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The Sonophysics and Sonochemistry of Liquid Waste Quantification and Remediation

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Research Objective

To perform an in-depth and comprehensive study of the fundamentals of acoustic cavitation and nonlinear bubble dynamics, to elucidate the fundamental physics of sonochemical reactions, to examine the potential of sonoluminescence to quantify and to monitor the presence of alkali metals and other elements in waste liquids, to design and to evaluate more effective sonochemical reactors for waste remediation, and to determine the optimal acoustical parameters in the use of sonochemistry for liquid-waste-contaminant remediation.

Research Progress and Implications

This report summarizes work performed during year 2 of a 3-year project. Our goals included performing near-IR spectroscopy of sonoluminescence. Cells have been designed for multi-bubble sonoluminescence (MBSL) and single-bubble sonoluminescence (SBSL) spectroscopy experiments. The MBSL cells are designed around a 20 kHz acoustic horn with replaceable titanium tips from Sonics & Materials. The horn is pressure-fitted into a stainless steel cell via O-rings and a compression ring, to seal the cell up to 100 psi for pressure experiments. The cell is thermostated by circulating coolant in a jacket, as well as flowing the cell fluid (at 4L/min.) through a temperature control bath. Several ports are located on the cell for gas ports (one for headspace, another for bubbling), a pressure transducer, a thermocouple, a needle hydrophone, and a septum port for addition or withdrawal of samples. The total volume is approximately 80 mL with a 10 mL head space. Directly opposite the horn tip is a 2 cm quartz window against which a fiber optic bundle is placed. Light collected through the fiber optic is imaged onto one of several detection systems.

SBSL cells were designed to provide maximum light throughput, since it was expected the near-IR intensities would be extremely low. We utilized a 45 mm diameter levitation cell, with a PZT transducer glued to the bottom of the cell. Fluid ports with leak-proof detachable connectors allowed for replacing the dissolved air with other gases. A photomultiplier tube (PMT) was used to record the overall light intensity, and to monitor the bubble stability. A computer-controlled system was used to generate a bubble, if the previous bubble became unstable, or disappeared. Initial experiments utilized a lens system to focus the emitted light onto the fiber optic bundle. This arrangement is acceptable, since the wavelength range that was studied was relatively narrow.

Positive results were obtained in both systems during year-2 using a Raman system, on loan from Kaiser Optical, Inc. This instrument covers the wavelength range from 790 to 1070 nm. Both single bubble and multiple bubble sonoluminescence spectra have been taken over this range, using air/water, argon/water, and argon/NaCl-water solutions. The intensities of both MBSL and SBSL decline towards the red end of the spectra for all systems studied. A dip in intensity from 960 to 1020 nm is observed in the single bubble spectra. This is probably due to the water absorption band in the near-IR. The dip is not apparent in the multiple bubble system, where cavitation occurs adjacent to the observation port (the path length through water is small). The profiles are otherwise quite similar for air/water and argon/water, with no spectral features, suggesting similar mechanisms for the observed light emission. The sodium doublet near 818/819 nm was observed in the MBSL system with a concentration as low as 0.5 molar. The lower concentration limit for detection of this doublet has not yet been explored. Sonoluminescence spectra from this wavelength region have never before been reported.

Further progress from year-1 involved the use of the newly discovered technique of changing the pressure head above the cavitation field to increase the light emission from MBSL. As the static pressure was slowly increased from atmospheric pressure (760 mmHg) to 4 atmospheres (3040 mmHg), the sonoluminescence intensity increased to a global maximum around 3.3 atmospheres (about 2480 mmHg) in our system, at which point the intensity began to decrease again. In year-2, we found that with pure water, no hysteresis was observed during this static pressure variation. However, if a sodium solution is used instead of pure water, a great deal of hysteresis around the intensity maximum occurs. One possible mechanism for the hysteresis involves the sodium acting to shield individual bubbles so that, once created, they are prevented from coalescing. To be useful in quantitative studies, the concentration would have to be much lower than used in these initial experiments (1 molar). Further studies are now being conducted to determine the lower concentration threshold for hysteresis effects. Additionally, this maximization of the sonoluminescence intensity may be useful for minimizing power consumption for economical alkali waste monitoring.

A second method for changing the pressure head involves pressure-jumping, whereby the pressure in the head space above the solution is quickly increased to a new steady value. This pressure-jump results in a dramatic increase in the light intensity that can last minutes. In order to obtain a better understanding of the physical processes occurring in the multiple bubble acoustic cell, the fiber optic was replaced with an endoscope to visually observe the bubble field (in absence of data collection). During a pressure jump experiment, the cloud of cavitation bubbles at atmospheric pressure disappears from sight at the moment of increasing the pressure to 3.3 atmospheres. As cavitation continues, microscopic bubbles are seen to grow in size. The time with which it takes the bubbles to grow to pre-pressure jump sizes corresponds with the end of enhanced emission when the light intensity is measured. These results agree with the new notion that small bubbles are responsible for the sonoluminescence emissions, and presumably, for sonochemical activity.

Planned Activities

We plan to use spectroscopic studies to determine if our pressure-jumping results in "hotter" bubbles, or simply more bubbles of the same temperature. We have also begun experiments to determine the feasibility of finding mercury emission lines from sonoluminescence. These experiments should last for approximately 3 months. These studies are designed to determine whether or not MBSL can be used to quantify mercury contaminants in waste pump oil. We have also undertaken a study to determine the mechanism for intensity quenching of sonoluminescence with alcohols, and other organics. As outlined in the original proposal, these studies will last for approximately 11 months.

Other Access To Information

The results of our research have been published in scientific journals, and presented at scientific meetings. A list of published papers and conference presentations is presented below:

A. Brodsky, "Casimir free energy of a spherical cavity in a dielectric medium," J. Mathematical Physics, 38, 5127-5142 (1997).

D. Kuhns, A. Brodsky, and L. Burgess, "Hydrodynamical perturbation effects in multiple bubble sonoluminescence," Phys. Rev. E, 57, 1702-1704 (1998).

T.J. Matula and L.A. Crum, "Evidence for gas exchange in Single-bubble sonoluminescence," Physical Review Letters, 80, 865-868 (1998).

T.J. Matula, "Sonoluminescence," European Society of Sonochemistry, Plenary lecture, May, 1998

T. Matula, "Sonoluminescence: Some recent results," NATO Advanced Study Institute, invited lecture, September, 1997.