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HEAVY OIL BEHAVIOUR IN THE OCEAN

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<u>OBJECTIVE</u> To determine the fate and behaviour of heavy oils in the Ocean

Environment Canada and the U.S. Minerals Management Service are jointly investigating the fate and behaviour of heavy oils in the Ocean. Of particular concern is the phenomena that oil can be overwashed by water, even though its density is somewhat less than water. Also under investigation is the sinking of dense oils and the long-term fate of sunken oil, namely the question of whether it remains in the water column and thus hits a shoreline or sinks to the bottom.

Several reports are in the literature regarding sinking or disappearing of oil slicks. These include the ARROW (Forester, 1971), in which large drops of emulsified Bunker C were detected at depths of up to 80 metres; the US/NS POTOMAC (Petersen,1978) incident during which subsurface oil mats were observed; and the IXTOC incident (Payne and Phillips, 1985) during which mats of emulsified oil were also observed below the surface. The current interest in this phenomenon was sparked by the KURDISTAN incident (C-CORE, 1980; Reimer,1981) where sunken pans of Bunker C were noted and some oil that was later beached was not observed during surveillance operations in the same area. Several reports of sunken oil in Southern California have been circulated. Recent documented incidents of sunken oil include the KATINA incident (Rijkwaterstaat, 1982) where Bunker Fuel submerged but later was beached and the THUNTANK 5 incident in Sweden (OSIR, 1987) where a quantity of 36 to 40 tons of Bunker fuel sank in icy waters.

All these incidents involved denser oils or water-in-oil emulsions. Some of these incidents also involved the formation of particles ranging in size from millimetres to metres.

<u>Past studies</u>

Several studies have been conducted in the past to address various aspects of sinking or submergence in oil spills. In 1982 Environment Canada contracted Seakem Oceanography to conduct a study of oceanographic conditions suitable for sinking of oil (Juszko et al, 1983). The study resulted in extensive density maps of Canadian waters. It was concluded that there are sufficient pycnoclines and areas of low densities to contribute to some of the observations of historical spill behaviour.

In 1984, the Atlantic regional office Environment Canada, with funding from the PERD (Program for Energy Research and Development) project began a 3-year study of the problem of submerged oil. The first year of the study was both a review of the movement of sunken oil and an exploratory study into the mechanisms of sinking.

The study of the subsurface movement of oil was contracted to Seakem Oceanography (Juszko, 1985). The study concluded that the movement forces for subsurface oil could be divided into three categories, macroscale, mesoscale and microscale. The macroscale features include general circulation patterns, seasonal water density distributions, topographically-related features (fronts and frontal circulation, upwelling and rectified flows) and macroscale waves and eddies. Mesoscale features include internal waves, fronts, longitudinal mixing and Langmuir circulation. The primary microscale feature is turbulence. An idealistic four-dimensional model is proposed for the movement of submerged oil.

The exploratory study of the mechanisms driving oil submergence was investigated by Don Mackay of the University of Toronto (Wilson et al, 1986). The study concluded that a substantial quantity of oil can be submerged in the water column under steady state conditions. The extent of submergence is increased by; a high oil density occurring naturally or induced by weathering, by the presence of significant surface turbulence, by the formation of small oil particles or drops, and by the formation of water-in-oil emulsions. A complementary exploratory study showed that large oil masses which are slightly less dense than water may be submerged for periods of time by surface turbulence. This important finding was called "overwashing" and was investigated further using wood blocks weighted with lead. It was found that oil and oil surrogates would become overwashed with water when the density was as low as .90 g/mL and overwashing time increased as the density increased and as the wave height increased. This phenomenon could explain some of the disappearances of oil at sea since even overwashing by as little as a few microns of water renders oil invisible to eye and some forms of remote sensing, especially at oblique angles.

The University of Toronto was contracted to conduct a follow-up study and the overwashing effect was investigated further (Clark et al, 1987). The investigators used oil and oil simulants such as weighted wood, lard packs and plastic balls. Waves were very important in causing overwashing. Overwashing becomes much more pronounced with increasing density. A first equation relating these factors was developed:

$$P = \exp\{-d/D^{x}\}$$

where $D = KU^2 / (SGD^{0.8} * (L + L_o))$

x, K, L_o are constants

d = depth of submergence

U = wind speed in m/s

SGD = the specific gravity difference between the water and the oil

L = the mean diameter of the oil drop

P = probability factor and overwashing occurs when p is .5

These studies were followed up by a series of larger tests in a wave tank conducted by S.L. Ross Environmental Research Limited (Buist, 1987). The findings included a further definition of transient submergence or "deep episodes" which had been observed but not quantified in earlier studies. This phenomena is described as the plunging of oil particles deep into the water column and residence for a period of time. The phenomena is transient and generally does not involve all of the oil in a test situation. An equation for the maximum overwash depth was developed and is the same form as the overwash depth equation but has different constants.

Equations were developed for the overwash depth as follows:

$$d = C * x(den * a^2/2x^2 * diff)^D$$

where d = overwash depth (m)

C = a constant, determined to be 7.5×10^{-4} and is 2.9×10^{-2} for measuring transient submergence depth

x = oil particle size (m)

den = the density of the water (kg/m^3)

a = wave height (m)

diff = the difference between the water density and the oil density (kg/m^3)

D = a constant, is 0.725 and is 0.625 in the case of transient submergence depth

The study also resulted in the development of equations relating the size of the oil pancakes produced under certain conditions. The size of the particle varies directly with the square root of the wave length and inversely with the square root of the wave amplitude.

The probability that oil is at a certain depth can again be predicted as given by the relationship found by Mackay as given above.

These results have been used to prepare simplified nomograms to predict the overwash or submergence depth. Figure 1 presents the overwash or maximum transient submergence depth for fuel oils and Figure 2 presents the same for water-in-oil emulsions.

<u>Summary of Past Research Results</u>

Heavy or high density oils can become overwashed or sink in water. Oils that have densities of 0.90 to 0.96 can become overwashed with water in higher sea states. Oils with densities of 0.96 to 1.03 will frequently become overwashed with water in higher sea states. The depth at which overwashing occurs can be predicted. Overwashed oil will weather differently than oil on the surface and may be difficult to detect as the thin layer of water renders it invisible to remote sensors and human vision at oblique angles.

Heavy oils will also submerge at greater depths than normal overwashing and this phenomenon has been called transient submergence or deep episodes. The maximum depth to which this occurs is also predictable.

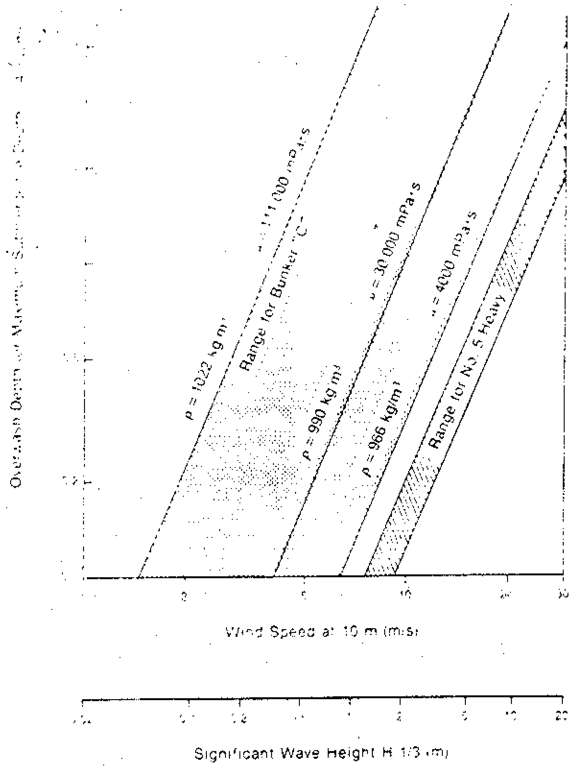

Figure 1 Nomogram showing Overwash Depth with Sea conditions

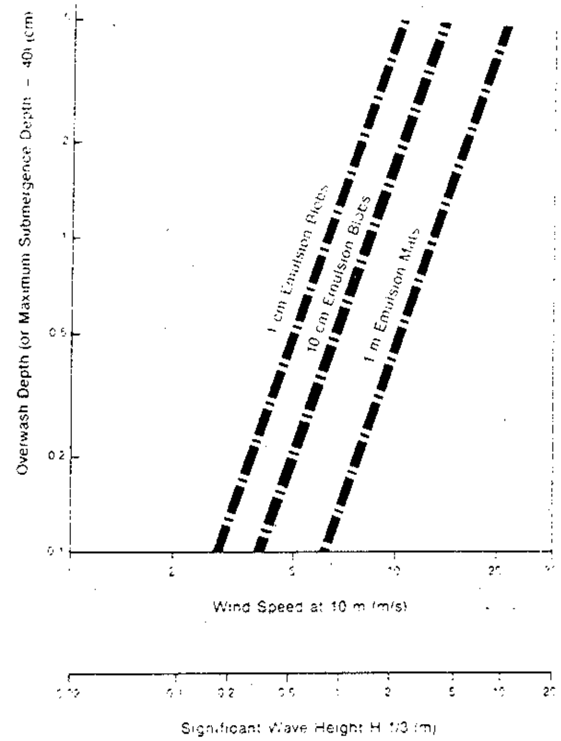

Figure 2 Nomogram showing Overwash Depth With Sea Conditions

Both overwashing and transient submergence are dependant on the wave height, density difference of the oil and water and size of the oil particle or blob. The latter can also be predicted by data on wave length, amplitude and oil properties.

Current Research Work

The U.S. Minerals Management Service and Environment Canada continue to conduct research in this topic. The current issues include: the long-term fate of sunken or overwashed oil, that is will it sink to the bottom or will weathering be slow enough to allow this oil be transported to a shoreline?; then, specifically, what is the long term weathering process and rate applicable to sunken or overwashed oil?; Can the length of time that oil floats at neutral buoyancy or is overwashed be predicted so that one knows whether or not a spill of such oil will hit the shoreline or the bottom?; and how do typical Californian and Canadian heavy oils behave with respect to oils already tested? Three studies are underway at the time of writing. Consultchem of Ottawa, Canada, is investigating the properties of a number of typical heavy oils including two California crudes. The same firm also has a contract to investigate the role of photooxidation as a long-term weathering process. The University of Toronto is conducting a study to examine all possible long-term weathering for sunken or overwashed oil, to examine the processes responsible for the long-term weathering and also to propose an initial model for this long-term weathering.

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