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

During the past year, 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 June 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 concentration 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. Figure 6 shows the response of the monitor to real-time experiments in the main loop. Two different constant solid concentrations (about 0.5 (a) and 1.0 (b) weight percent) are established after which air bubbles are introduced at five-minute intervals with increasing bubble volume fraction from 0.005 to 0.10 volume percent. The measured concentration based on attenuation at 7 MHz increases as more bubbles are introduced.

The green curves (upper) represent the predicted solids concentration if the presence of bubbles is not accounted in the analysis. The purple curves (lower) show the results obtained from our bubble interference removal analysis. Note that the predicted solid concentration is practically unaffected by the increase in bubble volume fraction. However, the scattering in this curve is significantly greater than in the attenuation-based concentration curve and there is a slight loss of accuracy (Fig. 6a). These effects are more pronounced at higher concentrations. Further improvements in data analysis are required to overcome these difficulties.

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:

- 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.

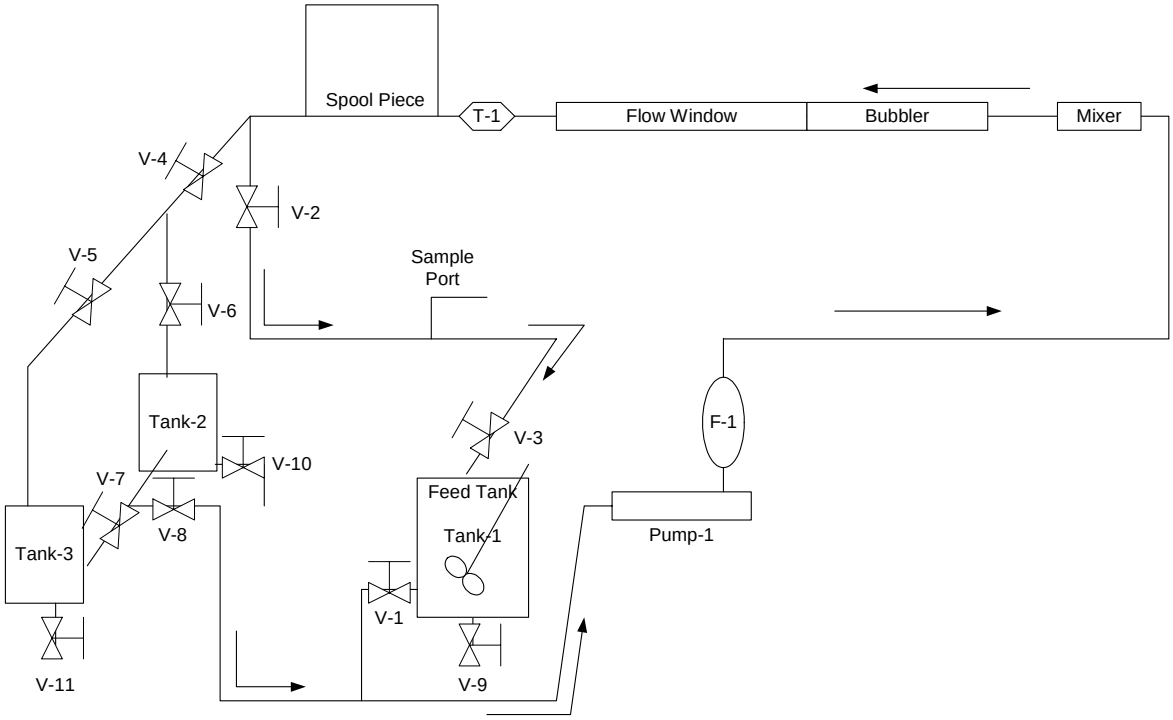

Figure 1: Diagram of the SU flow loop. The flow loop consists of a 150-gallon slurry feed tank (Tank-1), a seepex model 17-6L BN series Moyno pump, a bubble generator, the slurry acoustic monitor (T-1), a spool piece for the supernate monitor (see Fig. 7), and auxiliary equipment.

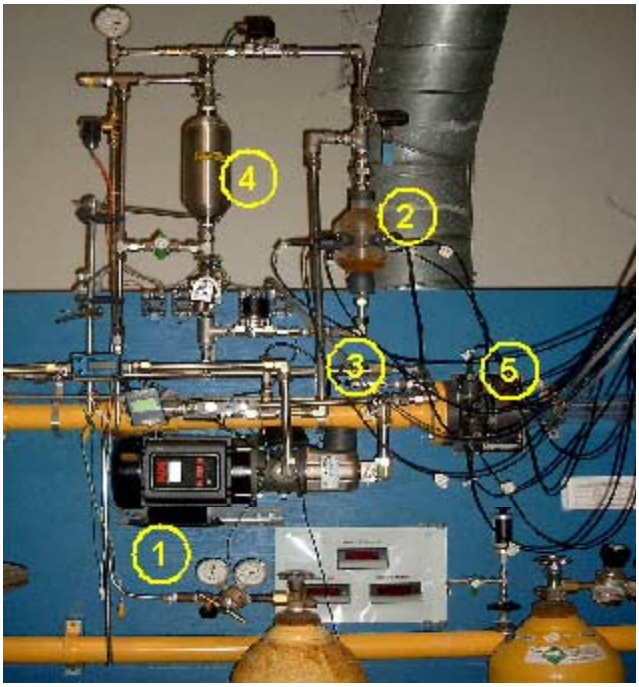

Figure 2: Photograph of the spool piece for the supernate monitor. The spool piece consists of an IMDS model 33252 Moyno pump (1), the supernate acoustic monitor (T-2) (2), a Mott filter for supernate generation (3), a 1-liter vessel for high-pressure backpulsing (4), and auxiliary equipment. Also shown is the slurry acoustic monitor (T-1) (5).

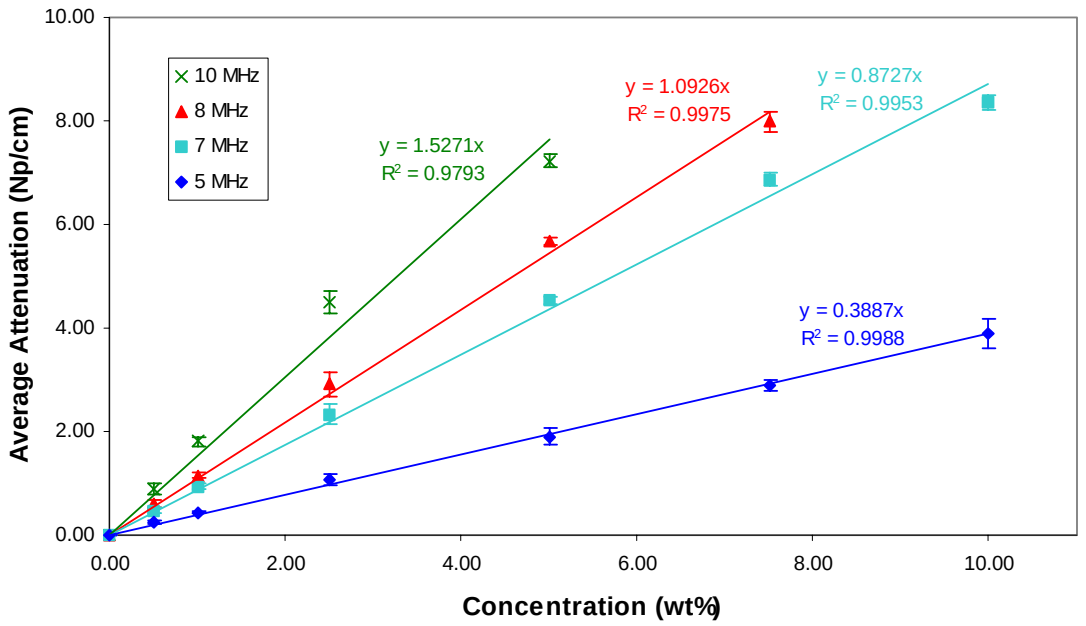

Figure 3: Calibration curves for 3M G-800 microspheres. Each series represents average data at increasing frequencies (5 to 10 MHz) over five trials of six different solid weight percents. Each series is labeled with the corresponding fit for the linear regions of data.

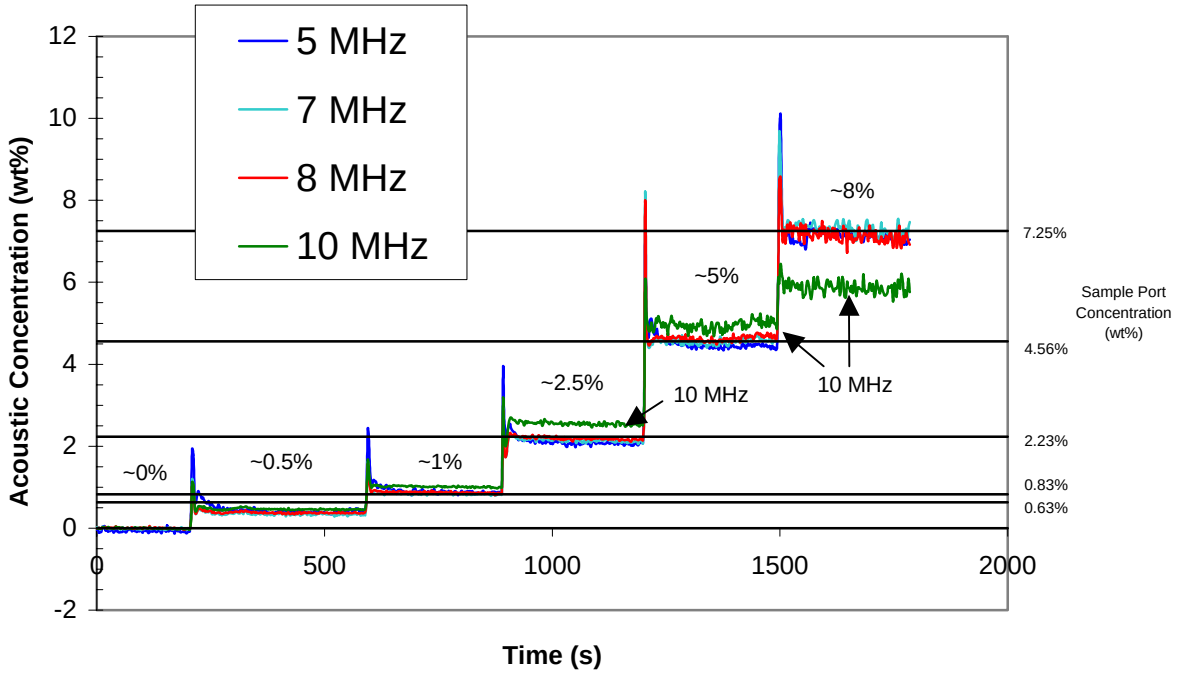

Figure 4: Concentration vs. time data from a S-L system in the flow loop.

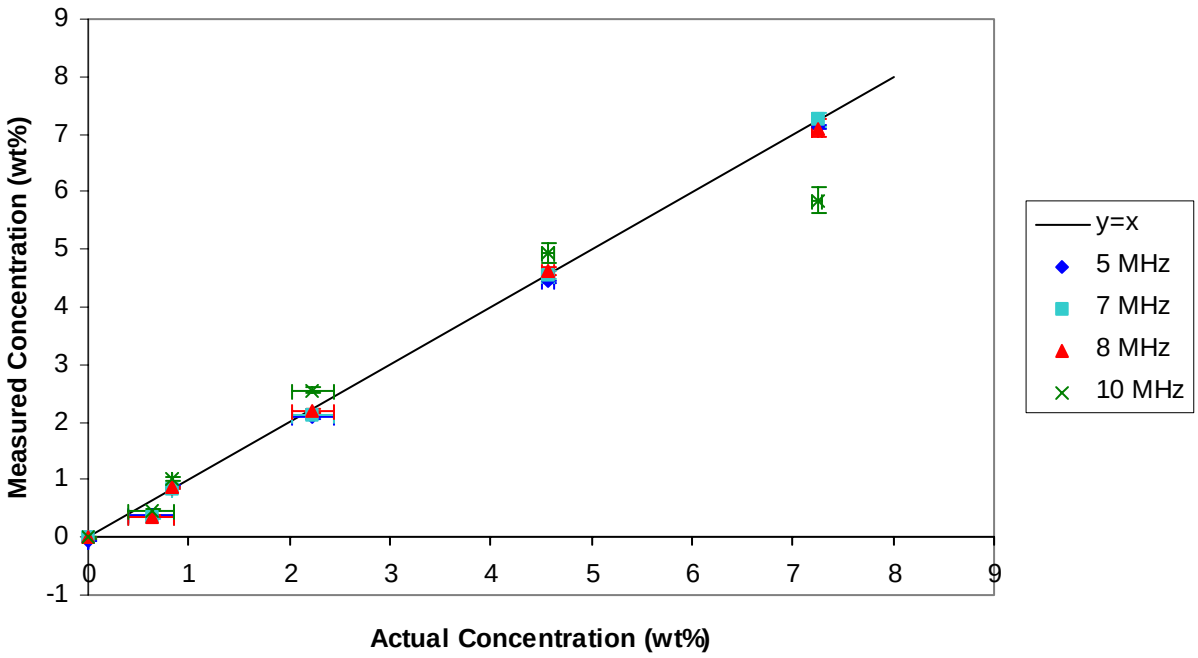

Figure 5: Comparison of concentration measured by the acoustic monitor with actual concentration from the in-line sample port.

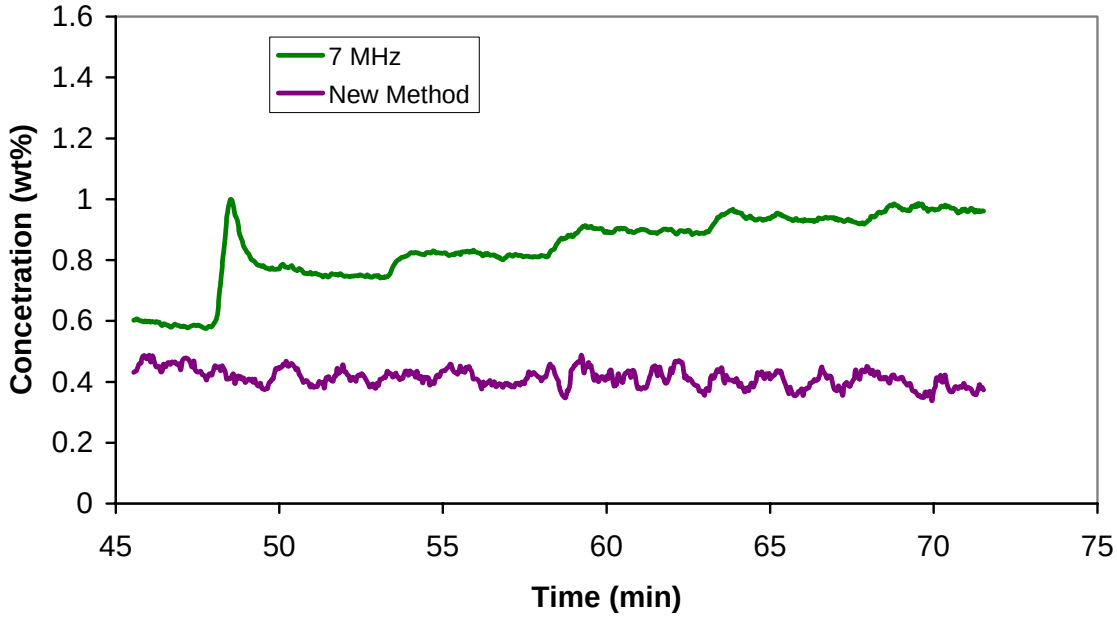

Figure 6a: Concentration vs. time at 0.58 weight percent solids. The 7 MHz curve shows the influence of bubble volume percent additions of 0.005% at ~50 minutes to 0.1% at ~67 minutes in five increments.

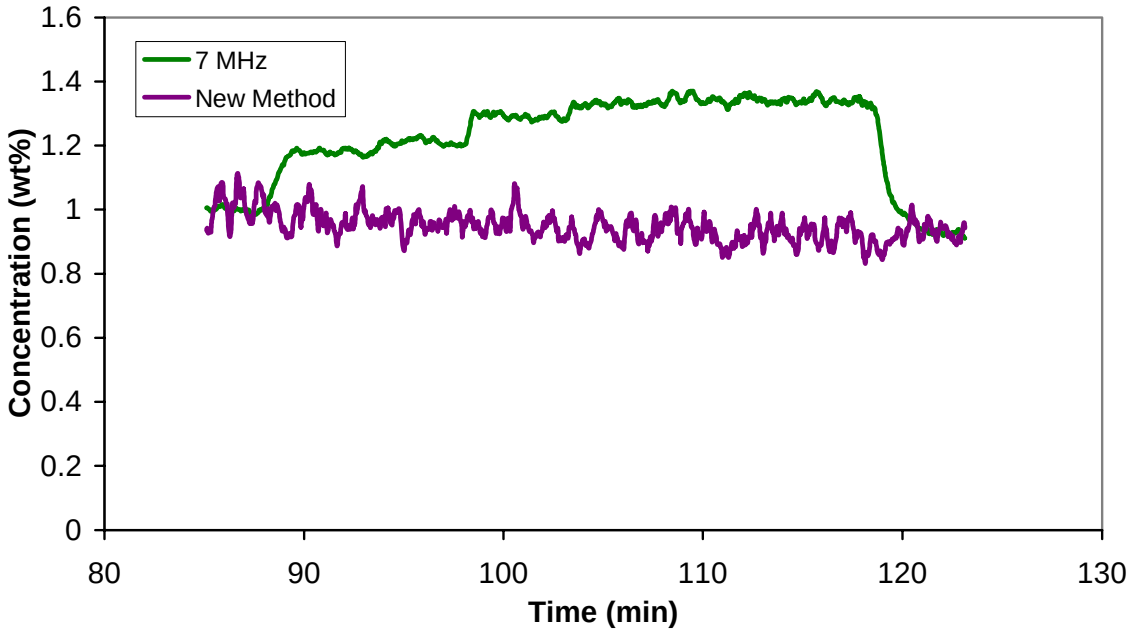

Figure 6b: Concentration vs. time at 0.95 weight percent solids. The 7 MHz curve shows the influence of bubble volume percent additions of 0.005% at ~90 minutes to 0.1% at ~112 minutes in five increments.