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

Robert W. Whittlesey, Ph.D., P.E.,[1] Timothy L. Morse, Ph.D., P.E.,[2] and Ann Michelle Morrison, Sc.D.[3]

Exponent; [1] 5401 McConnell Ave, Los Angeles, California 90066, USA; [2] 9 Strathmore Rd, Natick, Natick, Massachusetts, 01760 USA; [3] 1 Mill and Main Place, Maynard, Massachusetts 01754, USA

Abstract

Water accommodated fractions (WAFs) are standard laboratory preparations to **simulate 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 an aspirator bottle without vortex (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 surface 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, quantified by the turbulent dissipation rate generated in HEWAF and LEWAF preparations and compared the results to published turbulent dissipation rates for 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, even **LEWAF preparations are over 7 times stronger than a breaking wave**. Understanding the relevance of HEWAFs to environmental conditions is essential to ensure appropriate interpretation of laboratory toxicity tests of oil exposure.

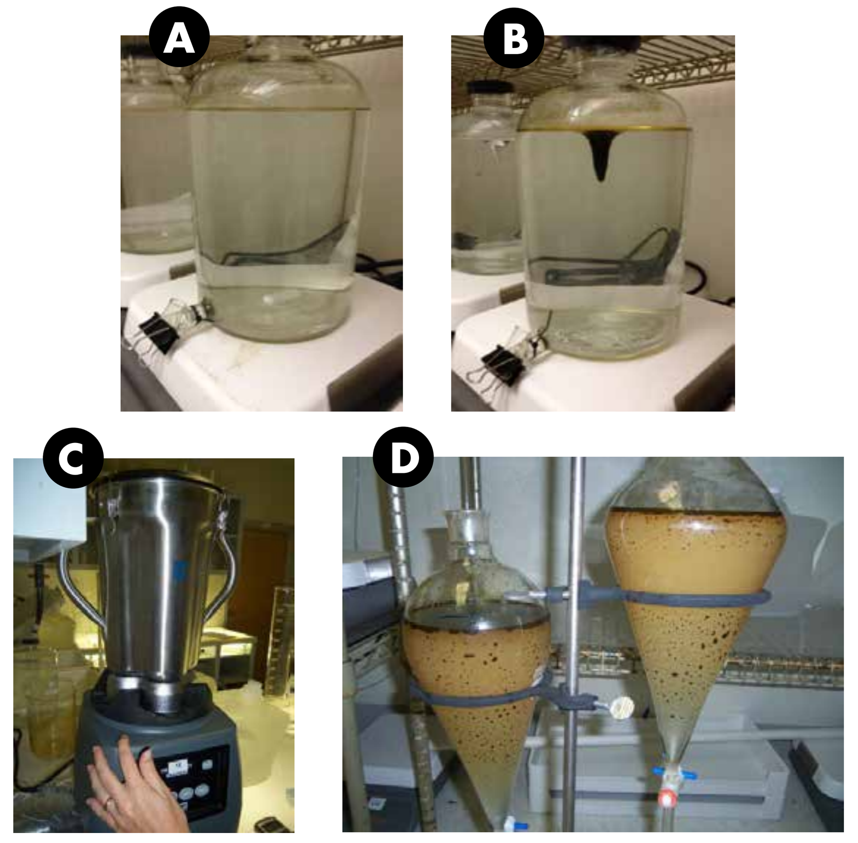
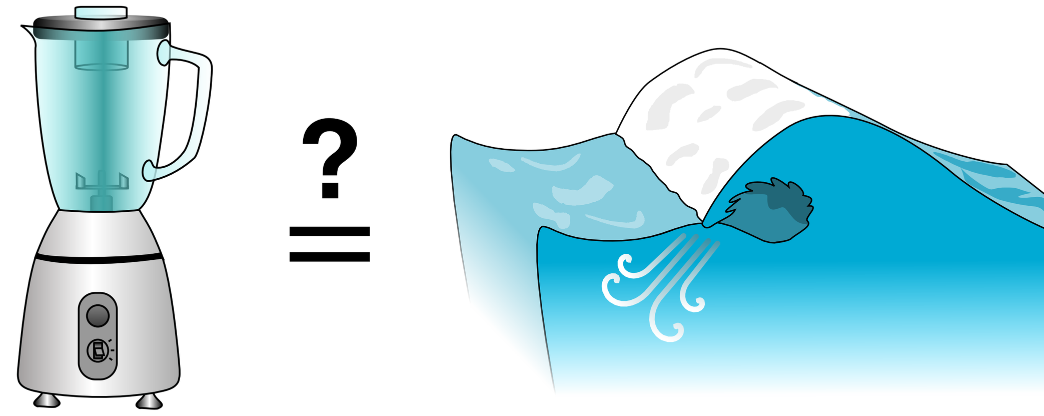


Figure 1.
Examples of LEWAF (A), MEWAF (B), and HEWAF (C,D) preparations in the laboratory

Introduction

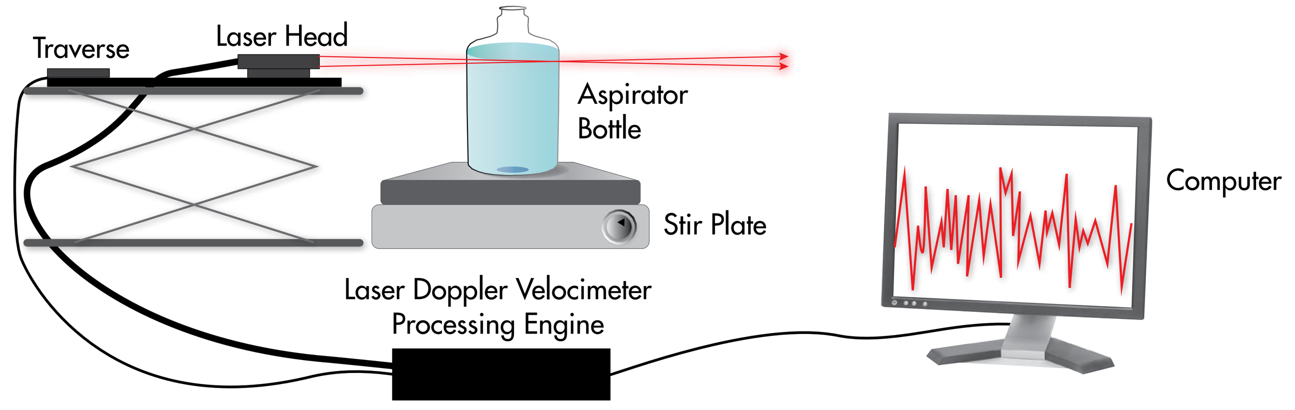
Mixing intensity, also known as the mixing energy, in the ocean has been documented in the peer-reviewed literature by measurements of the "turbulent dissipation rate." The turbulent dissipation rate has units of watts per kilogram (W/kg) and is the rate at which kinetic energy (i.e., energy due to fluid 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 publications in the peer-reviewed literature provide the turbulent dissipation rate 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 rates in the published literature), laboratory measurements of the dissipation rates in WAF preparations were conducted.



WAF Preparation

- LEWAFs, chemically enhanced water accumulated fractions (CEWAFs), and HEWAFs were prepared according to the protocols described in the "Quality Assurance Project Plan: Deepwater Horizon Laboratory Toxicity Testing," hereafter referred to as "the Protocols,"
- MEWAF conditions were assumed to be identical to CEWAF, without the addition of chemical dispersant.
- LEWAF, CEWAF, and MEWAF preparations, both 1 liter and 2 liter aspirator bottles were used.
- For LEWAFs, the Protocols do not specify the rotation rate of the stir-bar, thus the highest stir setting that did not generate a vortex on the water surface was used.
- Oil was not added to the water since the volume of the containers would have been vastly dominated by water. Any alterations to the dynamics of the water by adding oil were assumed to be negligible.
- CEWAF experiments were conducted without the addition of the chemical dispersant or oil. These were assumed to have very small effects on measured velocities.

Figure 2.
Schematic representation of the experimental setup. The aspirator bottle or blender jar is measured by the Laser Doppler Velocimeter (LDV). The computer records this data for further processing.



Turbulent Dissipation Rate Measurement

The turbulent dissipation rate was calculated based on Kresta and Wood (1993) using the equation below.

$$\varepsilon = A \frac{u'^3}{L}$$

Where ε is the turbulent dissipation rate, A is a constant of proportionality, u' is the characteristic turbulent velocity, and L is a characteristic length scale. A/L is equal to D/10, where D is the diameter of the impeller.

- Velocity was measured using a laser Doppler velocimeter (LDV). The LDV was mounted on a computer-controlled traverse to enable determination of the velocity at many spatial locations in the horizontal direction.
- The measurement depth for each WAF type was chosen to be the region of most intense mixing at the oil/water interface.
- LEWAF and MEWAF preparations have oil on the water surface that does not mix substantially with seawater thus measurements of the water velocity near the water's surface were made
- CEWAF and HEWAF preparations mix oil and water throughout the preparation; hence, the mixing intensity in these experiments was measured close to the blade or stir bar
- LDV measurements were analyzed with custom-built scripts to determine the turbulent dissipation rate. Of the many measurements taken at different horizontal locations at one depth, the maximum dissipation rate calculated is used for comparison.
- The maximum dissipation rates measured in HEWAF, CEWAF, MEWAF, and LEWAF experiments are shown in Figure 4.
- Results show HEWAF produces the greatest turbulent dissipation rate and the LEWAF the least.

Oceanic Mixing Energy

In the ocean, the mixing intensity generated by breaking waves is a function of the wind velocity. **Station 42040 from the NOAA National Data Buoy Center was located approximately 30 nautical miles away from the MC252 wellhead (Figure 3).**

- **Between April 1 and September 20, 2010, the maximum wind speed recorded at Station 42040 was 15.2 m/s.**

Two papers were identified that provide the turbulent dissipation rate of waves using units that are directly comparable to the results reported above from the experiments.

- **Terray et al. (1996) records maximum wind speed of 16.00 m/s, with a maximum turbulent dissipation rate equivalent to 0.004651 W/kg.**
- **Drennan et al. (1996) report a maximum wind velocity of 11.99 m/s and a maximum turbulent dissipation rate equivalent to 0.000541 W/kg.**

As these turbulent dissipation rates are taken from high wind events, these values are generally representative of the most intense mixing experienced in the Gulf of Mexico during the incident. For wind speeds lower than the 15.2 m/s maximum, the mixing intensity from breaking waves will be lower than these values of turbulent dissipation rate.

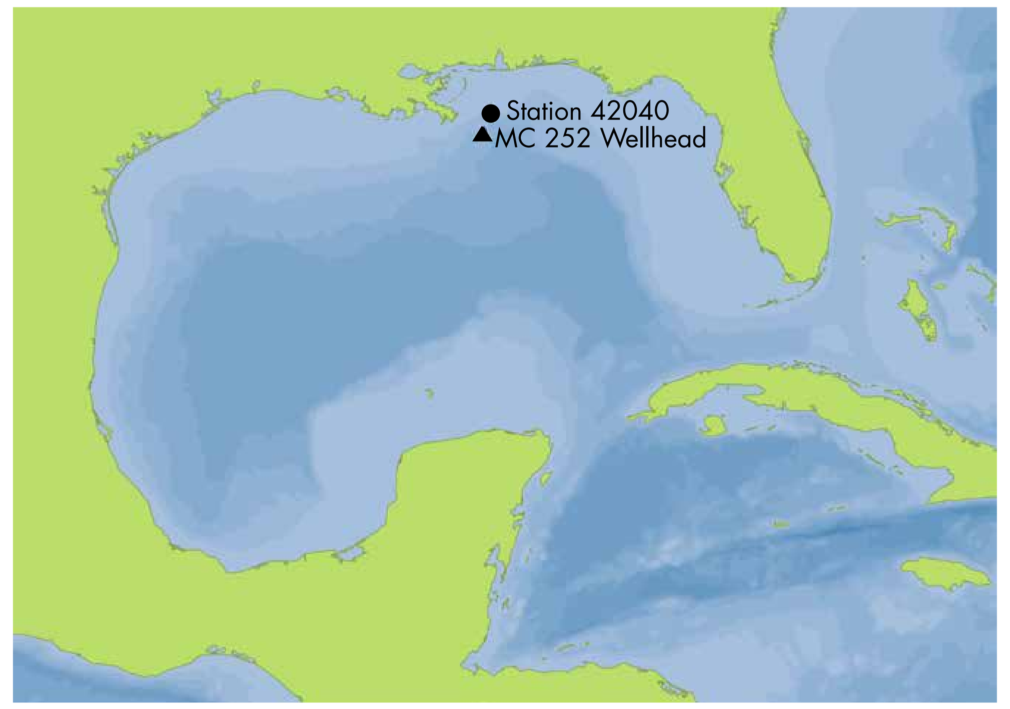


Figure 3.
Map of the Gulf of Mexico showing the location of the MC 252 wellhead and NOAA's National Data Buoy Center Station 42040.

Conclusions

- Only the LEWAF performed in a 2-liter aspirator bottle has a turbulent dissipation rate that approximates the turbulent dissipation rate in breaking waves.
- **CEWAF/MEWAF 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 HEWAF preparation is even more intense, with a mixing intensity that is greater than 60,000 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-liter aspirator bottle provides a mixing environment that is over 7 times stronger than a breaking wave.

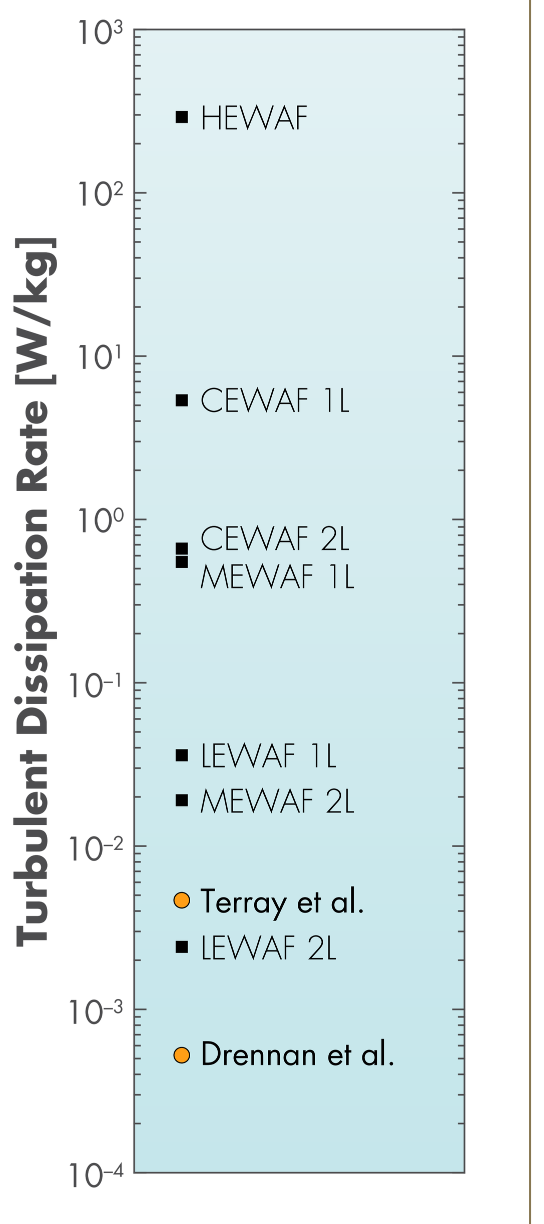


Figure 4.
Plot of the measured turbulent dissipation rate from this study alongside measurements from prior work.

References

"Quality Assurance Project Plan: Deepwater Horizon Laboratory Toxicity Testing," Stratus Consulting, Inc., Version 4, February 4, 2014.

Sandoval, K. and Gardinali, P.R. 2014. Characterization of oil water preparations of fresh and weathered MC252 oils used in toxicology testing. 35th Annual Society of Environmental Toxicology and Chemistry (SETAC) Meeting, Vancouver, BC, Canada, November 9–13, 2014.

Kresta, S.M., and Wood, P. E. 1993. The flow field produced by a pitched blade turbine: characterization of the turbulence and estimation of the dissipation rate. Chemical Engineering Science, 48(10):1761-1774.

Terray, E.A., Donelan, M.A., Agrawal, Y.C., Drennan, W.M., Kahma, K. K., Williams, A.J., Hwang, P.A., and Kitaigorodskii, S.A. 1996. Estimates of kinetic energy dissipation under breaking waves. Journal of Physical Oceanography, 26(5): 792-807.

Drennan, W. M., Donelan, M. A., Terray, E. A., and Katsaros, K. B. 1996 "Oceanic Turbulence Dissipation Measurements in SWADE. Journal of Physical Oceanography, 26: 808-815.

Data obtained from http://www.ndbc.noaa.gov/station_page.php?station=42040, accessed on October 15th, 2014.

Exponent®