Marine Pollution Bulletin 109 (2016) 446–452

Contents lists available at ScienceDirect

Marine Pollution Bulletin

journal homepage: www.elsevier.com/locate/marpolbul

Effects of oil and oil burn residues on seabird feathers

Janne Fritt-Rasmussen [a,*], Jannie Fries Linnebjerg [a,1], Martin X. Sørensen [b], Nicholas L. Brogaard [b], Frank F. Rigét [a], Paneeraq Kristensen [a], Grunde Jomaas [b], David M. Boertmann [a], Susse Wegeberg [a], Kim Gustavson [a]

[a] Danish Centre for Environment and Energy, Department of Bioscience, Aarhus University, Frederiksborgvej 399, DK-4000 Roskilde, Denmark
[b] Technical University of Denmark (DTU), Department of Civil Engineering, Brovej, Building 118, DK-2800 Kgs. Lyngby, Denmark

ARTICLE INFO

Article history:
Received 19 January 2016
Received in revised form 10 May 2016
Accepted 14 May 2016
Available online 24 May 2016

Keywords:
In situ burning
Burn residues
Oil spill
Damage
Seabirds
Feathers

ABSTRACT

It is well known, that in case of oil spill, seabirds are among the groups of animals most vulnerable. Even small amounts of oil can have lethal effects by destroying the waterproofing of their plumage, leading to loss of insulation and buoyancy. In the Arctic these impacts are intensified. To protect seabirds, a rapid removal of oil is crucial and in situ burning could be an efficient method. In the present work exposure effects of oil and burn residue in different doses was studied on seabird feathers from legally hunted Common eider (*Somateria mollissima*) by examining changes in total weight of the feather and damages on the microstructure (Amalgamation Index) of the feathers before and after exposure. The results of the experiments indicate that burn residues from in situ burning of an oil spill have similar or larger fouling and damaging effects on seabird feathers, as compared to fresh oil.

1. Introduction

Oil spills in Arctic waters are connected with great environmental consequences, and the challenges are more difficult to handle than oil spills in temperate waters. This is primarily due to the ice, as it complicates the accessibility to the spill site, thereby making conventional methods less efficient. The remote location, darkness for many months of the year and lack of infrastructure also add to the challenges of dealing with an oil spill in the Arctic. For removal of oil in ice-infested waters in situ burning (ISB) is a response technique with high potential. In short, ISB is to ignite the oil at the spill site and thereby removing large amounts of the oil by converting it into CO_2, water, soot and other combustion products. Burning effectiveness higher than 90% has been found under the right circumstances (fresh oil, thick oil slick and relatively large spill area; e.g. Fingas et al., 1995). After flame extinction a highly viscous and sticky burn residue that might sink is left behind (Fritt-Rasmussen et al., 2015). The residues, though substantially reduced in amount compared to the original spill, might be difficult and time consuming to collect as the measures for collecting is often done manually through the use of forks and absorption pads. During the Deep Water Horizon incident in the Gulf of Mexico in 2010, hundreds of burn operations were conducted as part of the oil spill response. However, the residue was not collected and hence the fate of the residue remains unknown (Shigenaka et al., 2015).

In spite of its potential environmental risk, little research has been made to gain knowledge about the residue and its environmental effects (Fritt-Rasmussen et al., 2015). A few toxicity studies have been made and the overall conclusion was that the burn residue is not more toxic than what is found from the oil spill itself (Gulec and Holdway, 1999; Cohen and Nugegoda, 2000; Fingas et al., 1994; Faksness et al., 2012). These studies include only a few aquatic species (including fish, amphipods, copepods, asteroids and snails) and a few oil types. Furthermore, studies on fouling effects from the burn residue on birds and other surface living organisms are also missing (Fritt-Rasmussen et al., 2015).

It is well known that in case of an oil spill, seabirds are among the groups of animals that are most vulnerable (e.g. Piatt, 1990). Most seabirds spend their entire non-breeding season at sea, relying on feathers for flight, insulation and buoyancy (Stephenson, 1997), and it is well documented that feather fouling from oil is the primary cause of mortality in seabirds exposed to oil pollution (Leighton, 1993). Even small amounts of fresh oil can have lethal effects on seabirds by destroying the waterproofing of their plumage, leading to loss of insulation and buoyancy and causing rapid death by hypothermia, starvation or drowning (Leighton, 1993). In the Arctic, these impacts are intensified, as the cold water leads more rapidly to hypothermia (O'Hara and

* Corresponding author.
E-mail address: jfr@bios.au.dk (J. Fritt-Rasmussen).
[1] Present address: Centre for Animal Movement Research (CAnMove), Department of Biology, Lund University, 223 62 Lund, Sweden.

http://dx.doi.org/10.1016/j.marpolbul.2016.05.029
0025-326X/

Morandin, 2010). Thus, the residues remaining on the water surface might represent a potential risk for the pelagic seabirds due to their biology and habits e.g. foraging behaviour.

Although oil pollution and its lethal fouling effects on seabirds is well documented, little research has been conducted on the effect of oil on the microstructure of the feathers (Hartung, 1967, O′Hara and Morandin, 2010, Morandin and O′Hara, 2014) and to our knowledge, no research has been made to investigate the potential effects burn residues might have on seabird feathers. The aims of the study are thus to investigate and compare the effects of fresh oil and of burn residues on seabird feathers.

2. Materials and methods

The experiments involved a two-step process, the first including the generation and collection of residue from burning of oil and the second was to study the potential effects of burn residues on seabird feathers.

2.1. Burning experiments

Burn residues tested in the study were collected from laboratory burning experiments conducted in an experimental set-up of the Technical University of Denmark. The laboratory burning set-up consists of a 1 × 1 m water bath that is placed under an exhaust hood. A Pyrex Glass Cylinder (PGC) with a closed bottom was placed in the middle of the bath filled with a 30‰ salt water solution. A known amount of oil was carefully placed on top of the salt water surface in the PGC. The oil was ignited with a butane blowtorch, and after flame extinction, the residue was collected by use of absorption pads. The residue was stored in a glass bottle in the freezer (−18 °C) until further analyses. More details regarding the set-up and method can be found in Brogaard et al. (2014) and van Gelderen et al. (2015).

Two types of oils were investigated; Grane (crude oil) and IFO30. Grane is an asphaltenic crude oil, rich in resins and asphaltenes and therefore forms stable water-in-oil emulsions, the density is high and the evaporative loss is low (Fritt-Rasmussen, 2010). IFO30 refers to an intermediate fuel oil and is a mixture of gasoil and heavy fuel oils, with a viscosity of 30 cSt at 50 °C. IFO30 was provided by Trumf Bunker in Aabenraa, Denmark (Fritt-Rasmussen, 2010). The physical and chemical properties for Grane and IFO30 are given in Table 1. Refined products even within the same IFO grade can vary in properties depending on the refinery process and type of crude oil (Moldestad and Leirvik, 2005), thus the values in Table 1 only gives an indication of the properties of such oil.

The burning efficiencies and other burning related parameters for both oils are given in Table 2. More details and discussions of results from the burning experiments for Grane are reported in Brogaard et al. (2014) and van Gelderen et al. (2015).

As a result of the burning, the residual changed its properties and became almost solid. The buoyancy of the residue was tested for the IFO30, 40 mm experiment. The fresh IFO30 was buoyant but after flame extinction the residue sank slowly (Fig. 1). The sinking was not observed for the 10 mm burning experiments.

Table 1
Physical and chemical properties for the fresh oils used in the experiments. Data from Brandvik et al. (2010). Data for IFO30 from SINTEF Oil Weathering Model (Johansen et al., 2010). Viscosity data for Grane from Faksness (2008).

Oil type	Density (kg/m^3)	Pour point (°C)	Wax (wt.%)	Asphaltenes (wt.%)	Viscosity (cP)
Grane	0.941	−24	3.2	1.4	22 at 5 °C
IFO30	0.936	6	Not available	Not available	236 a 13 °C

2.2. Experimental burn residue effects on seabird feathers

The laboratory study included exposure of seabird feathers in different oil and burn residue doses followed by measurements of the feather microstructure disruption following a modified methodology of O′Hara and Morandin (2010). Also, changes in the total weight of the feather due to increased uptake of water or fouling by oil or residue were measured.

Feathers from legally hunted seabirds of Common eider (*Somateria mollissima*) were used in the study. Common eider is widespread in the coastal area in the Arctic. To minimize the impact to the feathers, the feathers from the chest of the birds were removed carefully and at no point were the birds/skin frozen. The feathers were stored carefully to avoid any unwanted disturbances of the feather structure.

The samples for testing were: different dilution of fresh oil samples and burn residues of: Grane crude oil and IFO30 oil. Salt water and the solvent Dichloromethane (DCM) was included as controls.

2.2.1. Sample preparation

2.2.1.1. Burn residue and fresh oil. The burn residue that was sampled on an absorption pad (see Section 2.1) was dissolved in 25 mL DCM and stirred carefully for 30 min. The absorption pad was then removed and dried for 24 h before weighing. <5% of the burn residue was left on the absorption pad by this extraction method. The dilution series were made from these dissolved burn residue stock solutions diluted in 25 mL DCM to 10, 100, 1000 and 10,000 dilutions. The corresponding oil slick thicknesses can be found in Table 3.

The dilution series were made of fresh Grane crude oil and IFO30 respectively applied to a red-cap bottle and filled with 25 mL DCM. The amounts of oil added correspond relatively to the amount of oil that was removed by ignition. The dilution series were made from this stock solution to 10, 100, 1000 and 10,000 times dilutions.

0.5 mL of sample (burn residue or fresh oil) was carefully transferred to the 30‰ salt water layer in a Petri dish with a glass micropipette on the inner side of the dish to make sure that the sample positioned on the salt water surface. The set-up was left for at least 5 min to allow for the DCM to evaporate completely. The exposure procedure is described in Section 2.2.2.

Based on an assumption that oil/residue were homogeneously distributed over the salt water surface in the Petri dish, the doses applied have been converted to an estimated minimum oil slick thickness for the different dilutions (Table 3). The initial amount of residue was smaller compared to the fresh oils to simulate a burning situation where the oil amount is considerably reduced as a result of the burning. The burning efficiencies found in the burning experiments (Section 2.1) were used to calculate the amount of oil/residue used in the experiments. This is also reflected in the slick thickness of the burn residues that are thinner (Table 3).

2.2.1.2. Control experiments. Control experiments with only 30‰ salt water were made. The exposure procedure is described in Section 2.2.2. In addition, control experiments with 0.5 mL DCM carefully transferred to the Petri dish with a glass micropipette on the inner side of the dish were made.

2.2.2. Exposure experiments on seabird feathers

The following procedure was followed during all the exposure experiments:

1. A glass Petri dish (11 cm D) was filled with salt water (30‰).
2. The test sample was applied to the surface of the salt water with a micropipette.
3. The feather was weighed and subsequently placed on the surface film in the Petri dish for 15 s using tweezers and picked up by the calamus. Hereafter, the feather was drawn three times over the surface