Investigating Ultrasonic Diffraction Grating Spectroscopy and Reflection Techniques for Characterizing Slurry Properties

Environmental Management Science Program

Project 81889

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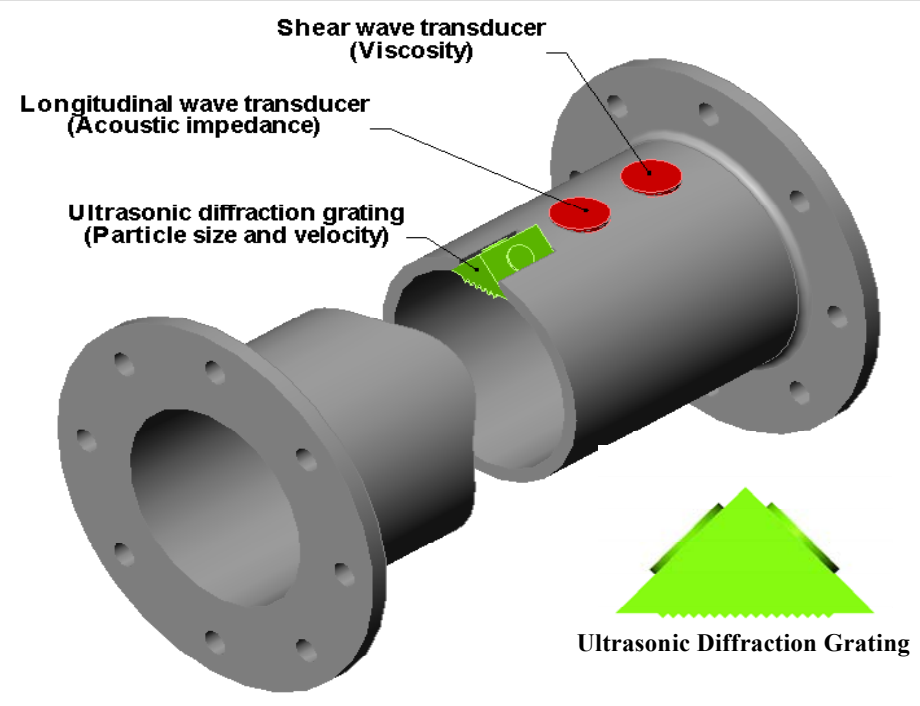
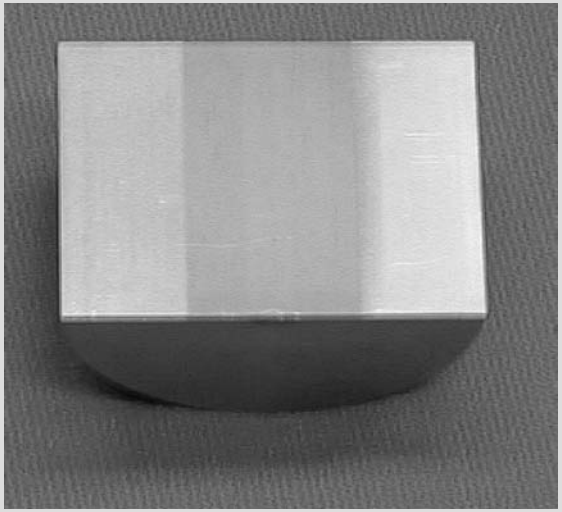
Objectives

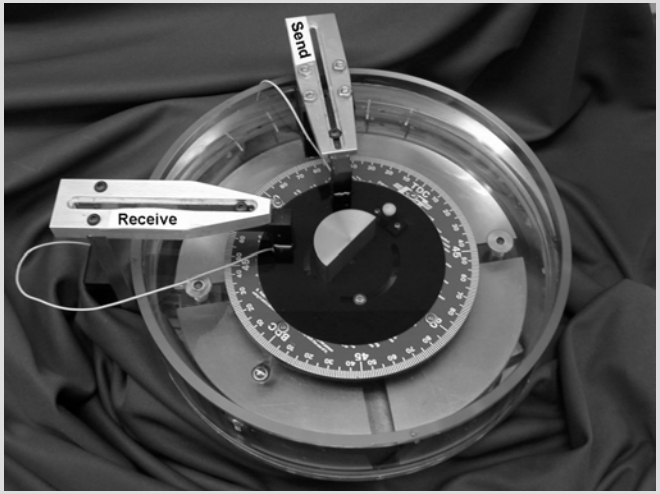
- Develop non-invasive methods for measuring particle size and viscosity that can be implemented on-line and in real-time.
- Ultrasonic diffraction grating spectroscopy—particle size, speed of sound, and possibly viscosity.
- Shear reflection techniques—viscosity
- Density—Measurement techniques have already been developed for other projects at PNNL.



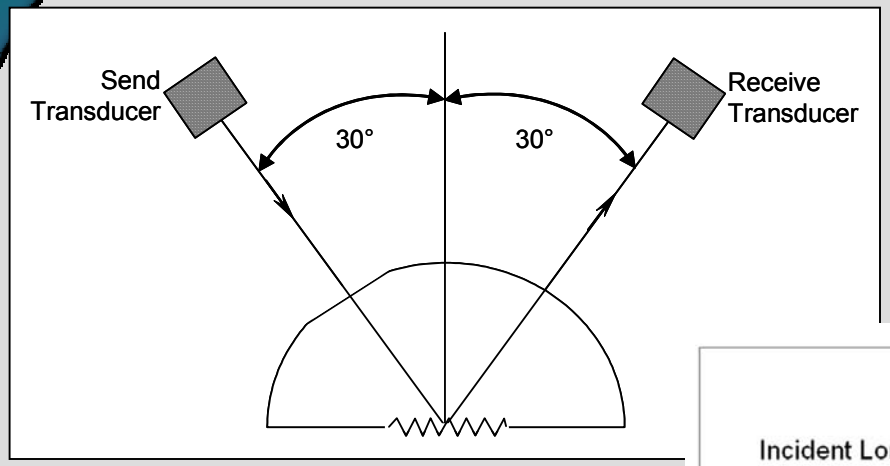
Description of Method

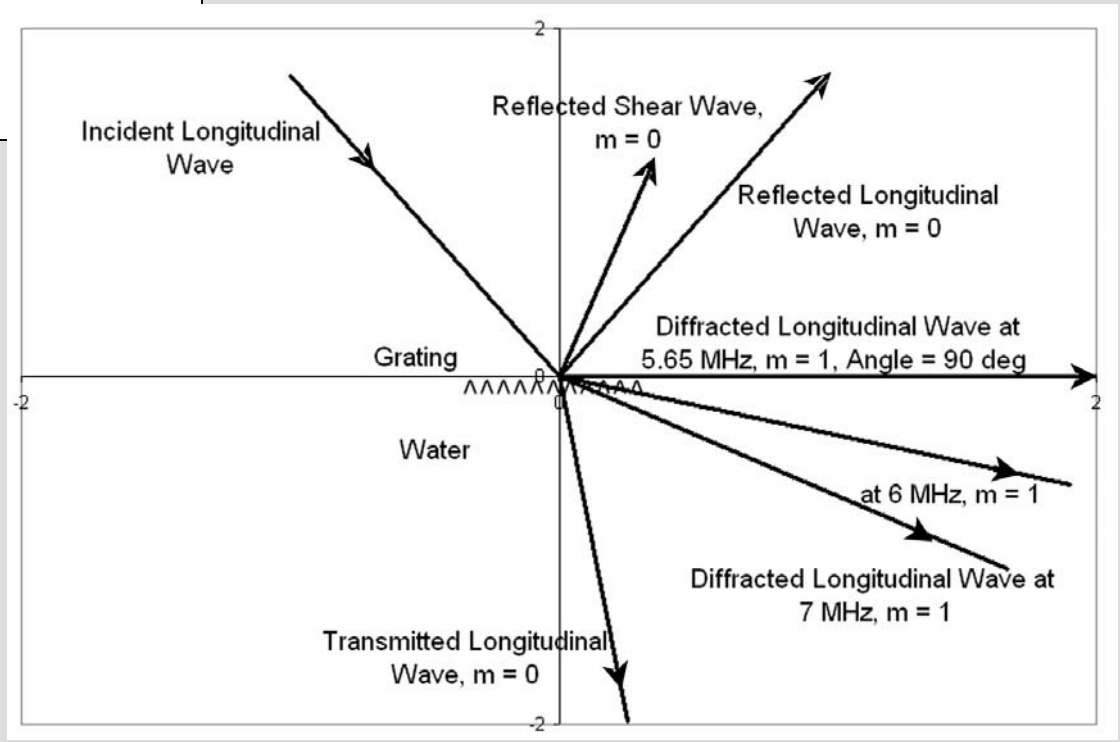
- Ultrasonic diffraction grating spectroscopy is analogous to the optical method developed at the University of Washington—grating light reflection spectroscopy (GLRS)
- Measurement: Send ultrasound to grating using a range of frequencies. Measure amplitude of the reflected signal and observe a peak in the data at a certain frequency, called the critical frequency.





Critical Frequency





Critical Frequency (contd)

- As the frequency of ultrasound decreases, the angle of the m = 1 transmitted wave in the liquid increases. At a frequency, called the critical frequency, the angle reaches 90º.
- At the critical frequency

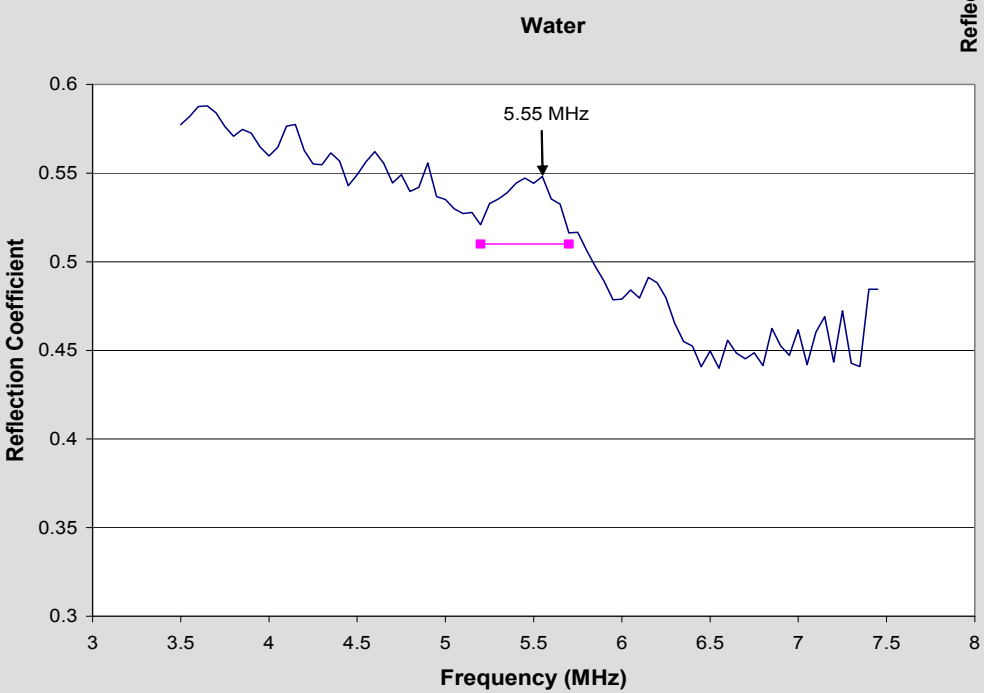
  Traveling wave → evanescent wave

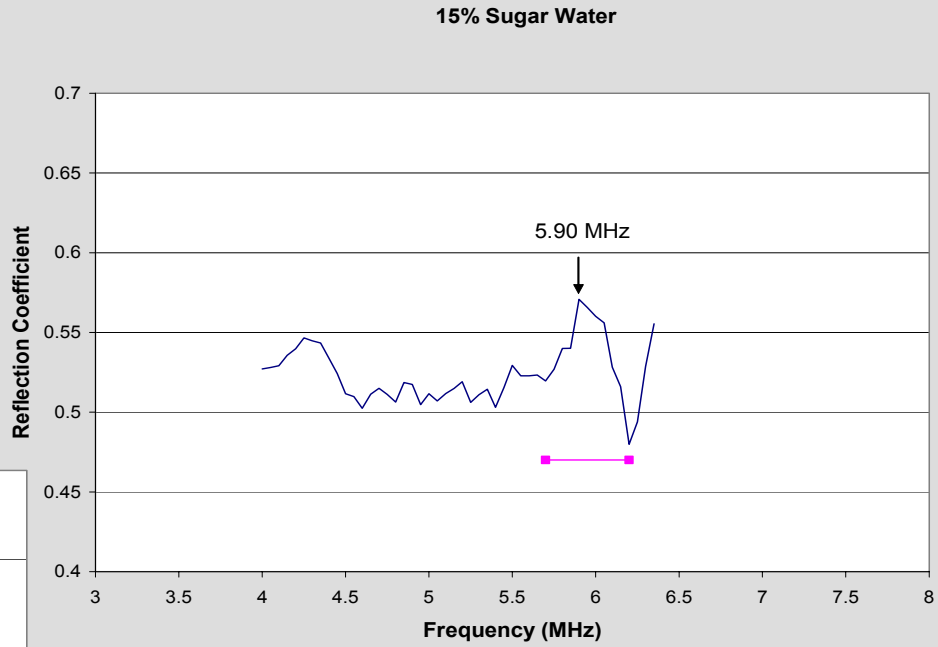
- At a frequency < critical frequency, m = 1 transmitted wave disappears.
- Conservation of energy: Energy is redistributed to all other waves.

  ↓

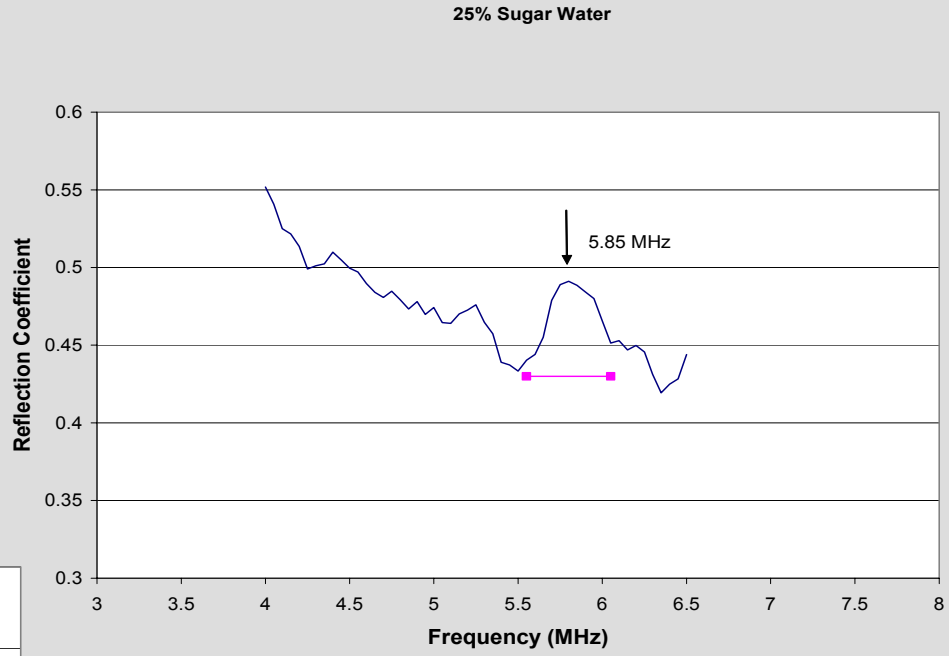
- Peak in data in receive transducer at critical frequency.

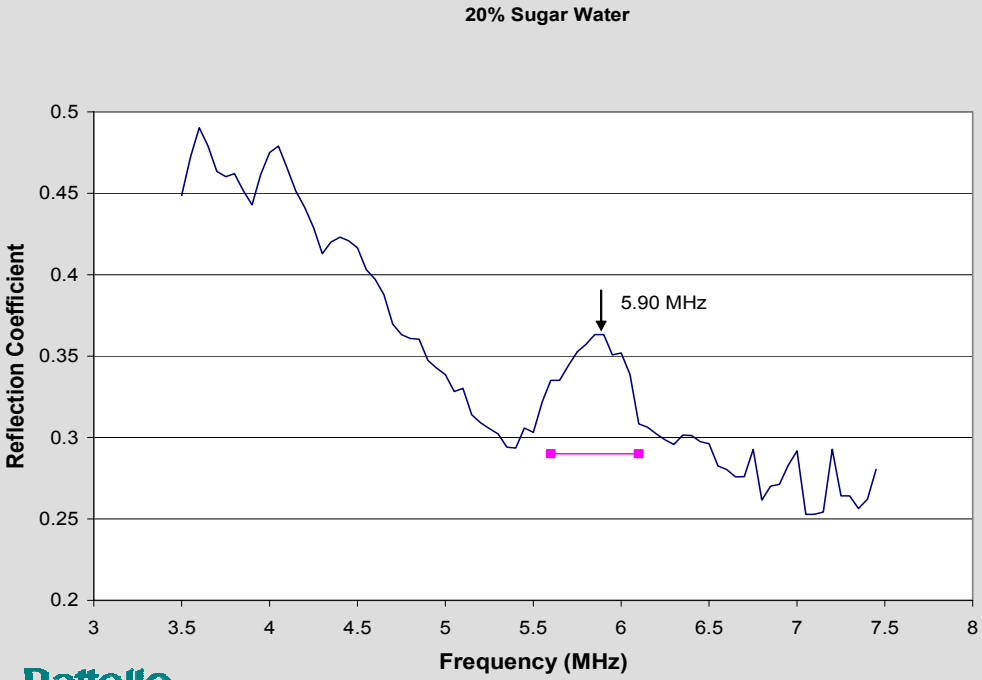
Results for Liquids



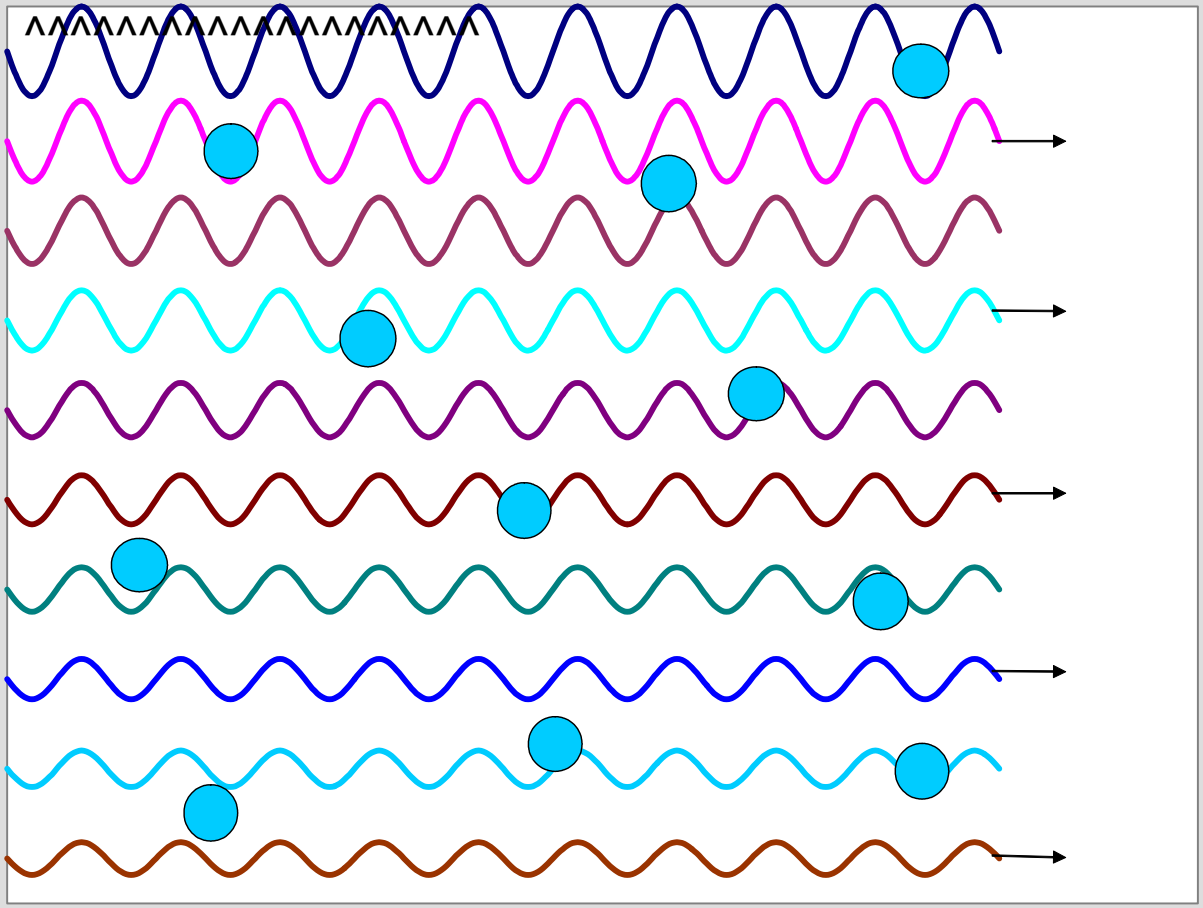


Results for Liquids (contd)





Evanescent Wave and Particle Size Measurement: Bulk Measurement



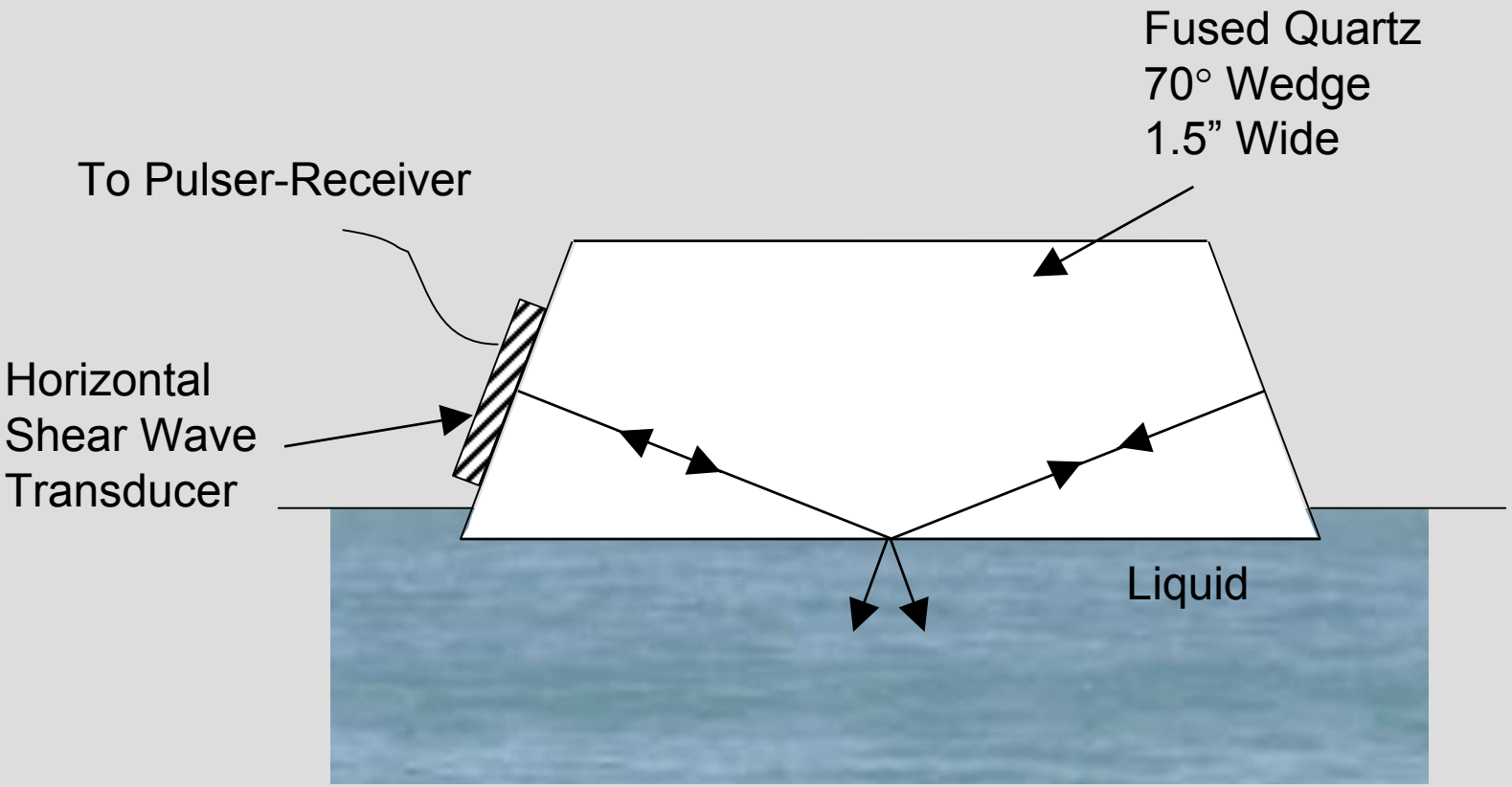
Evanescent Wave and Particle Size Measurement: Bulk Measurement (contd)

- Evanescent wave interacts with particles in slurry and energy is lost.
- Amplitude at critical frequency is reduced.
- Collaborators at University of Washington are developing an algorithm to relate reduction in amplitude to particle size.
- Also considering UDGS to measure viscosity and this analysis is also underway.

Path Forward

- Apparatus to measure particle size has been designed and is currently being fabricated.
- Selection of polystyrene particles have been purchased.
- Experiments will be carried out to observe decrease in amplitude for various particle sizes.
- Experiments will also be carried out to test the ability of UDGS to see changes in viscosity.

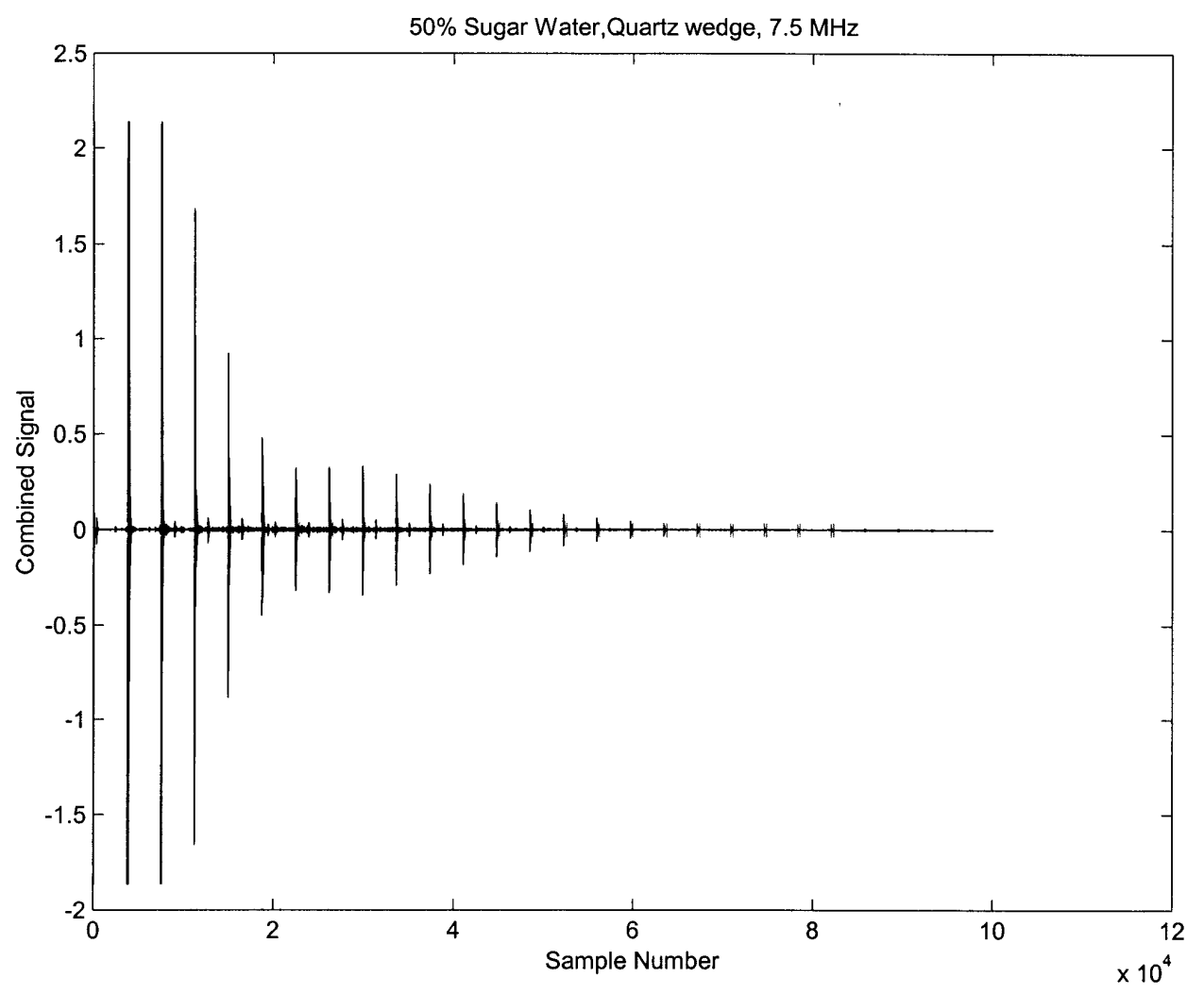
Apparatus for Multiple Reflections



Apparatus for Multiple Reflections (contd)

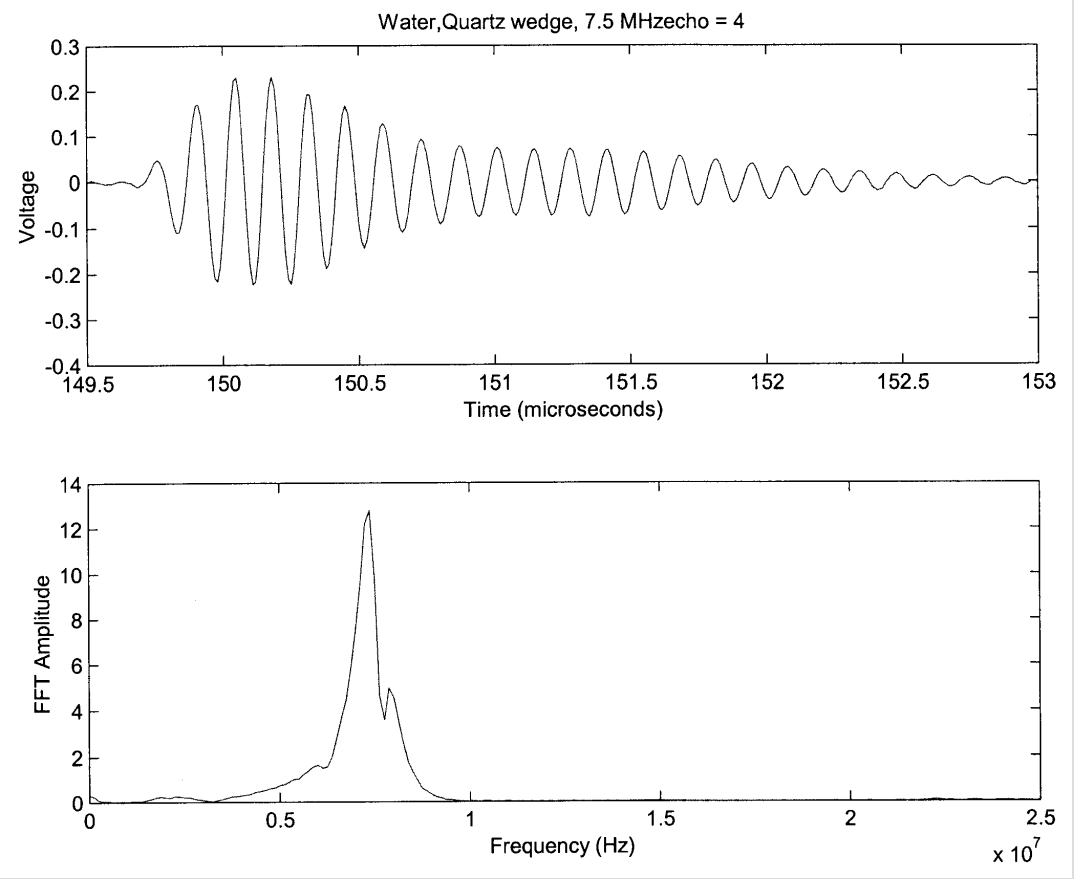
- Shear waves make many reflections between the two inclined surfaces.
- RC at quartz-liquid interface = $\frac{\text{amount reflected}}{\text{amount incident}}$
- Reflection coefficient is dependent upon the **viscosity**.
- The reflection coefficient decreases as the viscosity increases because more energy is transmitted into the liquid.

Multiple Reflection Data

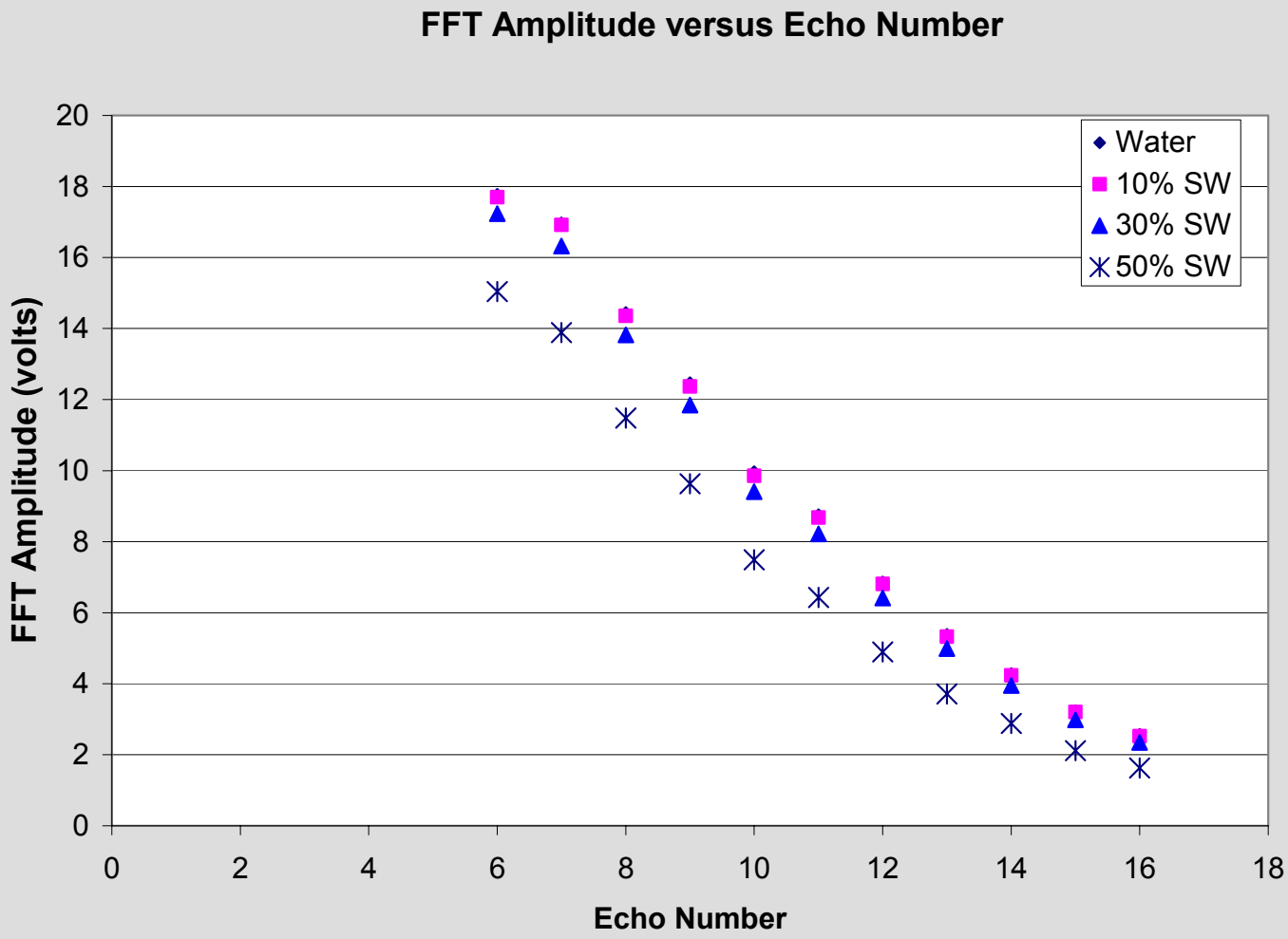


Signal and FFT

- Obtain amplitude at a frequency of 7.5 MHz for each echo.

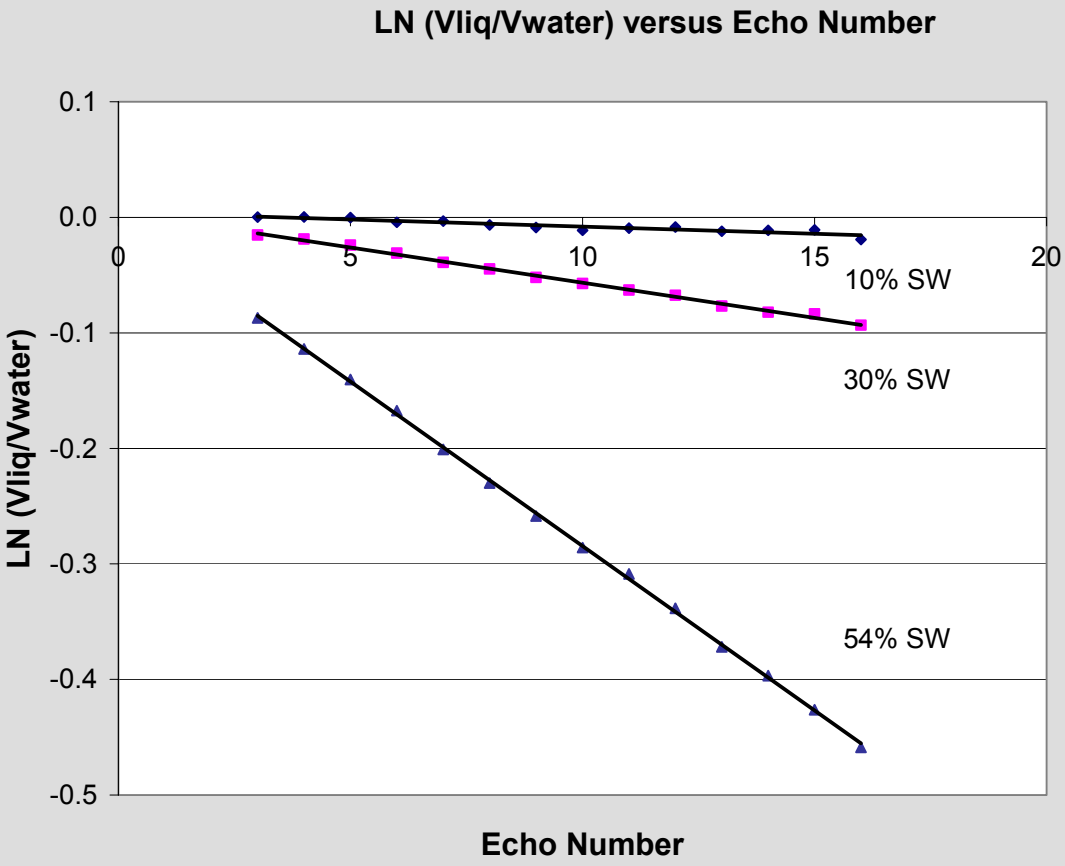


Basic Data


FFT Amplitude versus Echo Number
FFT Amplitude (volts)
Echo Number
Water
10% SW
30% SW
50% SW
0
2
4
6
8
10
12
14
16
18
20

Analysis

- Obtain
  $\frac{\text{FFT amplitude liquid}}{\text{FFT amplitude water}}$
- Plot as the logarithm versus echo number
- Reason: The only difference between liquid and water data is due to reflection at interface. All other factors cancel out.



Slope >>>> Reflection Coefficient >>>> (Viscosity)(Density)

Self-Calibrating Feature

- GOAL: Possibility of on-line in-situ sensor.
- Water is a reference and data for water stored in computer code.
- What happens if pulser voltage changes slightly? Is viscosity measurement in error? **NO!**
- Suppose the pulser voltage drops by 5%. Then each echo will also drop by 5%. On a plot of $LN(V_{liq}/V_{water})$ versus the echo number, the straight line will occur at a different place, **but the slope will be the same**. Concept tested experimentally.
- Measurement is not affected by changes in the pulser voltage >>> self-calibrating.
- Patent pending on self-calibrating feature for density and viscosity measurement.

Results

Liquid	Slope	Rc_{liquid}	Product of Density and Viscosity (cP-g/cm^3)	Density by Weight (g/cm^3)	Viscosity at 22 C (centipoise)	Handbook Viscosity at 20 C (centipoise)
10% SW	-1.28E-03	0.99594	1.401	1.038	1.35±0.04	1.33
30% SW	-6.15E-03	0.99352	3.587	1.121	3.20±0.04	3.18
54% SW	-2.83E-02	0.98257	26.313	1.253	21.0±0.2	24.6

Path Forward

- Increase sensitivity using higher frequency transducer.
- Measure density.
- Sensor with both features is currently being fabricated.