F. and I. Buist, 1999: "Countermeasures for Ice Covered Waters", *Pure Appl. Chem.*, 71:1:173-191.

- Fingas, M.F., 1998: "In Situ Burning of Oil Spills: A Historical Perspective", In Situ Burning of Oil Spills Workshop Proceedings, National Institute of Standards and Technology Special Publications, 935.
- Fritt-Rasmussen, J, 2010: Ignitability and In-situ burning effectiveness of oil spills as a function of oil type and weathering. PhD-thesis at the Arctic Technology Center, Denmark's Technical University, Copenhagen, Denmark (in Preparation).
- Guenette, C.C., P. Sveum, C.M. Bech and I. Buist, 1995: "Studies of In-Situ Burning of Emulsions in Norway", International Oil Spill Conference.
- Guenette, C.C. and P. Sveum, 1995: "In Situ Burning of Emulsions R&D in Norway", Spill Science and Technology Bulletin, 2:1:75-77.
- Guenette, C.C., 1997: "In-Situ Burning: An Alternative Approach to Oil Spill Clean-up in Arctic Waters", Proceedings of the Seventh International Offshore and Polar Engineering Conference, Honolulu, USA, pp.587-593.
- Singsaas, I., P.S. Daling, and H.V. Jensen, 1992: "Meso scale Flume Test for Laboratory Weathering of Oils", In *Proceedings of the Fifteenth AMOP Technical Seminar on Environmental Contamination and Response*, Environment Canada, Edmonton, Canada.

Appendix A:
Data from field experiments on Svalbard in 2007

Date	Time	Visc (cP)	WC (vol.%)	Evap (vol.%)	Dens (g/mL)	FP (°C)	Applied oil (g)	Recovered residue (g)	LabCell (100mL)		Meso-scale (300-600L)	
									BE%	BE%-Corr	BE%	BE%-Corr
2007-04-18	0,6	3100	8		0,863		130	33	75			
	1,3	2400	14		0,863		140	33	76			
2007-04-19	4,5	4800	26		0,864	40	120	20	83		95	93
	0,0	5300	0				110	20	82			
2007-04-19	0,6	4700	16	3,8	0,938	45	125	15	88			
	3,2	4500	42	4,2	0,939	50	108	41	62		98	97
2007-04-20	0,5	4450	24	3,7	0,938	44	112	20	82			
	1,0	4750	35	3,7	0,938	44	133	27	80			
	2,8	7700	45	3,8	0,938	45	109	15	86			
	4,1	18200	54	4,1	0,939	49	122	60	54			
2007-04-21	7,0	22500	64	4,9	0,941	59	112	100	0		15	0
	0,5	5200	25	3,5	0,938	41	113	15	87			
	1,0	6300	38	3,8	0,938	45	130	27	79			
	2,0	10400	47	4,2	0,939	50	105	16	85			
	5,3	14000	56	4,9	0,941	57	125	10	92		93	84
2007-04-22	0,5	5400	28	4,6	0,940	55	130	20	85			
	1,0	7500	35	4,6	0,940	55	122	25	80			
	3,0	11000	49	5,1	0,941	61	121	18	85			
	3,8	10100	49	5,1	0,941	61	130	22	83			
	4,5	15400	54	5,2	0,942	62	164	32	80		95	89
2007-04-24	0,5	3700	16	2,9	0,936	34	146	43	71			
	1,0	5050	26	3,9	0,939	47	107	42	61			
	2,0	7060	36	4,3	0,940	51	113	29	74			
	4,0	11600	55	4,6	0,940	55	124	45	63			
	5,0	16000	61	4,9	0,941	58	121	20	83			
	5,5	16000	62	4,9	0,941	58	110	32	71			
	6,0	16000	63	5,1	0,941	61	114	47	59			
	7,2	22000	65	5,3	0,942	63	155	145	6		8	0