In-Situ Burning of Orimulsion: Small Scale Burns

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Abstract

Burn tests were conducted on three scales or diameters of approximately 5 cm, 10 cm and 50 cm. Burning at the small 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 salt water which result in the separation of the bitumen from the water in the Orimulsion.

The Cleveland Open Cup apparatus was used to test if sufficient vapours could be generated to begin combustion. In 2 burns out of 8, limited burning of vapours was started. The same apparatus was also used to measure if 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, however in some burns, re-ignition was required. Orimulsion burns with frequent mini-explosions of entrained water droplets still in the bitumen. Some of these mini-explosions are large enough to extinguish the flame, if it is not large enough. This did not occur on large-scale burns. Thus the potential for successful burning increases with size. The amount of diesel ignitor required was found to be about 1mm in thickness in the given starting area. Large scale burns were ignited from an area less than 30% of the total area.

1 Introduction

In-situ burning is recognized as a viable alternative to mechanical methods for cleaning up oil spills on water. When performed properly and under the right 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 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-situ burning has largely not been considered because of the nature of Orimulsion and because the perception that the product could not be ignited. If it could be ignited, then combustion may not be sustained. This study examines the feasibility of burning Orimulsion, that is the bitumen in Orimulsion, at three small laboratory scales.

The fundamentals of in-situ burning are similar to that of any fire, namely that fuel, oxygen, and an ignition source are required (Fingas *et al.*, 2000). Fuel is provided by the vaporization of oil. The vaporization of the oil must be sufficient to yield a steady-state burning, that is one in which the amount of vaporization 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 a minimum 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 *et al.*, 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 0.2 mm thick to be ignited and yield a steady-state burn. This is 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 0.2 mm 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 *et al.*, 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)]. Since most tests and actual burns are greater than 100 cm (39 in) in diameter, this theory may not be relevant to in-situ burning. This may however be very relevant to these tests. Studies conducted in the last ten years have shown that the type of oil is relatively unimportant in determining how an oil ignites and burns. However, heavy oils require longer heating times and a hotter flame to ignite than lighter oils. Earlier studies appeared to indicate that heavier oils and oils with water content required greater thickness to ignite, however, recent testing has shown this to be incorrect (Fingas *et al.*, 2000).

Burn efficiency is the initial volume of oil before burning, less the volume remaining as residue, divided by the initial volume of the oil. The amount of soot produced is usually ignored in calculating burn efficiency. Efficiency is largely a function of oil thickness. For example, a slick of 2 mm (0.08 in) burning down to 1 mm (0.04 in) yields a maximum efficiency of 50%. A pool of oil 20 mm (0.8 in) thick burns to approximately 1 mm (0.04 in), yielding an efficiency of about 95%. Current research has shown that other factors such as oil type and low water content only marginally affect efficiency.

Most, if not all, oils will burn on water if they can be ignited. Except for light refined products, different types of oils have not shown significant differences in burning behaviour. Weathered oil requires a longer ignition time and somewhat higher ignition temperature (Fingas *et al.*, 2000).

2 Experimental

Three burn configurations were used. Details on these are given in Table 1. These devices are illustrated in Figures 1 and 2. The smaller apparatus is a standard flash and flame point tester, the Cleveland Open Cup device. This device is supplied with a gas flame device which can be used in a standard manner to measure flash or flame point. As used here, it was used 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 insides of the pan were used separately to yield different areas of 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

Two types of ignition were used in these tests, ignition by a small flame as supplied with the Cleveland Open Cup, or by the addition of diesel fuel and the ignition of this using a lighter. The ignition by the small flames tests if sufficient vapours can be created by the heat of the small flame to start ignition.

The procedure before each burn was to place salt water into the burn apparatus, so that the amount of oil added would be near the top of the apparatus. The Orimulsion was added by noting the volume, however the 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 for the separation of the bitumen 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. This was noted in the time records. For some burns in the Cleveland Open Cup and all burns in the larger pans, ignition was accomplished using diesel fuel and igniting this using 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 not subsequently 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 (eg. ½ pan, full pan, etc.) and times

Figure 1 The Cleveland Open Cup Apparatus Used for Small-scale Burning

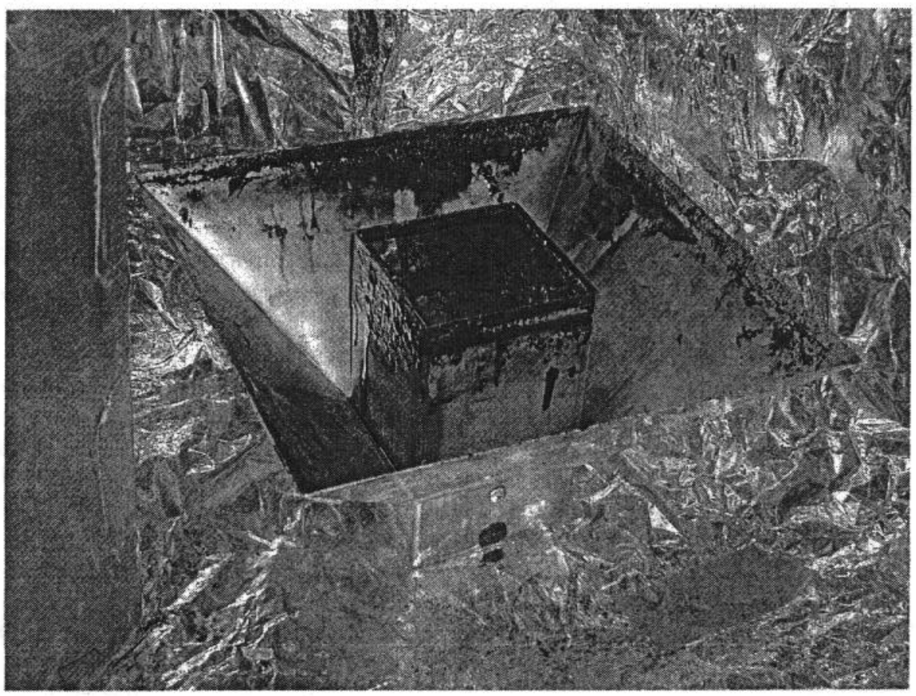

Figure 2 The Burn Pan Used for Larger-scale Burns

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. These were then weighed to yield measurement of the oil remaining. The apparatus and glassware were cleaned with dichloromethane and another run started.

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

3 Results of the Burns

Results are summarized in Table 2. This table gives the following data: column 1, the date of the experiment; column 2, the description of the test and sometimes the variables studied; oil weathering, the time that the oil was left to weather in the apparatus and on the salt water; 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 8, the burning time or the time length of the burn; Column 9, burning rate which is calculated from the previous values; and column 10, 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 correct 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, however, 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/sec, which is lower than the stated typical burn rate of 3.75 mm/sec for open pool burning. Small scale burns such as these will show this lower burn rate.

The table 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, 1.1, 1.7 and 0.8 averages 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.

4 Discussion

The observations of the burning and the ignitions attempts are very instructive. First, Orimulsion (eg. bitumen) retains a significant amount of water in various size droplets. When burning these droplets explode into vapour and this makes an audible pop and a visible streak of light, not unlike a miniature fire works. If these explosions are large enough, they can extinguish the fire, especially if the scale size is small. Figure 3 illustrates the exploding water droplets. This phenomena

Table 2 Results of the Orimulsion Burning Experiments

Experiment Date	Description	Oil Weathering	Ignition type	Ignition Delay	Initial Oil Thickness (mm) h	Final Oil Thickness (mm) hf	Actual Burning Oil Thickness (mm) h*actual = h-hf	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 Center Runs					**Average**	**0.4**			**1.1**	**28**
Sep-10	try with sterno, diesel	93 hours	6.5g diesel	1:03	4.4	0.15	4.25	2.80	1.50	66
Sep-11	diesel igniter	20 hours	13g diesel	3:35	6.3	0.44	5.86	2.20	2.70	29
Sep-12	diesel igniter	18 hours	6.5g diesel	2:00	6.8	0.58	6.22	2.10	3.00	14
Sep-14	diesel igniter	48 hours	5.9g 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	16g diesel	3:00	7.1	0.57	6.53	9.20	0.70	19
Sep-17	total value	70 hours	13g 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 - 27g,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 - 60g,91g	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**

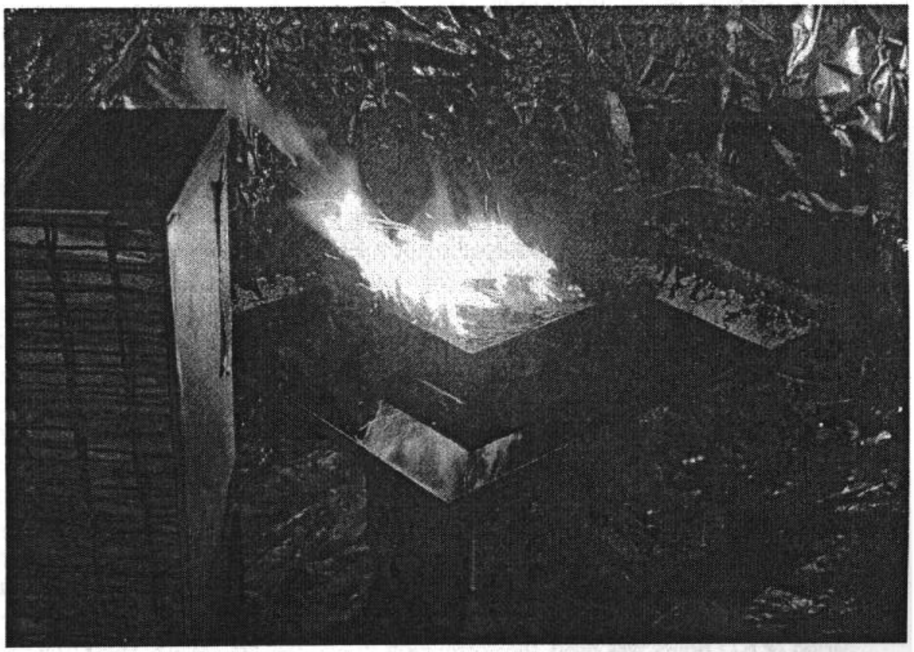

Figure 3 A Medium-sized Burn Showing a Number of 'Explosions' of Water Droplets Which Appear Like Small Comets in This Photograph

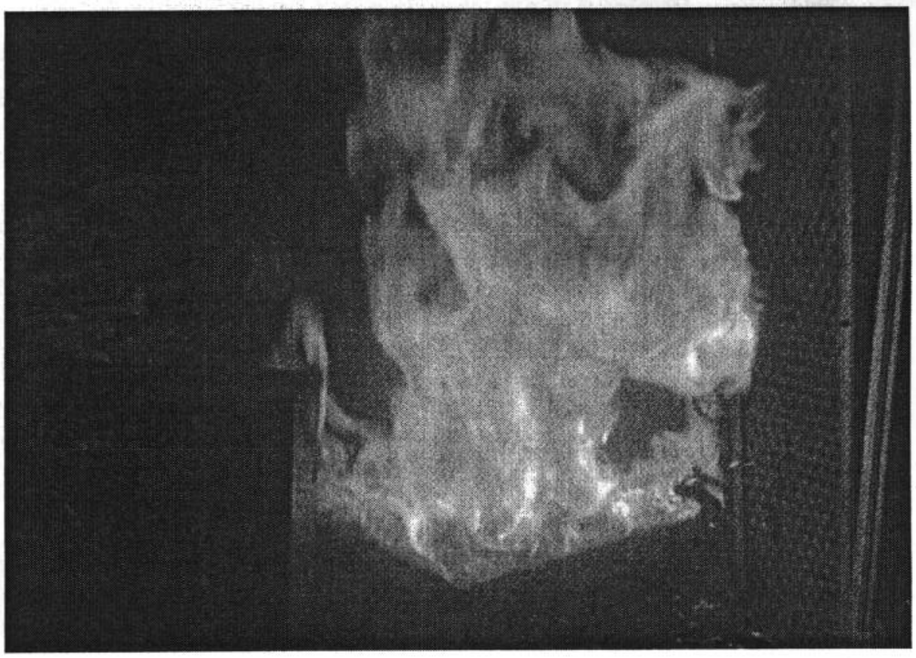

Figure 4 A Large-scale Burn, The Flame Is About One Metre in Length

of micro-explosions has been described in the literature (Ocampa-Barrera *et al.*, 2001). Second, 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 burn. Third, ignition of the burn itself was readily accomplished using about 1mm or more of diesel fuel. The diesel fuel can be ignited by placing a small wick of paper towel into it and lighting with a regular butane lighter. The use of pearlite and vermiculate as wicking agents was tried and this without success. The ignition of Orimulsion using only a flame was tried in the Cleveland Open Cup and did not work except in 2 cases 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 the fires, once started, 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.

A correlation was attempted among the various quantitative parameters measured. This is summarized in Table 3. There are two sets of correlations which are significant (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 somewhat related as shown by the correlation. This correlation was not apparent during the tests as it seemed that those oils which were weathered and separated for one day appeared to burn as well as those for longer periods. However, even removing the test where a weathering period of 672 hours was used, the correlation still stands. Thus, it appears that extra separation time does improve efficiency although this is not observed visually.

Table 3 **Correlation of Variables Related to Orimulsion Burning**

	weathering	igniter amount	number of ignites	initial oil thickness	ignition delay time
Efficiency	0.65	low	0.2	0.3	0.2
weathering			0.25		very low
igniter amount			0.6		0.2
number of ignites				0.4	0.1
initial oil thickness					0.15

The method of ignition is very important in the case of Orimulsion. The fact that most often the flame in the Cleveland Open Cup did not result in sufficient vapours to start a pan-wide burn, implies that this form of ignition would not work in open 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 doubtful whether Orimulsion could be ignited using a Helitorch dispensing gelled, burning fuel. Although this might be tested in a confined pool.

The thickness after burning are interesting. Table 2 shows that many of the thicknesses are less than the historically-suggested 1 mm. Orimulsion burns left only about 0.17 mm overall. However, it should be noted that continuous slicks were not left, but herding during the burn generally drove residual material into one or two areas of the pans.

The scale of the tests here are small and large scale (multi-metre) tests are recommended to confirm these laboratory results. Many of the factors noted above may be different in large scale burns.

Further, alternative means to ignite the bitumen such as the use of more sophisticated incendiary devices also might be investigated.

5 Conclusions

Orimulsion once separated into bitumen and water can be ignited on small scale and will burn with useful efficiency. Ignition of the Orimulsion is best accomplished with addition of 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 as an average, very little product was left on the surface.

These small scale results show that there is potential for Orimulsion in-situ burning. Larger scale tests should be conducted to confirm this potential and to measure the same parameters as were measured here.

6 Acknowledgements

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