IN-SITU BURNING OF ORIMULSION: SMALL-SCALE BURNS

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ABSTRACT: *Orimulsion is a heavy bitumen dispersed into water with a surfactant. In general, in-situ burning has not been considered as a countermeasure for Orimulsion because of the nature of Orimulsion and the perception that the product could not be ignited. If it could be ignited, then combustion may not be sustained. This study examined the feasibility of burning Orimulsion at three small laboratory scales. Tests were conducted on three scales or diameters of approximately 5 cm, 10 cm, and 50 cm. Burning at the smallest scale was conducted in a Cleveland Open Cup apparatus, which was run in standard mode. A special pan was built for larger-scale burns. All tests were conducted on saltwater which resulted in the bitumen separating from the water in the Orimulsion. The Cleveland Open Cup apparatus was used to determine whether sufficient vapours could be generated to begin combustion. In 2 burns out of 9, limited burning of vapours was started. The same apparatus was also used to measure whether sustained flame impingement would result in successful combustion. This latter experiment was also successful in most cases. The larger scale combustion tests were conducted in a special pan and were ignited using diesel fuel as a primer. In all cases, quantitative removal of Orimulsion was achieved, although re-ignition was required in some burns. Orimulsion burns with frequent mini-explosions of entrained water droplets still in the bitumen. Some of these mini-explosions were large enough to extinguish the flame, if the burn area was not large enough. This did not occur on large-scale burns. Thus the potential for successful burning increases with the size of the burn. The amount of diesel ignitor required was found to be about 1 mm in thickness in the given starting area. Large-scale burns were ignited from an area less than 30% of the total area.*

Introduction

In-situ burning is recognized as a viable alternative to mechanical methods for cleaning up oil spills on water. When performed under optimal conditions, in-situ burning can rapidly reduce the volume of spilled oil and eliminate the need to collect, store, transport, and dispose of recovered oil. In-situ burning can shorten the response time to an oil spill, thus reducing the chances that the oil will spread on the water surface and thereby protecting aquatic biota. Such rapid removal of oil can also prevent the oil from reaching shorelines, which are difficult to clean and where the greatest environmental damage caused by oil spills occurs.

Orimulsion is a surfactant-stabilized, oil-in-water emulsion of 70% bitumen in 30% water (Bitor, 1996). Because of its unique composition, its behaviour when spilled is very different from that of conventional fuel oils. The base bitumen has a density of 1.0202 g/mL at 15°C. In the absence of circulation in the water column, the droplets of bitumen will float in seawater with a typical density of 1.022 g/mL, but will slowly sink in waters of less density. Questions have long arisen over countermeasures to Orimulsion spills. In general, in-situ burning has not been considered because of the nature of Orimulsion and the perception that the product could not be ignited.

The fundamentals of in-situ burning are similar to that of any fire, namely that fuel, oxygen, and an ignition source are required (Fingas and Punt, 2000). Fuel is provided by the vaporization of oil. The vaporization of the oil must be sufficient to yield steady-state burning, that is one in which the amount of oil vaporized is about the same as that consumed by the fire. For in-situ fires, the rule-of-thumb is that the slick must be at least 2 to 3 mm (0.08 to 0.12 in) thick for ignition to start. It should be noted that the actual physical minimum is the minimum amount of vapours to sustain combustion which relates poorly to the slick thickness. Once an oil slick is burning, it burns at a rate of about 3.75 mm (0.15 in) per minute. This rate is limited by the amount of oxygen available and the heat radiated back to the oil. The oil burn rate is a function of the area covered by the oil because of the physics of a burn, that is, the volume does not affect the amount burned in a given time, only the area burned.

The 'steady-state' burning implies that the conditions noted above are met (Fingas and Punt, 2000). If not enough vapours are produced, the fire will either not start or will be quickly extinguished. The amount of vapours produced is dependent on the amount of heat radiated back to the oil. This has been estimated to be about 2 to 3% of the heat from a fire. If the oil slick is too thin, some of this heat is conducted to the water layer below it. Since most oils have the same insulation factor, most slicks must be at least 2 mm (0.08 in) thick to be ignited and yield a steady-state burn. This does not consider the amount of vapour necessary to ignite. Once burning, the heat radiated back to the slick and the insulation are usually sufficient to allow combustion down to about 1 mm (0.04 in) of oil. In practice, greater thicknesses are observed to be the rule as noted above. This is because wind and other factors affect the ignition and maintenance of a steady burn.

Historically, it was thought that the burn rates depended on scale size. The early work proposed a cyclic relationship between burn rate and pan diameter (Fingas and Punt, 2000). This theory was based on propositions about flame characteristics in the laminar flow region [0 to 10 cm (0 to 4 in)], to the transition zone [10 to 100 cm (4 to 39 in)], through to the turbulent flow regime [>100 cm (>39 in)]. This theory may be very relevant to these tests.

Experimental

Three burn configurations were used. Details of apparatuses used are given in Table 1 and the apparatuses are illustrated in Figures 1 and 2. The smaller apparatus is a standard flash and flame point tester, the Cleveland Open Cup device. This is supplied with a gas flame device which can be used in a standard manner to measure flash or flame point. It was used here to ignite the Orimulsion. The second device used was a burn pan which was originally constructed to burn oils to produce residue for toxicity testing. The outside and inside of the pan were used separately to yield different areas of burning.

Two types of ignition were used in these tests - ignition by a small flame as supplied with the Cleveland Open Cup or by adding diesel fuel and igniting it with a lighter. The ignition by the small flame tests whether sufficient vapours can be created to start ignition.

Before each burn, saltwater was placed into the burn apparatus so the oil added would be close to the top of the apparatus. The Orimulsion was added by volume, however, the actual weight added was used for all the calculations. The calculations were carried out presuming that 30% of the Orimulsion was water as described in previous analyses (Jokuty *et al.*, 1999). The Orimulsion was left to stand for the prescribed time to allow the bitumen to separate from the product.

For the Cleveland Open Cup apparatus, the methane flame was lit and then put to the side of the cup. The events were recorded by time. Two types of burning occurred in the Cleveland Open Cup apparatus - a partial burn under the flame and a burn that was self-sustaining and would spread over the entire cup. The time of both partial and full burns was recorded. For some burns in the Cleveland Open Cup and all burns in the larger pans, ignition was accomplished using diesel fuel and ignited with a small piece of paper towel as a wick and a butane lighter. The weight of the diesel used as igniter was recorded. The weight of the paper towel was less than 5% of the diesel fuel and was subsequently not recorded. The time to ignition and the time to full pan ignition was recorded. If the burn went out due to the explosive nature of the bursting of water bubbles in the oil, the bitumen was re-ignited using the same techniques.

The area of the particular burn was noted (e.g., ½ pan, full pan, etc.) and times recorded. This enables calculation of the actual burn rate, compensating for the partial area burns that sometimes occurred.

At the end of the burn, all remaining residues were removed using a tweezer and patches of oil sorbent. The sorbent was weighed to determine the amount of oil remaining. The apparatus and glassware were cleaned with dichloromethane and another run started.

Table 1. Apparatuses used to test Orimulation burning.

Table 1	Apparatuses Used to Test Orimulsion Burning		
Description	**Dimensions**	**Burn Area (cm^2)**	**Water under Oil**
Cleveland Open Cup Apparatus	6.2 cm diameter	30.2	40 mL
Burn pan	9.8 cm square	96	900 mL
Outside burn pan	30 cm square minus centre above	780	1200 mL

Figure 1. The Cleveland Open Cup apparatus used for small-scale burning.

Figure 2. The burn pan used for larger-scale burns.

The first three runs in the Cleveland Open Cup used Alberta Sweet Mixed Blend (ASMB) oil to ensure that results similar to past tests would be achieved (Nadeau, 2000).

Results

The results of the tests are summarized in Table 2. This table includes the following data: column 1, the date of the experiment; column 2, the description of the test and sometimes the variables studied; column 3, oil weathering and the time that the oil was left to weather in the apparatus and on the saltwater; column 4, the type of ignition applied; column 5, the ignition delay or time to the first sustained combustion or in the case of the Cleveland Open Cup, the time until Orimulsion burned as recognized by the popping of the entrained water; column 6, the initial oil thickness, calculated from the weight of the oil and the area; column 7, the final oil thickness calculated from the weight of the residual material; column 8, the thickness of the oil that was burned as calculated from the difference of column 6 and 7; column 9, the burning time or the time length of the burn; column 10, the burning rate which is calculated from the previous values; and column 11, the burn efficiency. If there were significant times that the burn covered only a partial area, this correction was applied to the burn rate. In other cases, a separate row was created to show the corrected value.

The three ASMB runs showed data consistent with past studies (Nadeau, 2000). These data also provide an interesting comparison to the Orimulsion which follows later. For the same size scale, ASMB burns more efficiently, as would be expected, although it burns to a greater final thickness. Other data are somewhat similar to the Orimulsion case.

The burn rates shown in Table 2 are typically between 0.6 and 1.7 mm/min, which is lower than the stated typical burn rate of 3.75 mm/min for open pool burning, but very typical of the burn rate for small scales. Table 2 shows that the average burn efficiency rose with increasing area. It averaged 28% in the Cleveland Open Cup, 38% in the centre pan, and 67% in the largest area. This would be expected as the wall effects decrease with pan area. The burn rates were very similar, averaging 1.1, 1.7, and 0.8 for the three sizes of burn. The final oil thicknesses were similar for the first two areas of burns, 0.4 and 0.49 averages. The final thickness for the largest- scale burn was only 0.17 mm.

Discussion

The observations of the attempted ignitions and the actual burning are instructive. Firstly, Orimulsion (e.g., bitumen) retains a significant amount of water in various size droplets. When burning, these droplets explode into vapour, making an audible pop and a visible streak of light, not unlike a miniature fireworks. If these explosions are large enough, they can extinguish the fire, especially if the burn pan is small. Figure 3 illustrates the exploding water droplets. This phenomena of micro-explosions has been described in the literature (Ocampo-Barrera *et al.*, 2001).

Table 2. Results of the Orimulsion burning experiments.

Table 2	Results of the Orimulsion Burning Experiments									
Experiment Date	Description	Oil Weathering	Ignition Type	Ignition Delay	Initial Oil Thickness (mm)	Final Oil Thickness (mm)	Actual Burning Oil Thickness (mm)	Burning Time (min)	Burning Rate (mm/min)	Burn Efficiency (%)
ASMB Preliminary Runs										
Aug-24	Initial test	fresh	flash flame	instant	2	0.89	1.11	1.70	0.70	56
Aug-24	Initial test	fresh	flash flame	instant	4	1.38	2.62	5.30	0.50	66
Aug-24	Initial test	fresh	flash flame	instant	6	1.83	4.17	7.90	0.50	70
Aug-24	Initial test	fresh	flash flame	instant	8	2.87	5.13	9.40	0.50	64
Cleveland Open Cup - Orimulsion Runs					Average	1.74			0.6	64
Aug-31	First run plus diesel	fresh	flash flame	2 min+dies	6.7	0.63	6.07	15.00	3.20	5
Sept 4-5	Second run	16 hours	flash flame	~2 hours	4.4	0.39	4.01	60.10	0.50	12
Sept 5-6	Third run - some perlite	42 hours	flash flame	~2hours	5.8	0.32	5.48	120.80	0.40	45
Sep-10	Fourth run	93 hours	flash flame	22:00	6	0.4	5.60	80.30	0.60	33
Sep-11	Fifth run	20 hours	flash flame	~2 hours	6.8	0.47	6.33	180.00	0.40	30
Sep-12	Sixth run	18 hours	flash flame - H	8:00	4.9	0.33	4.57	8.00	1.10	33
Sep-14	Seventh run	48 hours	flash flame - H	21:00	5.6	0.44	5.16	7.10	1.50	21
Oct-23	Eighth run	month	diesel - 9 g	1 min	4.9	0.25	4.65	4.30	1.10	48
Burn Pan Centre Runs					Average	0.4			1.1	28
Sep-10	Try with sterno, diesel	93 hours	6.5 g diesel	1:03	4.4	0.15	4.25	2.80	1.50	66
Sep-11	Diesel igniter	20 hours	13 g diesel	3:35	6.3	0.44	5.86	2.20	2.70	29
Sep-12	Diesel igniter	18 hours	6.5 g diesel	2:00	6.8	0.58	6.22	2.10	3.00	14
Sep-14	Diesel igniter	48 hours	5.9 g diesel	3:00	7.1	0.67	6.43	2.70	2.40	6
	Diesel igniter	48 hours	10 g diesel	7:00	6.1	0.57	5.53	6.50	0.90	6
	Total value	48 hours	16 g diesel	3:00	7.1	0.57	6.53	9.20	0.70	19
Sep-17	Total value	70 hours	13 g dies layer	3:00	6.9	0.25	6.65	7.80	0.90	63
	Correcting for partial pan		1.4 mm diesel		6.9	0.25	6.65	6.80	1.00	63
Sep-18	Diesel igniter, larger quan	24 hours	3 ignites, ~ 40 g diesel	~1	9.7	0.68	9.02	4.60	2.00	30
Sep-19	Large quantity	24 hours	3 ignites, ~ 20 g diesel	~1	14.1	0.75	13.35	8.30	1.60	47
Oct-17	Large quantity/long weath	672	2 ignites - 27 g,12g	~2	18.2	0.45	17.75	7.80	2.30	75
Burn Pan Outer Rim Runs					Average	0.49			1.7	38
Oct-19	Large pan burn	48 hours	85 g diesel	5	6.5	0.19	6.31	5.70	1.10	70
Oct-23	Large quantity	130 hours	2 ignites - 60 g, 91 g	1 min	4.5	0.16	4.34	4.30	1.00	65
	First part of above		first ignite	never	4.9	0.17	4.73	23.10		66
			combined	combined	4.5	0.16	4.34	5.10	0.90	65
					Average	0.17			0.8	67

Secondly, re-ignitions of the burns were possible if the burns were extinguished by this popping. Re-ignition was readily accomplished by using diesel as for the first ignition.

Thirdly, ignition of the burn itself was readily accomplished using about 1 mm or more of diesel fuel. The diesel fuel was ignited by placing a small wick of paper towel into it and lighting with a regular butane lighter. The use of pearlite and vermiculite as wicking agents was tried without success. The ignition of Orimulsion using only a flame was tried in the Cleveland Open Cup and only worked in 2 out of 8 tries. In these two cases, ignition did not occur until after two hours. The use of sterno was also attempted, however, the sterno was heavier than the oil and water and sank before ignition occurred. Finally, it was noted that, once started, the fires burned vigorously and produced very large flames. Figure 4 shows the flames of the largest burn area used in this experiment. These flames would be expected to be self-sustaining in larger areas and may not be subject to extinguishing because of water contained in the bitumen.

Figure 3. A medium-sized burn showing a number of 'explosions' of water droplets which appear like small comets in this photograph.

Figure 4. A large-scale burn, the flame is about one metre in height.

A correlation was attempted among the various quantitative parameters measured (Fingas, 2002). Two correlations were significant (r^2 above 0.5) - that between efficiency and weathering and that between igniter amount and number of ignites. The last correlation is not useful since it is an obvious connection. The weathering and efficiency are correlated somewhat. This correlation was not apparent during the tests as it seemed that those oils that were weathered and separated for one day appeared to burn as well as those that weathered for longer periods. Thus, it appears that extra separation time does improve efficiency although this is not observed visually.

The method of ignition is very important in the case of Orimulsion. The fact that the flame in the Cleveland Open Cup usually did not result in sufficient vapours to start a pan-wide burn, implies that this form of ignition would not work in open-burn scenarios. In addition to the techniques noted above, ignition was tried using diesel fuel in small weighing boats. This was marginally successful as well. A simple application of 1 mm of diesel fuel over an area of about 30 cm^2 resulted in flame spreading over the entire pool.

It is suspected that the role of the diesel is two-fold, that of an igniter and a solvent. As a solvent, it would dissolve the bitumen and result in better separation of water entrained in the bitumen. It is questionable whether Orimulsion could be ignited using a Helitorch dispensing gelled, burning fuel, although this might be tested in a confined pool.

The thickness of oil remaining after burning is also given in Table 2. Many of the thicknesses are less than the historically suggested 1 mm. Orimulsion burns left only about 0.17 mm (.007 in) overall. However, it should be noted that, while continuous slicks were not left, herding during the burn generally drove residual material into one or two areas of the pans.

Conclusions

Once separated into bitumen and water, Orimulsion can be ignited on a small scale and will burn with useful efficiency. The separation time after the Orimulsion is spilled into the water is not crucial to ignition, but longer times improve the burn efficiency somewhat. Separation times of at least 4 hours were used in this study. Ignition of the Orimulsion is best accomplished by adding a primer such as diesel fuel. The application of a flame alone does not appear to have potential for ignition.

Residual water contained in the bitumen explodes in the fire. Such explosions can extinguish a small fire. These appeared to have a lesser effect on the larger scales of burns in this series of tests and may not have a serious effect on full-scale burns.

The efficiency of burning Orimulsion is comparable to any other fuel. The burning process herded residual oil to one or more areas so that on average, very little product was left on the surface.

These small-scale results show that there is potential for using in-situ burning to clean up Orimulsion spills.

Biography

Merv Fingas is Chief of the Emergencies Science and Technology Division in Environment Canada. Dr. Fingas' speciality is research in the analysis and behaviour of oil spills in the environment. He manages 15 other scientists and staff studying various aspects of oil and chemical spills. He has devoted the last 29 years of his life to spill research and has over 500 papers and publications in the field.

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