Residues from In Situ Burning of Oil on Water

The small amounts of residue from *in situ* burning (ISB) of oil on water, particularly if they sink, can cause environmental concerns. Results of laboratory tests suggest the possibility that, for about 40 to 60% of crude oils worldwide, burn residues may sink. However, whether results from laboratory tests can be extrapolated to large-scale spills is not known. Burn residues have little to no acute aquatic toxicity. Their greatest impact would likely be to the benthos from smothering. For most ISB applications, impacts would be very localized because of the small volumes of residues generated and their dispersal by currents.

Background and Status of Knowledge

Residues of oils burned in laboratory tests in the 1970s and 1980s floated, probably because of the small scale of those tests and the thinness of the burned oil. The 1991 *Haven* spill, in which large amounts of heated and burned oil residue sank, stimulated research into whether residue density affects whether a residue will float or sink.

Results from recent larger-scale laboratory and meso-scale field tests suggest that the most important factors determining whether an ISB residue will float or sink are:

1. **Water density**
   Burn residues that are denser than the receiving water are likely to sink. The density of fresh water is 0.997 g/cm^3 at 25°C, and the density of sea water is 1.025 g/cm^3.

2. **The properties of the starting oil**
   Correlations between the densities of laboratory-generated burn residues and oil properties predict that burn residues will sink in sea water when the burned oils have (a) an initial density greater than about 0.865 g/cm^3 (or API gravity less than about 32°) or (b) a weight percent distillation residue (at >1000°F) greater than 18.6%. When these correlations are applied to 137 crude oils, 38% are predicted to sink in seawater, 20% may sink, and 42% will float.

3. **The thickness of the oil slick**
   Residues from burns of thick crude oil slicks are more likely to sink than residues from burns of thin slicks of the same crude oils, because higher-molecular weight compounds concentrate in the residue as the burn progresses.

4. **Efficiency of the burn**
   Factors affecting burn efficiency include original slick thickness, degree of emulsification and weathering, areal coverage of the flame, wind speed, and wave choppiness. For efficient burns, removal efficiencies are expected to exceed 90% of the collected and ignited oil. Rules of thumb for predicting residue thickness are[2]:

- For unemulsified crude oil up to 10-20 mm thick, residue will be about 1 mm thick.
- Thicker slicks result in thicker residues (up to 3-6 mm thick).
- Emulsified oils can produce much thicker residues.
- For light/medium refined products, the residue will be about 1 mm thick, regardless of slick thickness.

When burn residues sink, they do so only after cooling. Models of cooling rates predict that ambient water temperature will be reached in less than 5 minutes for 3 mm-thick residues, and in 20-30 minutes for 7 mm-thick residues **[6]**.

Physical properties of burn residues depend on burn efficiency and oil type. Efficient burns of heavy crudes generate brittle, solid residues (like peanut brittle). Residues from efficient burns of other crudes are described as semi-solid (like cold roofing tar). Inefficient burns generate mixtures of unburned oil, burned residues, and soot that are sticky, taffy-like, or semi-liquid.

Chemical analyses of burn residues show relative enrichment in metals and the higher-molecular weight PAHs, which have high chronic toxicity but are thought to have low bioavailability in the residue matrix. Bioassays with water from laboratory- and field-generated (NOBE) burn residues of Alberta Sweet Mix Blend showed little or no acute toxicity to sand dollars (sperm cell fertilization, larvae, and cytogenetics), oyster larvae, and inland silversides**[3]**. Bioassays using NOBE burn residues showed no acute aquatic toxicity to fish (rainbow trout and three-spine stickleback) and sea urchin fertilization**[1]**. Bioassays using laboratory-generated Bass Strait crude burn residue showed no acute toxicity to amphipods and very low sublethal toxicity (burying behavior) to marine snails**[4]**.

Localized smothering of benthic habitats and fouling of fish nets and pens may be the most significant concern when semi-solid or semi-liquid residues sink. At the *Honan Jade* spill, burn residue sank in 2 hours and adversely affected nearby crab pens[5]. All residues, whether they floated or sank, could be ingested by fish, birds, mammals, and other organisms, and may also be a source for fouling of gills, feathers, fur, or baleen. However, these impacts would be expected to be much less severe than those manifested through exposure to a large, uncontained oil spill.

Current Research

MMS is funding a project to develop standard laboratory tests for assessing suitability of an oil for burning. Environment Canada is analyzing residues from burns that they attend.

Consequences to Operations of Uncertainty of Research Information

Because of uncertainties in extrapolating laboratory results to actual spill conditions, responders cannot confidently predict the amount of residue that may be generated by burning of heavy crude oils and refined products or if/how much of the residue will float or sink.

Only a very short time window is available for surface recovery of residues that eventually sink, but this recovery option could be effective, since residues are readily recovered either manually or with sorbents. Limitations include logistics, worker safety, and slow-down in ISB operations. Residues may be re-burned as more oil is collected and burned. Once the residue sinks, recovery options are few, logistics-intensive, and ineffective.

Needed Research

Field trials and study of actual spills where ISB is conducted are needed to determine whether or not the small-scale test data and predictive models developed to date apply to large burns. These models then should be refined.

Chronic toxicity tests using burn residues, benthic organisms and habitats, and realistic exposure levels and pathways also are needed.

References

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