OPERATIONAL PARAMETERS FOR *IN SITU* BURNING OF SIX U.S. OUTER CONTINENTAL SHELF CRUDE OILS

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ABSTRACT: *A laboratory test program was conducted with six crude oils to determine the following parameters with respect to* in situ *burning:*

- *The limits to ignition using gelled-gasoline igniters imposed by evaporation and emulsion-formation*
- *The ability of commercially-available emulsion breakers and alternative fuel igniters to extend the window-of-opportunity for ignition of stable emulsions*
- *The effects of wave action on the combustion of emulsion slicks,*
- *The likelihood of the residues sinking after efficient burns of thick slicks of the crude oils*

As well as providing valuable spill-response oriented data, the study has shown that in situ *burning may not be an appropriate response option for all oils. Some oils were easily ignited and burned efficiently, even when emulsified to high water contents. One oil could not be ignited even when fresh. The ability of emulsion breakers to promote emulsion ignition and burning was found to be oil-dependent.*

Introduction

Before oil spill response plans are developed or approved, it is important to understand the physical characteristics of the spilled oil and how they change over time. The *Catalog of Crude Oil and Oil Products Properties,* jointly funded by the U.S. Minerals Management Service (MMS) and Environment Canada, contains the physical and chemical data of over 380 different types of oils, including some information on dispersability. This research study was intended to provide additional data on *in situ* burning that should be considered when developing oil spill response plans.

The MMS, in consultation with their Gulf of Mexico and Pacific regional offices, selected six U.S. crude oils produced on the Outer Continental Shelf (OCS) and subjected them to a laboratory test program. The crude oils selected by the Gulf of Mexico region were Amoco High Island, Green Canyon Block 65, and West Delta Block 30. The crude oils selected by the Pacific Region were Carpinteria, Santa Clara, and Santa Ynez.

Methods

The objective was to determine the following parameters related to *in situ* burning:

- The limits to ignition using gelled gasoline igniters imposed by evaporation and emulsification
- The ability of commercially-available oil spill emulsion breakers and alternative fuel igniters to extend the window-of-opportunity for ignition of stable emulsions
- The effects of wave action on the combustion of emulsion slicks
- The likelihood of the residues sinking after efficient burns of thick slicks

These parameters were determined by performing laboratory-scale tests that can be divided into six categories. The test procedures are described in detail in McCourt *et al.* (1998) and are summarised here.

Evaporation. To assess the effect of evaporation on the ignition and burning characteristics of each oil, the oils were artificially evaporated. First, one 450-mL sample of each oil was weathered in a wind tunnel for one week, in order to quantify the rate and extent of evaporation that would occur if the oil was spilled at sea. The wind tunnel was calibrated during the oil evaporation so that the duration of exposure to evaporative forces in the wind tunnel could be correlated with exposure during a spill.

Larger evaporated samples were prepared for the subsequent burn tests by bubbling compressed air through two or more heated 20-L batches of each oil in buckets until the desired mass fraction was evaporated.

Emulsion characteristics. The tendency of the each of the test oils to form an emulsion and the stability of the resulting emulsion were determined using the standard rotating flask technique (Zagorski and Mackay, 1982). The test was conducted on both the fresh and weathered samples, at a temperature of 20°C.

The effectiveness of three emulsion-breaking chemicals (also known as demulsifiers) were tested on the weathered crude oil samples. They were Alcopol 0 70% PG (Alcopol), Breaxit OEB-9 (Breaxit), and EXO-0894 (EXO). The procedure used was based on that of Hokstad *et al.* (1993).

Baseline burns. The limits to ignition imposed by evaporation and emulsion formation were determined for each oil by conducting a series of baseline burns. These tests also measured the burning characteristics of water-free and emulsified slicks of the fresh and and weathered crude oils. Beginning with the fresh oil, the water content of the emulsion to be tested was increased stepwise (from 0 to 25, 33, 50, and finally 60% water). This process was then repeated with the weathered oil samples.

The burns were conducted in a wave tank measuring $11 \times 1.2 \times 1.2$ m (L × W × H) that was filled with water to a depth of 85 cm. The air and water temperatures were maintained as close to 20°C as possible. The oil or emulsion was contained in a 40-cm diameter, steel ring, supported by a steel frame that rested on the bottom of the tank. For each test, 2.5 L of emulsion was used, which resulted in a 2-cm thick slick. Emulsions were prepared just prior to each test by recirculating the appropriate volumes of crude oil and water through a small gear pump.

The system of choice for igniting crude oil slicks is the Heli-torch, which uses gelled gasoline for fuel. To simulate this source of ignition, 40 to 50 g of gelled gasoline were used to start the baseline burns.

The parameters measured for the baseline burns included: initial mass and volume of the oil or emulsion; mass of the burn residue; air and water temperatures; flame and oil or emulsion slick temperatures; preheat time (time from ignition of gelled gasoline to initial spreading of flame); ignition time (time from ignition of gelled gasoline to complete ignition of slick surface); time to intense burn (time to the beginning of the vigorous burn phase); and time to extinction of slick. The efficiency and rate of each burn were calculated.

Burns with emulsion breakers. Emulsion breaker burn tests were conducted on emulsions that were determined to be not ignitable due to their water content and/or evaporation in the baseline burn tests. The objective was to determine if the addition of emulsion breaker would promote the ignition of the slicks, and what effect it would have on the burning characteristics of the oils. The most effective chemical, as determined from the emulsion breaker effectiveness test was used.

Burns in waves. Burn tests in waves were conducted to determine how the waves affected the ignition and burn characteristics of each of the oils. A 40-cm diameter, floating containment ring was used for these tests. The waves were produced by a paddle-board wave generator, located at one end of the tank. If the oil was amenable to the use of emulsion breakers with burning, further emulsion breaker burns were conducted in waves.

Residue-behaviour burns. Burns were conducted with 5- and 10-cm-thick slicks of the fresh crude oils, and the residues collected. After cooling, the density of the residues was determined and compared to that of fresh and salt water to see if the residue would float or sink.

Results

The test results are summarised in Table 1.

Amoco High Island. Amoco High Island (AHI) crude oil is produced by Amoco Corporation in the Texas sector of the Gulf of Mexico. AHI is a light crude oil (density of 0.815 g/cm^3 at 20°C), resembling a condensate in many respects, with a low viscosity and density, and a high volatility. AHI was the lightest of the oils tested. Amoco High Island crude oil is an excellent candidate for *in situ* burning. The test slicks were easy to ignite, even at high degrees of evaporation and with high percentages of emulsified water. The emulsified slicks did not require emulsion breaker for ignition and the residue of the thick test burn of AHI did not sink.

Carpinteria. Carpinteria is produced by Torch Operating Company in California. It is a medium crude oil (density of 0.910 g/cm^3 at 20°C). Based on the results of the test burns, *in situ* burning would only be suitable for Carpinteria crude oil if the response could be initiated before the oil emulsifies. For the test burns, evaporation did not seem to hinder ignition, but an emulsified water content greater than 25% prevented it. The Alcopol did not significantly enhance the ignition of the emulsified slicks. The residues of the thick test burns of Carpinteria would have sunk in salt water as they cooled.

Green Canyon Block 65. Green Canyon Block 65 (Green Canyon) is produced by Shell Offshore Inc. in the Gulf of Mexico. It is a medium crude oil (density of 0.880 g/cm^3 at 20°C). Based on the results of the test burns, *in situ* burning would only be suitable for Green Canyon crude oil if the response could be initiated before the oil emulsifies. Evaporation did not seem to hinder ignition of the test burns, but an emulsified water content greater than 25% prevented it. The Alcopol did not significantly enhance the ignition of the emulsified slicks. The residues of the thick test burns of Green Canyon would have sunk in salt water as they cooled.

Santa Clara. Santa Clara crude oil is produced by Chevron U.S.A., in California. It is a heavy, waxy crude oil (density of 0.932 g/cm^3 at 20°C), characterised by a very strong sulphur smell. Based on the test burn results, *in situ* burning would only be suitable for Santa Clara crude oil if the burn could be initiated before the oil emulsifies. Evaporation did not hinder ignition of the test slicks, but an emulsified water content greater than 25% prevented it. Alcopol did not significantly enhance ignition of the emulsified test slicks. The residues of the thick test burns of Santa Clara would have sunk in salt water as they cooled.

Santa Ynez. Santa Ynez is produced by Exxon U.S.A. in California. It is a heavy crude oil (density of 0.955 g/cm^3 at 20°C), characterised by a strong sulphur smell, and was the heaviest oil tested. Based on the results of the test burns, *in situ* burning would

Table 1. Summary of test results.

Crude oil	Amenable to *in situ* burning?	Could residue sink?	Forms emulsion?	Best emulsion breaker	Breaker promotes burning?
Amoco High Island	Yes	Unlikely	When highly weathered	All worked well	Yes
Carpinteria	If initiated emulsification	Possible	When fresh	Alcopol	No
Green Canyon	If initiated emulsification	Possible	When fresh	Alcopol	No
Santa Clara	If initiated emulsification	Likely	When fresh	All worked poorly	No
Santa Ynez	No	Unknown	When fresh	All worked poorly	No
West Delta	Yes	Likely	When fresh	All worked well	Yes

not be a suitable response for spills of Santa Ynez crude oil. The sample that was received had a water content of about 30%, right out of the drum and could not be ignited even when fresh. The sample must have been taken before the de-watering stage of the refining and production process. It would be worthwhile to obtain de-watered sample and conduct the same *in situ* burning suitability tests. It is possible that the de-watered Santa Ynez would be better suited to *in situ* burning.

West Delta Block 30. West Delta Block 30 (West Delta) crude oil is produced by Exxon U.S.A. in the Louisiana sector of the Gulf of Mexico. It is a medium crude oil (density of 0.915 g/cm^3 at 20□C). Based on the results of the test burns, *in situ* burning would be a suitable response option for spills of West Delta crude oil. EXO 0894 was successful in promoting the ignition of emulsified test slicks, and could potentially be used to extend the *window-of-opportunity* for burning if the oil was emulsified. The residues of the thick test burns of West Delta sank as they cooled.

Conclusions and recommendations

The stability of a water-in-oil emulsion and its response to emulsion breakers is highly dependent on the properties of the oil. Only three of the more widely available emulsion breakers were tested on the oils in this study. It is likely that there are other emulsion breakers that would perform as well or better on some of the oils. It would be worthwhile to pursue testing with other emulsion breakers for those oils that were difficult to break (i.e., Carpinteria, Green Canyon Block 65, Santa Clara, and Santa Ynez).

This study has shown that *in situ* burning is not a suitable response option for all oils. Thus, it is important that this work be continued and other oils be tested to establish a catalogue of oils and their *in situ* burning properties. This must be done before in situ burning can be considered for use at an actual spill.

For these six OCS crude oils, the information required now exists to make an informed decision regarding the window-of-opportunity for various response options.

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