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Research article

Scale-up considerations for surface collecting agent assisted in-situ burn crude oil spill response experiments in the Arctic: Laboratory to field-scale investigations

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ABSTRACT

In the event of a marine oil spill in the Arctic, government agencies, industry, and the public have a stake in the successful implementation of oil spill response. Because large spills are rare events, oil spill response techniques are often evaluated with laboratory and meso-scale experiments. The experiments must yield scalable information sufficient to understand the operability and effectiveness of a response technique under actual field conditions. Since in-situ burning augmented with surface collecting agents ("herders") is one of the few viable response options in ice infested waters, a series of oil spill response experiments were conducted in Fairbanks, Alaska, in 2014 and 2015 to evaluate the use of herders to assist in-situ burning and the role of experimental scale. This study compares burn efficiency and herder application for three experimental designs for in-situ burning of Alaska North Slope crude oil in cold, fresh waters with ~10% ice cover. The experiments were conducted in three project-specific constructed venues with varying scales (surface areas of approximately 0.09 square meters, 9 square meters and 8100 square meters). The results from the herder assisted in-situ burn experiments performed at these three different scales showed good experimental scale correlation and no negative impact due to the presence of ice cover on burn efficiency. Experimental conclusions are predominantly associated with application of the herder material and usability for a given experiment scale to make response decisions.

1. Introduction

The Deepwater Horizon (DWH) oil spill resulted in increased efforts towards enhancing knowledge and preparedness for oil spills globally. One risk, in particular, that has been identified is the possibility of oil spills in Arctic waters (NRC, 2014) especially with increased warming in the Arctic leading to more possibilities for oil exploration. The Arctic is both a unique and challenging environment. Its uniqueness is generally derived from its culture, ecosystem, climate, and remoteness (NRC, 2014). Each of these characteristics presents challenges when planning for and responding to an oil spill. One response method, in-situ burning, has been cited as a potentially viable option for rapid and effective response to oil spills in icy waters (Buist et al., 2006; Fingas, 2011). Since the 1970s, experiments have been conducted on the use of in-situ burning in open and ice-infested waters (Buist et al., 2014; Fingas et al., 1995). Several studies have also been performed on the use of surface collecting agents ("herders") to enhance collection of surficial oil spills and aid in-situ burning (Buist et al., 2011, 2013, 2014).

Decisions about the choice of oil spill response methodology are based on a net environmental benefit analysis, which might result in the question, will burning reduce the harm of oil compared with other response options? Since observations of the efficacy of herder augmented in-situ burning are limited, the results from laboratory and meso-scale experiments are needed to estimate the efficacy of proposed burns. Despite an extensive dataset from these efforts, relatively few studies have included experiments of burn effectiveness in ice infested waters at different scales, conducted by same personnel and using same analytical techniques to enhance comparability (Buist et al., 2014).

The use of chemical surfactants (herders), such as shell oil herder and corexit, to contain oil slicks on the surface of open waters and with some amount of ice coverage has been evaluated in the laboratory setting employing different size containment vessels (Buist et al., 2011; Pope et al., 1985). The physical and

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chemical characteristics of the tested surfactant chemicals are documented in their Material Safety Data Sheets (MSDS), United States Environmental Protection Agency (EPA) submittals and a few research studies (Buist et al., 2006; Pope et al., 1985). However, the effect of the herders on the spreading of different fuel types and operational parameters is less certain. Thus, testing of various herder formulations with different oil types and conditions will yield information valuable to the decision makers. Key knowledge is the burn efficiency, the composition and physical properties of the burn residue. Efficiency of an in-situ burn on waters is determined by measuring the percentage reduction in oil mass following the burn. While a burn experiment might be straight forward to conduct, the relevance of such experiments to the likely conditions in an actual spill bears some analysis. The area of the burn relative to the thickness of the oil may be important. We know burn efficiency increases with the thickness of the slick (Buist et al., 2014), but the effect of burn area is less clear. Also, the presence of ice is an additional factor that needs to be considered since ice can impact experimental procedures and results during in-situ burn experiments (Buist et al., 2006).

To address the knowledge gaps with regards to scalability of herder assisted in-situ burning in cold waters containing surficial ice, specific to the question of oil spill response preparedness in Arctic waters, a series of experiments were conducted in early 2015 at Fairbanks, Alaska. These experiments included field-, meso- and laboratory-scale experiments. The multi-scale approach improves our understanding of the usability of results from smaller scale in-situ burn experiments towards predicting larger scale outcomes. The focus of this paper is to document the comparability of multi-scale in-situ burning trials with herder application in response to release of Alaska North Slope (ANS) crude oil in fresh water with approximately 10% ice cover.

2. Equipment, materials and methods

2.1. Experimental facilities

A series of experimental facilities were designed and constructed at the University of Alaska Fairbanks (UAF) to evaluate the important mechanisms of oil herding and in-situ burning in the presence of ice. Each facility was constructed during the period September 2014 to April 2015 with locally available equipment, materials and labor. All experiments were conducted during late winter (March through early May) 2015, outdoors in Alaska with the intent to simulate a range of Arctic climatic conditions. The experiments described in this paper focused on simulating an oil spill in fresh water containing approximately 10% ice cover. Fresh water was used as the experimental medium, since prior research has shown little difference between herder effectiveness in fresh versus salt water (Pope et al., 1985; Buist et al., 2006).

In all laboratory bench-scale experiments water cooled down to 1 °C was used, in the meso-scale experiments also water was at 1 °C, and in the larger field-scale experiments water steadily warmed from 1 °C to 5.5 °C. Outdoor ambient air temperatures varied from March through May 2015 (period of experiments); from below 0 °C–13 °C. All experiments were conducted in calm wind conditions (<1.5 m/s) to not cause concern to adjacent landowners, fire fighters or to aerial equipment.

2.2. Laboratory bench-scale experiments

A laboratory scale experiment chamber was constructed to conduct laboratory bench-scale experiments described in this study. The stainless steel, bench-scale ‘experiment chamber’ was custom built (Holaday Parks, Fairbanks, AK). The chamber contains galvanized metal sample pans (dia. = 38 cm), and a galvanized metal oil release ring (dia. = 8 cm), in addition to multiple ignition ports and air emission probe ports at the top (Fig. 1A).

Metal pans (Fig. 2A) were placed within the bench-scale ‘experiment chamber’ prior to beginning an in-situ burn experiment. The pans were filled with approximately 5 cm of cold (1 °C) deionized water (DI). The laboratory experiments discussed herein also included addition of three to five DI ice blocks (approximately 8 cm thick by 6 cm diameter; Fig. 2A) placed generally midway between the oil release mechanism and the pan perimeter. The ice blocks were placed in the pan to simulate 10% ice coverage. The entire bench-scale setup was placed outdoors to simulate in-situ burns in cold climate conditions, and a total of six experiments were conducted.

2.3. Meso-scale experiments

Two meso-scale experiments were conducted at UAF Fire Station Number 2 (Fig. 1B). Two 3 m × 3 m x 0.23 m basins were constructed, lined with 8218 LTA fusible liner placed on snow packed, frozen ground. The two experiment basins were temporary experiment sites established solely for the purpose of this experimental program.

The basins were built to a height of 23 cm by placing timbers (2.43 m × 0.2 m × 0.23 m) at the perimeter to provide structural stability to the overlying liner. Each basin contained approximately 10% surface cover from ten ice blocks (~20 cm × 25 cm) and snow, placed randomly between the oil release mechanism and the basin perimeter (Fig. 2B). Each basin was filled with approximately 15 cm of fresh cold municipal water. In addition, each basin was supplemented with a snow packed perimeter, which also acted to protect the interior liner during the burn. For oil release, a galvanized metal oil release ring (dia. = 0.6 m) was used. A total of two meso-test experiments were conducted, one in each meso-scale basin.

2.4. Field-scale experiments

A field-scale experiment basin (90 m × 90 m) was designed and constructed in the fall of 2014 at the UAF Poker Flat Research Range (PFRR), and five field-scale experiments were conducted in April 2015. The basin was filled with 15 cm fresh water (similar to the meso-scale test) from a nearby lake. Large cardboard boxes covered with plastic liners were filled with water and frozen in-place (in January 2015) to provide 10% simulated ice-cover in the basin (Fig. 1D). However, as the weather warmed by April 2015, the icebergs melted and subsequently circular sheet metal structures were constructed as replacements and were used to simulate an ice-cover of approximately 6% in the basin. Aerial platform (helicopter) was employed for herder application and subsequent ignition. A 2.4 m square aluminum spill release frame was used for instantaneous release of crude oil in the central portion of the basin. Further details on the basin and the five field-experiments conducted therein (in April 2015) have been described separately (Potter et al., 2016). Only three of the five field experiments used the Siltech OP-40 herding agent, and thus only those three field-scale experiments are discussed here.

2.5. Crude oil release

ANS crude oil was used for all experiments, obtained from the feedstock pipeline at the Petro Star Refinery located in Fairbanks, Alaska. The spill related properties of the ANS crude oil used in bench- and meso-scale tests are described in Table 1, and are similar to those of previously documented unweathered ANS crude. The testing for the oil was conducted by an external laboratory