Sound Speed and Attenuation in Multiphase Media

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Grant Number: N00014-04-1-0164

LONG-TERM GOALS

One research goal developed from conducted shallow water (SW) acoustic transmission experiments in sandy-silty areas revealed a nonlinear power law frequency-dependent attenuation at lower frequencies consistent with results reviewed in [2,3] the observations by the ONR-HEP program. The Biot Theory [4] predicts that sandy sediment attenuation should have a quadratic dependence, however the nonlinear dependence observed was closer to a 1.8 power law most likely due to modal effects. Thus one long-range goal is to develop a simplified theory of sediment attenuation verified by laboratory measurements that can be applied to ocean sediments.

A second long-range goal is to better understand that acoustical behavior of individual bubbles and bubbly assemblages in water and water-filled sediments. The focus is on attenuation, dispersion, and bubble response near and about the resonance frequency.

OBJECTIVES

The first research objective is complete the experimental and theoretical study of bubbly liquids and to show the applicability of the BU impedance tube to the determination of the impedance characteristic in turbulent bubbly liquids in large laboratory tanks and latter at-sea. We also seek a theoretical – analytical- method for the prediction of the two-point coherence function in low volume fraction bubbly liquids and to propose signal path at sea experiments to verify the utility of this method. Finally, the acoustical characteristics of individual bubbles and bubbly assemblages in water and encapsulated in non-Newtonian media (such as muddy and silty sediments) will be studied using both acoustical and optical techniques.

The second objective is to determine the frequency dependent attenuation and phase speed characteristics of selected sandy and muddy sediments (both water saturated and partially saturated) at the lower frequencies to verify the simplified Biot theory [4] and to provide a theoretical / experimental basis for the water-sediment boundary condition necessary for the accurate prediction of wide band transmission loss in shallow waters.

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **29 SEP 2005**	2. REPORT TYPE	3. DATES COVERED **00-00-2005 to 00-00-2005**

4. TITLE AND SUBTITLE **Sound Speed and Attenuation in Multiphase Media**	5a. CONTRACT NUMBER
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Boston University,Dept. of Aerospace and Mechanical Engineering,110 Cummington Street,Boston,MA,02215**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S)
	11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES
code 1 only

14. ABSTRACT
One research goal developed from conducted shallow water (SW) acoustic transmission experiments in sandy-silty areas revealed a nonlinear power law frequency-dependent attenuation at lower frequencies consistent with results reviewed in [2,3] the observations by the ONR-HEP program. The Biot Theory [4] predicts that sandy sediment attenuation should have a quadratic dependence, however the nonlinear dependence observed was closer to a 1.8 power law most likely due to modal effects. Thus one long-range goal is to develop a simplified theory of sediment attenuation verified by laboratory measurements that can be applied to ocean sediments. A second long-range goal is to better understand that acoustical behavior of individual bubbles and bubbly assemblages in water and water-filled sediments. The focus is on attenuation, dispersion, and bubble response near and about the resonance frequency.

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**6**	

APPROACH

The technical approach involves a balance between theory, laboratory measurements, and carefully performed field experiments. One accomplishment of our previous ONR-sponsored research effort (*The Physics of Sound Scattering From, and Attenuation Through, Compliant Bubbly Mixtures*) was been the development of a water-filled impedance tube for characterizing bubbly liquids. We intend to extend this measurement capability to the measurement of bubbly liquids in large tanks and then at-sea such as in the wake of a ship. This enables the verification of our theoretical assumptions in specifically designed experiments to test our analytics and consequently the use of the analytics to extend the results to more realistic naval applications. It also allows for the probing for relatively high void fraction flows (order 1-5%) that are normally inaccessible due to high acoustic attenuation. The impedance tube relies of a measurement of the complex reflection coefficient, and is thus not compromised lossy propagation in the test media.

Based on our feasibility testing, it is our opinion that this measurement technology has the capability of acoustically characterizing marine sediments, specifically, the measurement of frequency-dependent sound speed and attenuation [5]. We will modify the apparatus to facilitate the measurement of these propagation parameters in laboratory sediment samples for frequencies ranging from 100 Hz to 10 kHz. This measurement scheme provides estimates of the compressional wave speed and attenuation. It is recognized that shear may be important and will be addressed with conventional measurements; however, at the lower frequencies saturated sands and muds are thought to behave as fluids and can be characterized by three quantities. The impedance tube discussed here has the potential to become an at-sea apparatus, and thus a means for the comparison of laboratory at-sea measurements of saturated and partially saturated sediments. The proposed work is aimed at enhancing our understanding of saturated and partially saturated sediment acoustics for frequencies ranging from 10's of Hertz to 10's of kilohertz. The basic hypothesis is based on the simplified Biot sediment model [4] and the prediction that high permeability sands will have a quadratic frequency dependent attenuation, and that these measurements can be described by a Biot time constant. We intend to confirm this hypothesis using our impedance tube measurement capability.

A second accomplishment of our previous research effort is capability to optically measure the dynamical response of single bubbles in viscoelastic media [6]. In these experiments, bubbles of known size (measured *in situ* with a microscope) were suspended in a viscoelastic polymer, driven acoustically at frequencies ranging from 2-14 kHz, and monitored using laser light scattering to measure the bubble response. This approach will be modified to permit us to study the dynamics of highly non-spherical bubbles normally encountered in muddy sediments using transparent gels possessing the same mechanical properties as saturated muds [7].

WORK COMPLETED

During the past year several major tasks have been performed. [1-4]. Pierce, Carey and Lynch have developed a simplified Biot Theory. This theory has been compared to previously publish experimental results. Modal propagation theory and calculations have been performed to determine the relevance of depth dependent geo-acoustic profiles on the attenuation observed in shallow water propagation. An experiment has been performed at frequencies between 600 and 1200 Hz to determine the nonlinear dependence.

In our laboratory-based effort, using both time of flight and modal techniques to probe a cylindrical tank filled with a water-saturated granular sediment, we successfully measured sound speed and attenuation at several discrete frequencies between 2-4 kHz and 20-300 kHz [8]. In addition, the impedance tube apparatus was transported down to NRL/DC for testing in their bubbly water tank facility in collaboration with Michael Nicholas. This “shakedown” experiment revealed some important limitations in the tube’s performance (see below) that we are currently working to resolve.

RESULTS

A key result is the development of a simplified Biot theory characterized by a parameter that can be measured in the laboratory. This parameter is called the Biot Time Constant. Examination of the value of this time constant from available results with known sediments revealed it to be a robust characteristic. The simplified theory also yields the frequency dependent attenuation and sound speed dispersion characteristic. A second result is the quantification of the role of modal propagation effects on shallow water wave-guide measurements.

The sand tank experiments revealed dispersion consistent with Biot theory [9]. Deviations from Biot are ascribed to the presence of small gas bubbles in the test sample. The impedance tube experiments performed at NRL showed that biases in the data can result if the impedance at the tube opening is not stationary over the measurement time. We are working to correct this limitation, which will prove problematic when performing measurements of flowing bubbly assemblages.

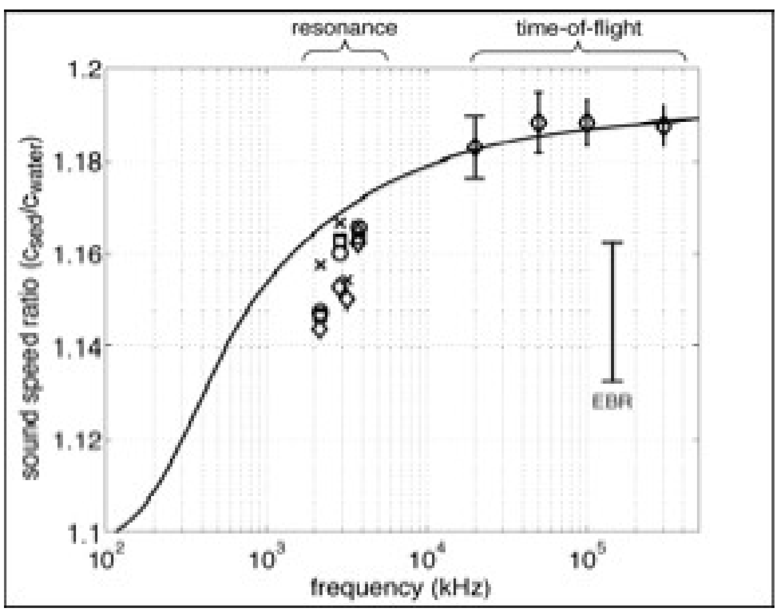

Figure 1. Measured data and model predictions for sound speed dispersion in a water saturated granular sediment. The error bars associated with the resonance-based measurements were withheld from the plot for clarity, but their size is represented by the vertical line labeled “EBR.”

IMPACT/APPLICATIONS

The results of this research has the potential for dramatically improving the use of geo-acoustic models to accurately predict the propagation and dispersion of sound at the low frequencies (~100 Hz) to the high frequencies (~10 kHz). It could also contribute to our ability to detect mines buried in sediments, particularly in those cases where the sediment is partially saturated with water.

RELATED PROJECTS

This work is related to ongoing investigations at the Woods Hole Oceanographic Institution, Dr. J. Lynch and The Rensselaer Polytechnic Inst., Dr. W. Siegmann. We maintain close cooperative efforts sharing resources and students. It is related to work proposed in collaboration with ARL/UT (P. Wilson) and NRL/Stennis (W. Wood) as a result of the ONR Workshop on Gassy Sediments (Bay St Louis, June 2005). It is related to a proposed ONR project on detecting buried mines using iterative time-reversal acoustics.

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HONORS/AWARDS/PRIZES

William Carey was awarded the Distinguished Service Award by the Oceanic Engineering Society of the IEEE in the fall of 2004 and he received the award in June of 2005 at an International Oceans in Brest France.