Energetic Analysis of the Relevance of WAF Preparations to Field Mixing Conditions

Abstract

Water accommodated fractions (WAFs) are standard laboratory preparations to stimulate oil exposure in the water column in toxicity testing. A traditional WAF is generally created by mixing water with oil using a stir bar in a beaker or bottle without waves (i.e., low-energy WAF or LEWAF). However, following the Deepwater Horizon accident, a new “High-Energy Water Accommodated Fraction” (HEWAF) was developed. HEWAFs are generated using a commercial food blender to mix an oil and water solution. Consequently, assessment of the relevance of HEWAF toxicity test preparations to field conditions in the field requires understanding how the energetics of the HEWAF preparation compare to the energetics in the ocean in general, and to the oil spill to which the test data are being applied. This study focused on the relevance of HEWAF preparations to field conditions during the Deepwater Horizon oil spill. We measured the mixing intensity generated by breaking waves in various conditions. The results indicate that HEWAFs subject the oil and water mixtures to a mixing intensity that is greater than 60,000 times more intense than the mixing intensity that has been reported from breaking waves, and, on the basis of mixing intensity alone, were LEWAF preparations are over 7 times stronger than a breaking wave. Understanding the relevance of HEWAF to environmental conditions is essential to ensure appropriate interpretation of laboratory toxicity tests of oil exposures.

Introduction

Mixing intensity, also known as the mixing rate, has been documented in the peer-reviewed literature by measurements of the “turbulent dissipation rate.” The turbulent dissipation rate has units of watts per kilogram (W/kg) and is the rate at which kinetic energy (i.e., energy due to fluid motion) is dissipated (i.e., converted into thermal energy). It is directly related to the amount of mixing that occurs in a fluid flow. The turbulent dissipation rate was measured in a variety of oceanic locations and conditions. In order to directly compare the energy of WAF preparations to the energy in waves (as described by the dissipation rate in the published literature), laboratory measurements of the dissipation rates in WAF preparations were conducted.

Turbulent Dissipation Rate Measurement

The turbulent dissipation rate was calculated based on Kees and Wood (1992) using the equation below. Where \( \varepsilon \) is the turbulent dissipation rate, \( u' \) is a constant of proportionality, \( \kappa \) is a characteristic turbulent velocity, and \( L \) is a characteristic length scale. This equation is in SI units and is used to determine the velocity at many spatial locations in the horizontal direction.

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\varepsilon = \frac{u'^3}{\kappa L}
\]

The measurement depth for each WAF type was chosen to be the 90m contour in the ocean.

Conclusions

• Only the LEWAF performed in 2-L aspirator bottles had a turbulent dissipation rate that approximates the turbulent dissipation rate in breaking waves.

Oceanic Energy

• CEWAF/HEWAF preparations expose the oil and water solutions to a mixing intensity that is at least 140 times greater than that of the measured breaking waves.

• The LEWAF preparation is even more intense, with a mixing intensity that is greater than 40,000 times stronger than measured breaking waves.

• Furthermore, on the basis of mixing intensity alone, even the LEWAF preparations may be too energetic, as the 1-L aspirator bottle provides a mixing environment that is over 7 times stronger than a breaking wave.

References


