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Pumice stones as potential in-situ burning enhancer

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ABSTRACT

Small-scale and mid-scale experiments were conducted in order to evaluate pumice stones as a potential enhancement for in-situ burning (ISB). Four oil types, several emulsification degrees of one crude oil were studied. In general, it was observed that the pumice stones did not improve the burning efficiency (BE). In fact, for large pumice coverage ratios, the BE was affected negatively, especially for the emulsified crude oil, which is the most likely condition of the oil that may be subjected to ISB. Furthermore, it was observed that a relatively large amount of the pumice stones were sinking during and after the burn, thus bringing the oil into the water column. Finally, the species production of CO and CO_2 was not reduced. Based on the presented results, pumice stones have a negative impact on the efficiency of ISB, and they are ruled out as an ISB enhancer and should not be used in relation to ISB.

1. Introduction

After the first major oil spill happened in the 1950s, both government officials and researchers have put special emphasis on remediation of spilt oil on the sea, and even more so after the Deepwater Horizon oil spill (Buist et al., 2013). During an offshore oil spill, there are several techniques to remove the oil from the water surface. One method that has been widely used is the in-situ burning (ISB) of oil on water. For example, ISB accounted for about 21% of the total clean-up by the three main methods (dispersants, mechanical and ISB) of the oil spill in the Gulf of Mexico (The Federal Interagency Solutions Group, 2010). This technique consists of igniting the oil, at or near the spill site and letting the oil burn until most of the oil spilt has transformed into gases and soot. The method has been shown to have high elimination rates and high efficiency of burn. It has been reported in a review of several studies (Buist et al., 2013) that up to 90–99% of removal efficiency can be achieved or lower depending on the weathering state of the oil which evaporates and emulsifies with the seawater (Fritt-Rasmussen, 2010).

The drawbacks associated with ISB are a generation of toxic gases, CO, CO_2 and soot, and the sinking of oil residues (Buist et al., 2013; Fritt-Rasmussen, 2010). In order to diminish these problems, several techniques have been explored to enhance the burning, such as herding agents (Buist, 2006; Buist et al., 2008; S.L. Ross Environmental Research Ltd., 2012), adding combustion promoters (Buist et al., 2013), and the usage of pumice stones as a burning enhancer was proposed by some companies. It has been claimed that less smoke was observed when the oil on water was burnt with pumice stones than without. Moreover, since the pumice stones float on water due to their low density compared to water, no sinking of residues could eventually happen since the residues cling to the pumice stones.

An experimental study was undertaken to quantify the effects of introducing pumice to in-situ burning experiments. The results are presented in the following, where ignition and combustion-related parameters to ISB of crude oil on water are analysed. The majority of tested pumice stones had a diameter of approximately 35 mm to 50 mm. Larger diameters were also tested but did not yield significant differences. The main parameters studied were the burning efficiency, the burning time, the mass flow rate and the yield of two combustion species (CO and CO_2). In addition, the oil residues' behaviour was studied.

2. Method

Various parameters, related to ignition and combustion of crude oils on water, were systematically studied in a series of small-scale and mid-scale experiments. The scenarios are presented in the following:

A. Different crude oils:

Four crude oils were investigated: Grane, Alaska North Slope (ANS), Danish Underground Consortium (DUC) and Siri. Grane is an asphaltenic crude oil with a high content of resins and is able to form stable emulsions (Fritt-Rasmussen, 2010). ANS is a medium grade crude oil,

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Table 1
Measured densities and viscosities of three oils and three water-in-oil emulsions.

Properties (at 25 °C)[a]	Oil type				Emulsion type		
	Grane	ANS	Siri	DUC	Grane_5%	Grane_10%	Grane_15%
Bulk density [g/cm^3]	0.918	0.871	0.883	0.870	0.935	0.933	0.938
Kinematic viscosity [mm^2/s]	143.2	12.3	6.4	9.16	157.0	183.7	199.1
Dynamic viscosity [mPa·s]	131.4	10.7	7.6	6.5	169.3	196.8	212.7

[a] The properties of the fresh crude oils and water-in-oil emulsions are average values measured at 25 °C obtained from several measurements performed in the "Paar Stabinger Viscometer SVM 3000" apparatus. The apparatus follows various standards for measuring the kinematic viscosity (ASTM D7042, EN 16896, and DIN 51659-2), the dynamic viscosity (ASTM D7042), and the density (EN ISO 12185, ASTM D4052, and IP 365).

with lower density and viscosity than Grane. DUC is a low sulphur, naphthenic type North Sea crude oil with a medium content of waxy components (Anon, n.d.). And the last, Siri, is a paraffinic crude oil with a high content of waxy components and medium evaporative losses compared to other crude oils. The measured densities and viscosities of the crude oils are displayed in Table 1.

B. The degree of emulsification:

Fresh Grane crude oil was emulsified with 5, 10 and 15% water content, respectively. The water-in-oil emulsions were produced by the rotating flask technique, a modified technique based on Mackay and Zagorski (Mackay and Zagorski, 1982). The measured physical properties of the emulsions are displayed in Table 1. The artificial emulsions created for this study can be considered unstable, following classification given by other studies (Fingas and Fieldhouse, 2003). In real scenarios, the spilt oil undergoes a weathering process where it evaporates and emulsifies. During emulsification, small water droplets penetrate into the oil slick layer due to mechanical movement caused by wave-action. Evaporation of the lightest components will onset the crystallisation and precipitation of the asphaltenes along with resins in the crude oil; it is well accepted that these agents can stabilise the water droplets in the oil layer (Fingas and Fieldhouse, 2003; Bobra, 1991; Buist et al., 2013). In order to ignite the emulsified oil, it is first required to break the emulsion by increasing the temperature until the water droplets evaporate, which leaves the oil to evaporate and produce the required gas mixture to sustain combustion. Highly stable emulsified crude oils (higher content of water) will theoretically require higher energy, which is practically not feasible in the Arctic context. Therefore, unstable emulsions were used for this study, since it enabled the study to assess the effect of the pumice stones on the ISB.

C. Pumice coverage ratios:

Several pumice coverage ratios were tested, these ranged from 25 to 80%. The pumice coverage ratio (PCR) is defined as:

$$\mathrm{PCR} = \frac{A_{pumice}}{A_s}[\%] \tag{1}$$

where A_{pumice} is the area occupied by the pumice stones, and A_s is the pool area or oil slick area. The first was calculated based on pictures that were taken from above the oil pool. The pictures were individually analysed using image processing software.

2.1. Small-scale experiments

The Crude Oil Flammability Apparatus (COFA) was developed to study in-situ burning of crude oils spilt on the water in a controlled laboratory environment (Brogaard et al., 2014; Van Gelderen et al., 2015), see Fig. 1. In the tests, the crude oil was poured into the Pyrex glass cylinder (PGC), 26 cm diameter, along with the pumice stones (mechanically confined). Then, the pumice stones were stirred with a spatula in order to let them absorb oil during for approximately 10 min.

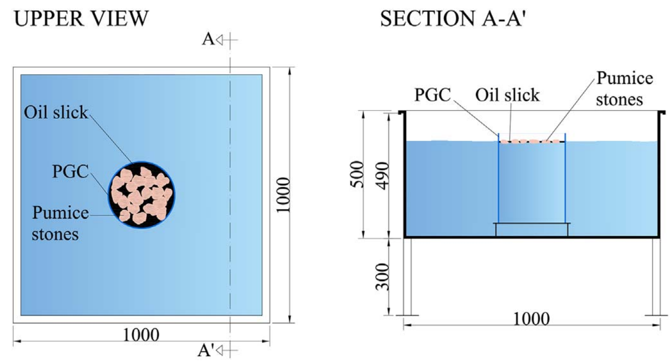

Fig. 1. Overview of the COFA with pumice stones. The dimensions are mm.

Finally, the oil was ignited with a butane torch. The oil residues were collected with oil sorbent pads, which were dried along with the pumice stones (24 h in an oven at 60 °C) and weighed.

2.2. Mid-scale experiments

Two mid-scale experiment took place in a 20 m^2 octagon water basin, see Fig. 2. The first experiment was executed without the addition of pumice stones, and during the second experiment, pumice stones were added to obtain 20% PCR approximately. The weather conditions were very similar during both experiments. The water temperature, the air temperature and the air velocity around the water basin measured 5–6 °C, 2–6 °C and 1–2 m/s, respectively. The crude oil was poured onto the water and allowed to spread for 30 min. The oil was then chemically confined by applying from basin's edges 3 ml of the herding agent OP40, which in turn was allowed to herd (towards the centre of the basin) the oil for 30 min. Then, the pumice stones were carefully distributed over the herded oil slick. Finally, the oil was ignited by applying a gelled batch of gasoline and diesel fuel. The oil slick thickness was estimated based on the area of the oil slick, the initial oil volume and the density of the oil. The area was estimated by processing manually the pictures taken by the video camera located above the water basin. The initial oil slick thickness (after herding) for both tests was 8 mm, for the second test after adding the pumice stone the oil slick thickness increased to 10 mm.

2.3. Oxygen consumption method

The oxygen consumption method is based on the observation that, in general, the net heat of combustion is directly related to the amount of oxygen required for combustion (Huggett, 1980). The method was used to measure the oxygen consumption and gas flow rates during some of the small-scale in-situ burning experiments with oils and pumice stones. The method is mainly applied for determining the heat release rate. However, it is possible to measure other parameters, such as the specimen mass loss rate, the smoke obscuration generated, specimen ignitability, the effective heat of combustion and the yields of