The Sonophysics and Sonochemistry of Liquid Waste Quantification and Remediation

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Executive Summary

When an ultrasonic field of moderate to large intensity is applied to a liquid, the liquid often fails under the action of the dynamic tensile stress applied by the ultrasound. Consequently, the vapor cavity that is formed during the rarefaction portion of the sound field can thus grow rapidly so long as the applied negative acoustic pressure exceeds the vapor pressure of the liquid; subsequently, however, this cavity is driven into an implosive collapse as the sound field turns positive and applies a compressive force to the cavity. Because of surface tension, the cavity remains spherical for much of its life cycle and, accordingly, an enormous energy concentration—as much as 12 orders of magnitude—can result from this growth and collapse sequence—a phenomenon called acoustic cavitation. The temperatures and pressures experienced by the material contained within the imploding cavities can achieve values in excess of tens of thousands of degrees and tens of kilobars, respectively. These high temperatures and pressures can act as an intense microreactor and induce a variety of chemical reactions; the ability of these reactions to induce a particular effect is called sonochemistry, and holds high promise as a specific chemical approach to waste contaminant remediation.

A variety of investigators have demonstrated the utility of the sonochemical reactor; for example, the natural half-life of parathion, a pesticide of widespread use, is 108 days. Under ultrasonic irradiation at 20 kHz in deionized water, all of the initial parathion is degraded in less than two hours; ultrasonic irradiation in an aqueous solution containing the highly toxic pentachlorophenate (PCP) results in the almost complete degradation of PCP in about 100 minutes; researchers have also found that acoustic irradiation of chlorinated C1 and C2 volatile organic compounds (VOCs) resulted in a VOC destruction of up to 99.9% in less than an hour.

Although sonochemistry holds such high promise for use in waste contaminant remediation, the principal mechanism that leads to chemical degradation, acoustic cavitation, is a complex and difficult to understand phenomenon. Chemists who are performing experiments in sonochemistry know little of acoustic cavitation and how to use it in an optimal way; physicists who know something about cavitation bubble dynamics don't understand the chemistry. Indeed, the President of the European Society of Sonochemistry has deemed this field a "black art", whose progress is mainly empirical, and which will lack credibility as a mature science until multidisciplinary teams involving both physicists and chemists examine the problem from a fundamental viewpoint. We propose a systematic study of the phenomenon of acoustic cavitation as it applies to sonochemistry, and especially as it applies to waste contaminant remediation.

Research Progress and Implications

We have established a multidisciplinary team involving internationally recognized experts in the field of acoustic cavitation from the Applied Physics Laboratory at the University of Washington; they will be joined by experts in the field of industrial/analytical chemistry from the Center for Process Analytic Chemistry, also at the University of Washington; participating as consultants are recognized experts from Lawrence Livermore National Laboratory, Savannah River Technology Center, Pacific Northwest National Laboratory, and the University of California, Irvine. Finally, the University of Washington itself plans an extensive and comprehensive research program in this general area.

Research Objective

We propose 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, and to determine the optimal acoustical parameters in the use of sonochemistry for liquid-waste-contaminant remediation.