PROGRESS REPORT

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Acoustic Monitor for Liquid-Solid Slurries Measurements at Low Weight Fractions

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Progress Report

Research Objectives

The principal objective of the project is to develop an acoustic probe for determining the weight fraction of particles in a flowing suspension. The suspension can be solid-liquid (S-L) or solid-gas-liquid (S-G-L). The work will include testing the theory of acoustic wave propagation in suspensions and demonstrating the application of the probe by installing it on a flow loop through which a suspension is flowing and determining the particle weight fraction. The signal from the probe must be processed such that the noise arising from the presence of gas bubbles is removed to yield an accurate estimate of the particle weight fraction. Particular attention will be given to testing suspensions with low particle weight fractions since slurries to be transported in nuclear waste processing will have low particle weight fractions. Originally, the probe was to be developed and tested at Syracuse University (SU) then installed and tested at Oak Ridge National Laboratories (ORNL) for surrogate slurries from the Hanford Nuclear site. However, after discussions between SU and ORNL in June 2002 it was agreed that all tests would be conducted at SU.

Research Progress and Implications

Since the last progress report, our efforts were directed to commission a flow loop with two acoustic probes. Towards this goal, two hexagonal-interior, inline acoustic monitors were fabricated for the slurry and supernate fluid; data processing software for the monitor using six transducer pairs was developed; the two acoustic monitors were tested and their performance was verified; the spool piece for supernate filtration and backpulsing was designed, constructed, and tested; and the integrated flow loop was designed, constructed, and tested.

The flow loop and acoustic probe system were commissioned in May 2002. Refer to Figure 1 for a schematic of the main flow loop and Figure 2 for a photograph of the spool piece. A series of preliminary tests were conducted from June to August 2002 to assess the functionality of the flow loop and the acoustic probe. Full-scale experiments were conducted from August to October 2002 after necessary alterations were made. These experiments consisted of bench-scale batch calibration and three experiments in the main flow loop. The latter were with S-L, gas-liquid (G-L), and S-G-L systems, using ceramic microspheres (~80 μm diameter) as solids, air as gas, and tap water as liquid.

The batch calibration compared the attenuation of signals in slurry of a known weight percent with signals in distilled water. These data are plotted against the concentration of solids at various frequencies to obtain calibration curves for the system (Fig. 3). At high weight percents a non-linear relationship is evident in the 10 MHz range, thus only the linear regions are fit and at high regression coefficients. The 5 and 7 MHz responses are linear up to 10 weight percent (wt%) solids and the 8 MHz up to 7.5 wt%.

Figure 4 shows a plot of attenuation versus time for the S-L system in the main flow loop at four different frequencies. Solids were added stepwise to the system and each region of the plot is labeled with its expected concentration. Actual concentration measurements from an inline sampling port are labeled on the right axis and expressed by horizontal lines in the figure. Note that the 10 MHz signal does not concur with the other signals due to non-linearity. These results show excellent measurements of the actual solids concentration up to 7.25 wt% using the offline calibration at 5, 7, and 8 MHz. These measurements are recorded in real time and demonstrate rapid response to instantaneous changes in solids concentration.

The concentration measurements from the acoustic probe are plotted against measurements from the inline sample port in Figure 5. The 5, 7, and 8 MHz data compare extremely well with expectations. As before, however, the 10 MHz data are not in agreement with this model due to non-linearity. The acoustic data and sample port data can be compared using the statistical F-test method and provides approximately 95% confidence. If the 10 MHz data are excluded, the confidence level is improved to 99% indicating almost perfect correspondence between the two data sets.

The S-G-L experiment was designed to show the direct effects of air bubbles on the slurry. It was expected that the data produced would be a sum of the data from the S-L and G-L experiments. After analyzing the S-G-L data, it would be possible to separate the solid and gas attenuations.

The average attenuation at each frequency for the three flow loop tests is plotted against the frequency (Fig. 6). This is done first for the 0.01 and 0.1 volume percent (vol%) trials of the G-L experiments then for the 2.5 wt% portion of the S-L experiments. The solid line in Figure 6 represents the summation of data from these experiments and should coincide with the section of the S-G-L study using 2.5 wt% solids and 0.1 vol% air. Similarly, the dashed line represents 2.5 wt% solids and 0.01 vol% air. The expected overlapping of the S-G-L and summation curves is evident for the majority of frequencies. At higher frequencies (~8-12 MHz), however, the S-G-L curve follows the S-L curve only and, thus, is not apparently affected by the presence of air. This means that if data from higher frequencies are used then those data would represent only the solid concentration in the slurry and no further data processing would be necessary to eliminate the attenuation due to gas bubbles.

Conclusions and Planned Activities

In conclusion, we have:

- Developed a robust data acquisition system to continuously acquire attenuation spectra from 0.6 - 12 MHz for S-L, G-L, and S-G-L slurries with 6-pairs of ultrasonic transducers installed in two acoustic monitors;
- Demonstrated linear calibration of attenuation versus concentration;
- Demonstrated online, real time measurement of S-L concentrations; and
- Obtained results that indicate possibilities to remove gas phase attenuation interference to determine S-L attenuation in S-G-L mixtures.

In future activities, we will:

- Further analyze the possible lack of bubble influence at higher frequencies,
- Eliminate the bubble signal from the solid signal in the S-G-L system at lower to mid-range frequencies,
- Conduct studies on the physical surrogate slurry (kaolin-bentonite clay mixture),
- Conduct studies on the chemical surrogate slurry (SY-101 sodium salt mixture),
- Conduct final experiments at SU under the supervision of ORNL personnel, and
- Write the final report.

Figure 1: Diagram of the flow loop for acoustic monitor testing. The flow loop consists of a 150-gallon slurry feed tank (Tank-1), a seepex model 17-6L BN series moyno pump, a bubble generator, the slurry acoustic monitor (T-1), a spool piece for the supernate monitor (see Fig. 2), and auxiliary equipment.

Figure 2: Photograph of the spool piece for the supernate monitor. The spool piece consists of:

- 1) IMDS model 33252 moyno pump,
- 2) Supernate acoustic monitor (T-2),
- 3) Mott filter for supernate generation,
- 4) 1-liter vessel for high pressure backpulsing,

and auxiliary equipment. Also shown is

- 5) Slurry acoustic monitor (T-1).

Figure 3: Calibration curves for 3M G-800 microspheres. Each series represents average data at increasing frequencies (5 to 10 MHz) over five trials of six different solid weight percents. Each series is labeled with the corresponding fit for the linear regions of data.

Figure 4: Real time concentration data for a solid-liquid suspension. Each region of the figure is labeled with the corresponding expected solid weight percent. Actual concentration measurements from an inline sampling port are labeled on the right axis and expressed by horizontal lines in the figure.

Figure 5: Comparison of acoustic probe measurements and sample port data. Data measured by the acoustic monitor are plotted on the y-axis against data from the inline sample port, assumed to be the actual concentration. The solid line, $y=x$, represents the parity line.

Figure 6: Comparison of attenuation between experiments. The two G-L curves represent the 0.1 and 0.01 vol% air portions of the G-L experiment. The same notation is used for data from the S-G-L experiment. The G-L + S-L curves represent a summation of data from the G-L and S-L experiments.