Distribution of oil in sea ice:
Laboratory Experiments for 3-dimensional microCT investigations

M. L. Salomon 1, S. Maus 1, M. Arntsen 2, M. O’Sadnick 2, C. Petrich 2, F. Wilde 3

(1) Department of Civil and Transport Engineering, Norwegian University of Science and Technology, Trondheim, Norway.
(2) Northern Research Institute (Norut) Narvik, Narvik, Norway.
(3) Helmholtz-Zentrum Geesthacht, Geesthacht (Germany).

ABSTRACT

With increasing exploration and operations in the Arctic, resulting in a growing risk for oil spills, a sound understanding of fate, detection and impact of hydrocarbons in sea ice is vital for planning and spill response. Sea ice contains pores and channels forming a network of effective porosity. During the growth season (October-March) oil becomes entrained and encapsulated in the ice quickly and remains trapped in the ice as a relatively static and discrete layer. With increasing ice temperature in spring, the interconnectivity of the pores increases and gives rise to movement of oil to the surface. To enhance understanding of oil distribution in sea ice, laboratory experiments of oil in ice were conducted. The ice was imaged with 3-D synchrotron X-ray microtomography (SRµCT), a non-destructive method ideally to obtain accurate measurements. An understanding of these processes is a prerequisite for optimal timing of oil spill clean-up as well as the interpretation of remote sensing data. This paper describes the measurement process and preliminary results in the context of future research opportunities to explore these applications, ranging from small in-situ experiments (5-10 cm)-, to ship tank experiments and field experiments.

KEY WORDS

oil; sea ice; synchrotron; microstructure; micro-CT; non-destructive imaging

INTRODUCTION

Experiments were designed to investigate the detection of oil in laboratory-grown sea ice. With increasing interest in exploration of Arctic oil resources, this study is a step toward a fundamental framework of oil hazard management in ice-covered waters. The presented experiment is one out of a series of planned investigations, ranging from in-situ (5-10 cm) to lab-, ship tank- and field experiments.

Sea ice hosts a network of channels and pores, making it a potential entrainment medium for spilled oil (e.g., Karlsson et al., 2011, Petrich et al., 2013). Discharged crude oil in ice-covered waters preferentially collects in concave depressions underneath the ice. The thickness of these oil pools typically range from 0.08 to 0.2 m. (Glaeser and Vance, 1971; NORCOR, 1975, Goodman and Fingas, 1983; Wilkinson et al., 2014)

During the growth of sea ice (October-March), crude oil spilled beneath sea ice becomes quickly (12 to 48 hours) entrained and encapsulated as discrete layer within the ice as ice continues to grow underneath the oil film (Bui et al., 1983; Dickins, 2011). The ability of oil to penetrate sea ice is limited by the pore space. Laboratory and field observations indicated that the porosity of oil-infiltrated sea ice exceeds 0.1 to 0.15 (Otsuka et al., 2004, Karlsson et al., 2011). Below this porosity, sea ice remained oil-free. Based on these observations, the expected depth of oil entrainment in the sea ice pore space increases toward the end of the growth season when the ice is warm (Petrich et al., 2012). However, sea ice porosity is likely not the only relevant parameter for oil entrainment and migration in ice. Based on theoretical calculations, oil entrainment and migration is further controlled by variables such as oil layer thickness, age of the ice, size of pores and pore necking and convection driven by desalinization (Dickins 1992; Maus et al., 2013).

Oil lenses remain trapped as relative static layers until warming in spring (Wolfe and Hoult, 1974). With the rise of temperature the interconnectivity of the pores increases and the amount of oil saturation in ice reaches up to 4.5 to 7 mass percent oil by mass of sea ice (Otsuka et al., 2004, Karlsson et al., 2011). Eventually, oil migration reaches the surface (NORCOR, 1975).

Several studies were conducted since the early 1970s to investigate different aspects of the interaction between oil and ice (cf. Dickins 1992, 2011). Earlier observations were based mainly on destructive two-dimensional investigations such as photography, spectral reflectance measurements, and observation of thin sections under crossed polarized microscope (Martin, 1979; Taylor and Peron, 1995). Recently, numerical modelling on 3-dimensional micro-CT pore space data were used to predict the displacement-likelihood of brine by oil (Maus et al., 2015).

This study describes a laboratory setting and methods used to transport and image samples at the synchrotron facility in Hamburg (DESY). Using a synchrotron light source facilitates the segmentation of ice constituents even if their absorptive properties are similar (e.g., ice, oil, brine). Preliminary results from 3-dimensional micro-computed Tomography (CT) images of laboratory grown sea ice with oil inclusions are presented.

Focus of the micro-CT measurements are

1. detectability of crude oil from the different phases in sea ice