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Acoustic Probe for Solid-Gas-Liquid Suspensions

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Research Objective

The proposed research will develop an acoustic probe for monitoring particle size and volume fraction in slurries in the absence and presence of gas. The goals are to commission and verify the probe components and system operation, develop theory for the forward and inverse problems for acoustic wave propagation through a three phase medium, and experimentally verify the theoretical analysis. The acoustic probe will permit measurement of solid content in gas-liquid-solid waste slurries in tanks across the DOE complex.

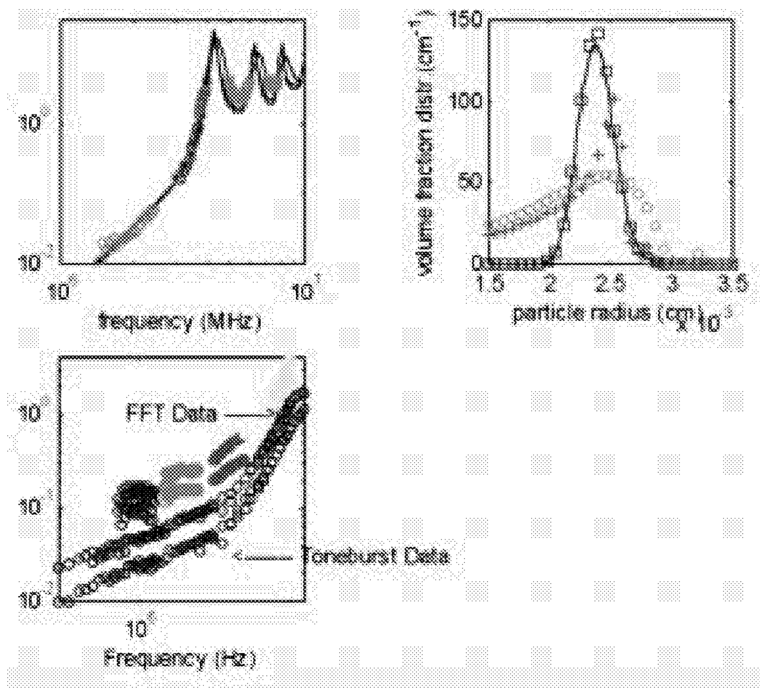
Research Progress and Implications

Theoretical Analysis Accomplished: As of October 1, 1997, conditions have been explored under which it is possible to determine the particle size distribution of a solid-liquid system from measurements on the attenuation of sound waves through the mixture. The attenuation in a polydisperse suspension can be written as follows:

$$\int v^*(a,\omega)\, \phi(a)da = v(\omega),$$

where $v^*(a,\omega)$ is the attenuation due to particles with radius a, and $\phi(a)$ is the volume fraction density, which is related to the particle size distribution. In the above equation to solve for the unknown $\phi(a)$, the right-hand side is known from experiments on a particular mixture, and $v^*(a,\omega)$ is known from theory. Such a problem is referred to as an 'inverse problem'. The theory used here for $v^*(a,\omega)$ is that of Allegra and Hawley (1972) for dilute suspensions of solids in liquid. This theory has been tested against experiments by solving a so-called 'forward problem': suppose we know the particle size distribution, what is the attenuation? Figure 1 shows very good agreement between the theory and experiments of the attenuation as a function of frequency for almost monodisperse polystyrene particles (radius 79μm).

In the past the inverse problem has been solved to determine bubble populations (Duraiswami 1993). Having used the same technique now for solids we have found that success is limited to very specific cases. Figure 2 shows that for the inverse problem to work for polystyrene particles it is necessary to have the attenuation over a suitable frequency range: the frequency range should include the wavelengths that are comparable to the particle size. However, it was not possible to solve the inverse problem for glass particles. This is explained by the differences in resonance behavior between glass and polystyrene particles.



Top, left (Figure 1): comparison between theory (lines) and experiments (markers); top, right (Figure 2): result for the particle size distribution when using different frequencies (Circles = 10 MHz, Crosses = 13 MHz, and Squares = 17 MHz) ; bottom, left (Figure 3): FFT and toneburst experimental data for different volume fractions.

The implication of this result is that one ***is not*** *able to solve the inverse problem to estimate the particle size distribution and volume fraction for solids in some cases.*

Experimental Work Accomplished: Extensive experimentation in solid-liquid systems has been carried out using the experimental setup described in the first year report. We have obtained attenuation data as a function of frequency in solid-liquid slurries of soda-lime glass beads (05-18.5 μm in radius, 9.5 μm mean) in water. Data have been obtained over the frequency range of about 0.5 to 12 MHz for slurries with concentrations ranging from 5 % to 30 % by volume, and these curves are shown in Figure 3. Attenuation data have also been obtained for a 5 % by volume slurry of 79 μm radius (essentially monodispersed) polystyrene spheres in water, and these results were compared with the forward solution in Figure 1. Additional attenuation measurements have been made in slurries of soda-lime glass beads (55-75 μm in radius, 64 μm mean) in a mixture of glycerol (29.7 wt %) and water. Measurements over the frequency range 1 to 7.5 MHz have also been made.

Fast Fourier Transform (FFT) analysis of received signals of spike pulse input signals has been tested and found to yield comparable results to those obtained by toneburst measurements, and is now the predominant data acquisition technique used in obtaining attenuation data.

Two sets of broadband transducers are being tested to replace the presently used five pairs of transducers for attenuation data acquisition from 1 to 10 MHz.

Planned Activities

The theory will be modified for non-dilute solid-liquid suspensions and the combined theory for gas-solid-liquid suspensions will be developed to determine the solids volume fraction in three phase slurries.

Attenuation measurements are also being attempted in bubbly liquids, and this work requires bubbles of desired properties. The most favorable method of bubble generation appears to be electrostatic spraying to generate bubbles in both the bubbly liquid and three phase experimentation. The gas-solid-liquid theory will be compared to three phase attenuation data.

Other Access To Information

"Determination of Particle Size Distributions from Acoustic Wave Propagation Measurements", P.D.M. Spelt, M.A. Norato, A.S. Sangani, and L.L. Tavlarides. in preparation.

"Measurements in Solid-Liquid Slurries to Determine the Effects of Finite Solids Volume Fraction on Ultrasound Attenuation Behavior", M.A. Norato, P.D.M. Spelt, A.S. Sangani, M.S. Greenwood, and L.L. Tavlarides. in preparation.