IN SITU BURNING WAVE TANK TESTS AT PRUDHOE BAY, ALASKA[1]

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ABSTRACT: *A series of research burns was carried out in the fall of 1997 in Prudhoe Bay, Alaska, in a new wave tank purpose-built for oil spill research and training. These tests were the culmination of a 3-year research project by Alaska Clean Seas (ACS) and S.L. Ross into the effects of oil type, emulsification, temperature and waves on in situ burning in Arctic open water conditions. The 1997 experimental program involved conducting mid-scale burns with fresh and weathered Alaska North Slope (ANS) and Milne Pt. crude oils and emulsion slicks in waves, including tests involving the addition of emulsion breakers. Emulsion breakers are surface active chemicals which are added at very low dosages (1:500 to 1:5000) to petroleum emulsions to promote separation of the emulsion into discrete oil and water phases.*

Wave tank tests

A custom tank was commissioned for this project. It is of all-steel construction and was designed to be road-transportable. The tank, photographed at the ARCO Fire Training Ground in Prudhoe Bay where the tests were conducted, is shown in Figure 1. The inside dimensions of the tank are 12 m long × 2.4 m wide × 2.25 m high (40 ft × 8 ft × 7.4 ft). The tank was fitted with a simple, hydraulically-driven wave paddle at one end and passive, perforated-metal wave absorbers. The wave paddle was controlled by an electronic sine wave function generator system that regulated the flow of hydraulic fluid from the power pack to the cylinder. The frequency and amplitude of the movement of the cylinder (and thus the wave paddle) could be independently controlled from a panel mounted on the side of the tank.

A 1.7-metre (5’4") diameter burn ring was tethered loosely in the centre of the wave tank by wires attached to the sides. A full description of the test procedures and results may be found in the report (S.L. Ross, 1998). A total of 58 experimental burns were conducted, 31 with ANS crude and 27 with Milne Pt. crude. Several repeat burns with ANS crude were conducted. The water temperature in the tank ranged from 3 to 9°C (37 to 48°F) over the course of the tests; air temperatures ranged from 0 to 4°C (32 to 40°F). The wind speed ranged from 0.25 to 13 m/s (0.5 to 30 mph). Most tests were conducted in winds of 2 to 8 m/s (5 to 20 mph).

Figure 1. Wave tank on location in Prudhoe Bay.

Results

Alaska North Slope crude burns. Figure 2 shows the results of the burns conducted with 5, 10 and 20 mm thick slicks of fresh ANS crude in four wave conditions (steepness, or wave height/length, of: 0, 0.03, 0.05 or 0.06). All these test slicks were successfully initiated with a 120 mL (4 fl oz) gelled gas igniter. This data set is the only one that involved tests with a wave steepness of 0.06. Two test burns were attempted at this setting. This wave setting was found to set up a standing circular wave inside the burn ring that highly disturbed the oil slick. Figure 2a shows the calculated burn rate as a function of wave steepness. The deleterious effect of the standing wave at a steepness of 0.06 is clear. It appears that increased wave steepness slightly decreased burn rate. It was unusual that the 20 mm thick slick burned consistently slower than the 10 and 5 mm thick slicks. A repeat burn was conducted with the 20 mm thick slick to confirm this. Normally, the trend is for a slight increase in burn rate with increasing slick thickness. The burn rates for the 5 and 10 mm thick slicks in calm conditions are in the range of other data for crude oil *in situ* burn rates (e.g., Buist *et al*., 1994). Figure 2b shows the effect of wave steepness on the burn time. For the thinner slicks, there appears to have been little effect; however, for the 20-mm thick slicks, an increase in wave steepness increases

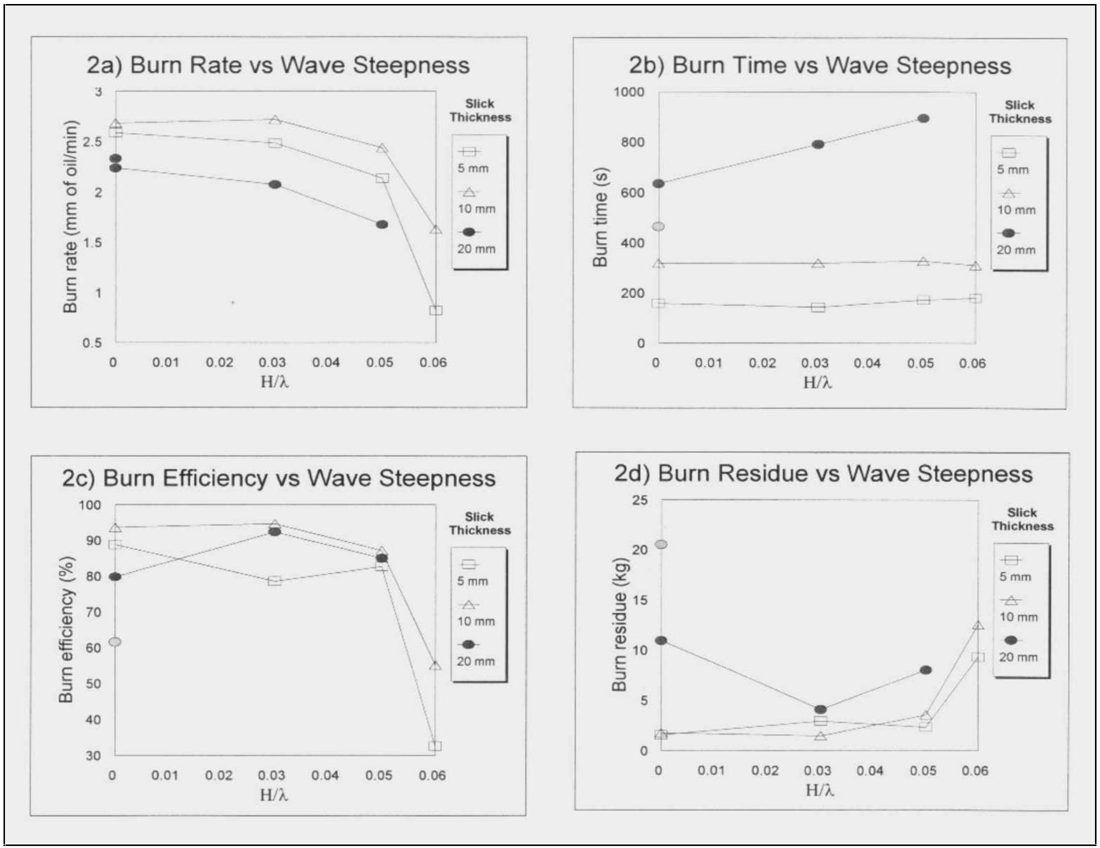

Figure 2. Mid-scale burns with fresh ANS in waves.

burn time. Figure 2c shows the effect of wave steepness on burn efficiency. Discounting the 0.06 wave steepness data points, there does not appear to be a discernible trend. The effect of the standing wave on the burn efficiency at a wave steepness of 0.06 is quite apparent; the increased slick disturbance caused a dramatic decrease in oil removal efficiency. Although there is considerable scatter in the data shown in Figure 2d there may be an increase in residue remaining with increasing wave steepness. The behaviour of the 20 mm thick slick was unusual; one test resulted in almost 21 kg of residue and an identical repeat test resulted in 11 kg of residue. Both of these are much higher than the expected 2 to 3 kg.

Similar results were obtained from the mid-scale test burns with 20.4% evaporated, unemulsified ANS crude slicks.

Emulsified ANS crude burns. Figure 3 shows the results for the test burns with water-in-oil emulsions of 20.4% evaporated ANS crude. All of these tests involved 20 mm thick slicks. It was during this series that it was discovered that the water being used to emulsify the oil was only brackish and the emulsions created were thus not fully stable. All of the 25% water emulsions were created with brackish water (10 ppt) as opposed to normal sea water (35 ppt). For the first 50% water emulsion burn the emulsion was not stable and was easily ignited (with only four gelled crude igniters). A repeat test was conducted with an emulsion made with 35 ppt salt water; this ultimately required 8 L (2 gallons) of fresh crude for ignition and burned sporadically with several instances of the fire dying down and then flaring back up. This was more typical behaviour for ANS emulsion fires (Buist *et al*., 1995). All subsequent tests (all the 50% and 60% emulsion burns shown on Figure 6-19 and all the Milne Pt. crude emulsion tests) were conducted with emulsions created with 35 ppt salt water. Samples of these emulsions taken just after their creation did not visually break over a 3-day period. All the ANS emulsion burns after the 50% water test in calm conditions required the application of EXO 0894 emulsion breaker, a 45-minute waiting period and 8 L (2 gallons) of fresh crude for successful ignition. The emulsion was manually mixed in, then allowed to work in low-energy waves for approximately 45 minutes.

Figure 3a shows the effect of wave steepness on the oil burning rate for the three emulsion water contents. The data point for the 50% water content test in high waves should be ignored; this resulted from the high dispersion rate of the treated slick causing a considerable amount of the slick to escape beneath the skirt of the burn ring. Although there is a lot of scatter in the data, there appears to be a trend of slightly increasing burn rate with increasing wave steepness. This indicates that something different is controlling the rate of oil burning in emulsions as compared to unemulsified oil slicks. This difference is probably the rate that oil separates from the emulsion to form a water-free slick on top of the emulsion.

Figure 3b shows the burn time as a function of wave steepness. Again discounting the 50% water data point in the high waves, there is a trend of decreasing burn time with increasing wave steepness. Figure 3c shows the effect of wave steepness on burn efficiency. Excluding the 50% water, high waves data point, there is little correlation. The oil removal efficiency for the 50% water slicks decreased and the removal efficiency for the 60% water slicks increased with increasing waves. Figure 3d shows similarly scattered data for the amount of residue remaining after each burn.

Milne Pt. crude oil burns. The results obtained from the tests involving water-free, fresh and weathered Milne Pt. crude were similar to those presented above for the ANS crude burns.

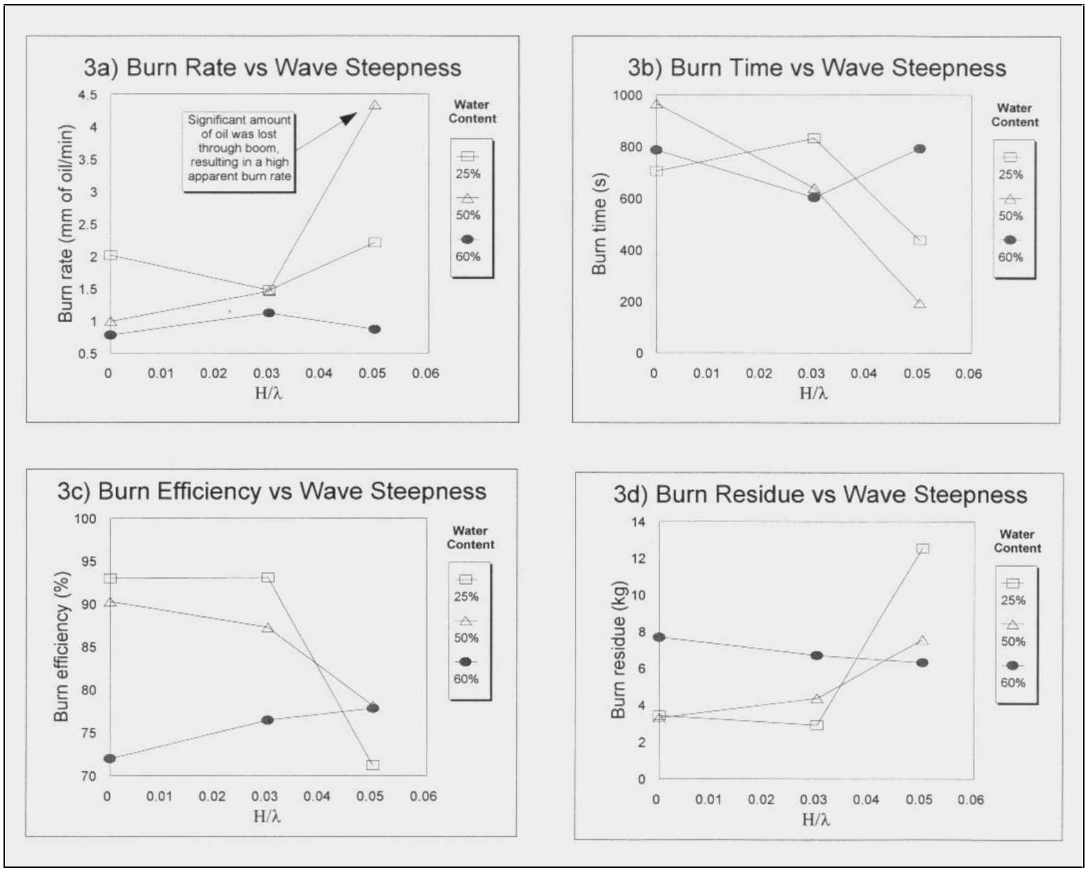

Figure 3. Mid-scale burns with emulsified ANS in waves (20 mm slicks).

Emulsified Milne Pt. crude burns. Figure 4 gives the results of the test burns with emulsions of Milne Pt. crude. All of these tests involved 20 mm thick slicks. All the emulsions were created with 35 ppt salt water. Samples of these emulsions taken just after they were created did not break over a 2-day observation period. Most of the emulsions were easily ignited with only a single gelled gas igniter; only the 60% water emulsions in waves required the more powerful ignition source of four gelled crude igniters. None of the emulsions required the application of the emulsion breaker to promote ignition. Figure 4a shows that there was little effect of wave steepness on burn rate of the emulsions. In the case of the mid-scale ANS emulsion burns there appeared to be an increase in burn rate with increasing wave steepness. The different behaviours for the two oils may relate to the different stability indices of the emulsions; the ANS emulsions required emulsion breaker to separate: the Milne Pt. emulsions would separate and burn with only the application of heat. This was apparent in observing the progress of the flame spread over the Milne Pt. emulsions. Comparing the burn rate of the Milne Pt. emulsions in calm conditions, the typical reduction in oil removal rate with increasing water content is apparent, as it was with the comparable ANS emulsion burns. Figure 4b shows the burn times as a function of wave steepness. The burn time does not appear to depend on the wave steepness. In comparison, the burn time for the equivalent burns with ANS emulsions decreased with wave steepness. Figure 4c presents the effect of waves on the emulsion burn efficiency. There is considerable scatter; however, there appears to be little or no effect, as was the case for the comparable ANS emulsion burns. The burn residue data in Figure 4d is too scattered to indicate any correlation of residue amount with wave steepness, as was the case for the ANS emulsions.

Conclusions

The mid-scale burn tests showed that larger oil and emulsion slicks of ANS and Milne Pt. crudes could be successfully burned in waves. Emulsified slicks of ANS crude with water contents greater than 25% required treatment with emulsion breakers and a period of settling for successful ignition and efficient burning.

A test slick of 60% water emulsion of weathered ANS crude was successfully burned after treatment with emulsion breakers in the highest waves tested, with an oil removal efficiency of 79%. A similar test slick of 60% water emulsion of weathered Milne Pt. crude was successfully burned in the highest waves tested, without the need for treatment with emulsion breakers, with an oil removal efficiency of 83%.

At this scale, increasing wave steepness (or wave energy) appeared to reduce both burn rates and burn efficiencies of the unemulsified oil slicks. For emulsified slicks, increasing wave steepness did not appear to appreciably affect the oil burning rates, but did reduce the oil removal efficiencies.

Comparing the results of previous lab-scale burns (Buist *et al.*, 1997; S.L. Ross, 1998) with the mid-scale tests, it appears that the lab tests were a good predictor of the likely success of ignition and the oil removal efficiency for the mid-scale tests; however, they did not adequately predict trends in oil burn rate as a function of wave steepness at the larger scale.

Recommendations

These mid-scale tests have indicated that adding emulsion breakers to extend the window of opportunity for *in situ* burning of

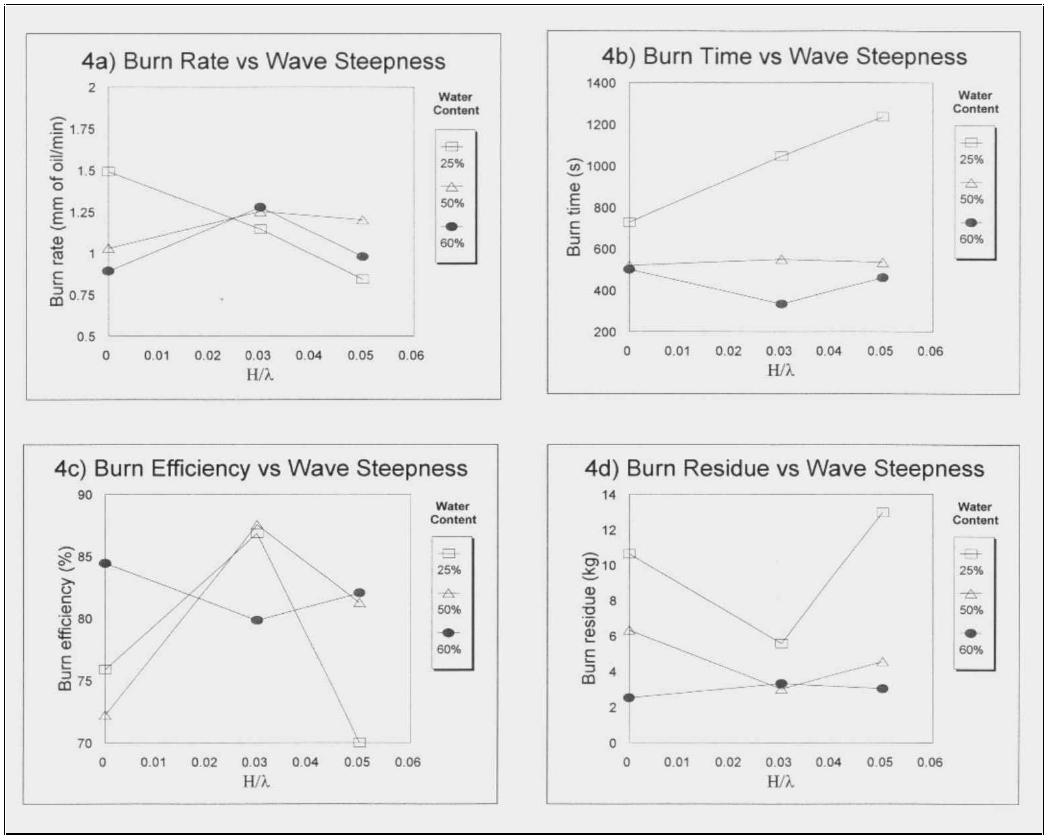

Figure 4. Mid-scale burns with emulsified Milne Pt. in waves (20-mm slicks).

Alaskan oils continues to show promise; however, in themselves, they are not sufficient to conclude that the operational use of emulsion breakers offshore is feasible. In order to implement emulsion breaker addition as a technique to extend the window of opportunity for in situ burning operations offshore, several areas still need to be researched. These include:

1. Exploring the regulatory regimes covering the application of emulsion breakers to oil slicks, and obtaining approval for specific chemicals being considered for ISB;
2. Investigating and developing systems for the application, and perhaps mixing, of emulsion breakers at dose rates on the order of 1:500 onto contained slicks at sea;
3. Conducting large-scale trials in realistic wave conditions to further prove the operational feasibility of burning water-in-oil emulsions in situ. Although ideally these trials should be conducted at sea, tests in another large water body could serve as a substitute.

Acknowledgements

The construction of the wave tank and the program of mid-scale outdoor burn tests was funded by: the Alaska Department of Environmental Conservation; Alaska Clean Seas and its member companies Alyeska Pipeline Services Company, ARCO, BP and Exxon; ARCO Marine; the Canadian Coast Guard; Clean Sound; the Cook Inlet Regional Citizens Advisory Committee; Cook Inlet Spill Prevention and Response Inc.; the Minerals Management Service of the U.S. Department of the Interior; the U.S. Coast Guard; and, Western Canada Marine Response Corp.

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[1] The research described in this paper was supported by the Alaska Department of Environmental Conservation. However, the findings and conclusions presented by the authors are their own and do not necessarily reflect the views or position of the department.