2.5 In Situ Sensor Development: Ultrasonic Density Measurement Probe

Technology Need

All DOE sites with radioactive wastes stored in tanks need to measure density of the waste supernate, the mixed layer, and the settled sludge, to characterize the waste and to ensure that waste is sufficiently mixed and meets criteria to sustain transport prior to pumping waste from the tanks. The ultrasonic reflection coefficient sensor can be used to meet these DOE needs to measure bulk density in tanks and during transport in pipelines. Accurate measurement and tracking of density and density variation in real time provide the potential to control the transport process and to sustain steady transport without transport line blockage. This task supports the US DOE TFA need for real-time measurement of slurry density in-tank and during pipeline transport. In situ density measurements, in the supernatant and mixed layer, provide a profile of the waste density as a function of elevation. These measurements are useful in several applications: to profile the supernate and mixed layer prior to selection of mobilization and retrieval technology, and to profile the supernate and mixed layer during mobilization and retrieval to provide real-time monitoring of the density profile changes during mobilization and retrieval. As the profile reaches a steady state, the success of mobilization and mixing can be quantified. A constant profile shows a fully mixed tank. A profile that varies with elevation shows a stratified tank. Real-time analysis of this data will provide feedback during waste mixing to ensure that waste is retrieved for transport only when it meets the transport criteria. Density measurements can also be used to monitor solids settling, sludge washing, and pretreatment operations.

Technology Description

This project is developing an in situ technique to measure fluid (liquid and slurry) density in vessels and in pipelines. The sensor can be used to measure density with real-time measurement update. The method is based on the reflection coefficient of the ultrasonic signal as it passes through a wedge and impacts the slurry to provide data to calculate slurry density. The bottom surface of the wedge must contact the fluid whose density is to be measured. Alternatively, the sensor can be submerged in the fluid, if this is advantageous. Sensor operation is described in Figure 2.5-1

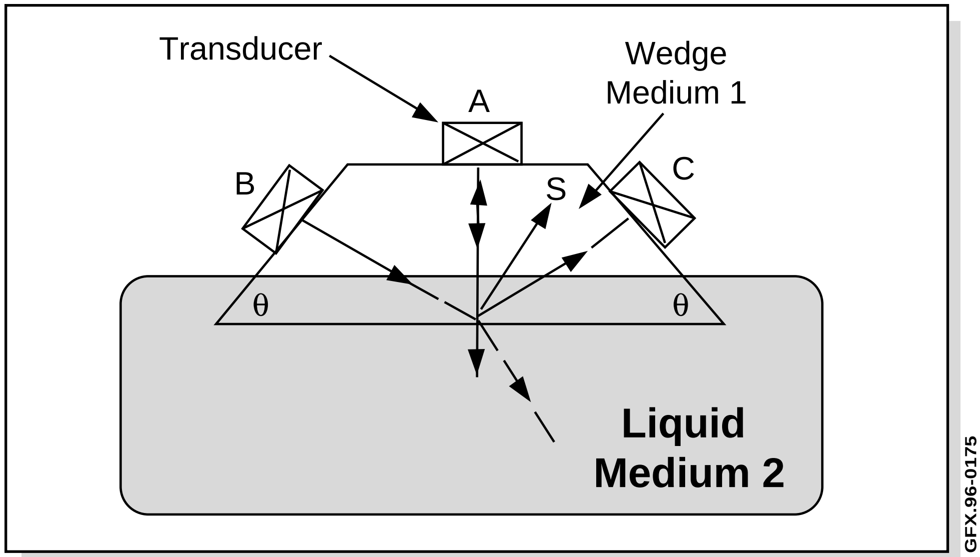

Figure 2.5-1 Reflection Coefficient Sensor Configuration

The transducers operate at an ultrasonic frequency of a million cycles per second. Ultrasound emitted from transducer A travels through the wedge material and strikes the wedge-fluid interface; part of the signal is reflected and travels back to transducer A, producing a voltage signal or echo; part of the signal is transmitted into the liquid. Similarly, when the ultrasound from transducer B strikes the wedge-liquid interface: 1) some is reflected to transducer C producing a voltage signal, 2) some of the longitudinal wave mode converts to a shear wave, and 3) some is transmitted into the liquid. The double arrows along the direction of the ray indicate longitudinal waves and those perpendicular, shear waves. The signals of interest are those reflected back to A and received by C. In both cases, the reflection coefficients are obtained by comparing the voltages on the transducers when the bottom surface is in contact with a liquid to a reference measurement made in air.

The reflection coefficients depend upon 1) the density of the wedge, 2) the speed of the longitudinal wave in the wedge, 3) the speed of the shear wave in the wedge, 4) the angle at which the ultrasound beam strikes the surface, 5) the speed of the longitudinal wave in the liquid, and 6) the density of the slurry or liquid. Only the last two of these quantities are unknown. By measuring two reflection coefficients from transducers A and B, one has two equations with two unknowns, and therefore the density of the liquid and the speed of sound in the liquid can be determined.

Experiments to verify this technique were performed using solutions of sugar in water, 2-propanol, paraffin oil, trichloroethane, and slurries consisting of silicon dioxide particles (0.0015 in. diameter) in water. Density measurement uncertainties were less than 3%. For slurries, the ultrasonic wavelength is many times the diameter of the particles; individual particles cannot be resolved, and the ultrasound senses an average density.

The task objectives in FY96 are to develop an in situ ultrasonic sensor to measure slurry density in tanks and during pipeline transport, and to demonstrate this sensor during nonradioactive transports tests using waste simulants. Objectives in FY97 are to complete a radiation hardened probe and to conduct a radioactive demonstration in-tank and/or in-pipeline at a site to be selected. The objective in FY98 is to transfer the technology to the private sector to commercialize the ultrasonic density measurement system for radioactive in-tank and pipeline density measurement.

Benefits

This sensor provides a simple in situ method to measure slurry or liquid density in real time. Real-time, in situ density data of liquids, and slurries inside waste storage tanks and in pipelines can be used to characterize wastes prior to and during mixing and transfer operations to provide process monitoring and control. Multiple sensors arranged over a range of elevations can provide stratification or settling information.

There are several advantages to this reflection coefficient method. One novel feature of this method is that it can measure the density of very attenuative slurries. Secondly, the voltage on the transducers can be low (on the order of 30 V) because the signals travel only a short distance; this is important for safety considerations. Thirdly, no previous laboratory calibration measurements are needed because the density is determined directly.

Collaboration/Technology Transfer

Sensor development is occurring at Pacific Northwest National Laboratory (PNNL). Selection of a site for radioactive demonstration of the technology in FY97 is underway. A patent application has been filed for this technology. The technology is available for licensing.

Accomplishments

- This project was initiated in March 1996.
- A patent for the technique was filed in April 1996.

TTP Information

The In Situ Sensor Development: Ultrasonic Density Measurement Probe technology development activities are funded under the following Technical Task Plan (TTP):

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Bibliography of Key Publications

Greenwood, M.S., and J. Lail. "Ultrasonic Reflection Coefficient Sensor to Measure the Density of a Liquid," submitted to *Journal of the Acoustical Society of America* (1996).

Greenwood, M.S., and J. Lail. "Using Reflection Coefficients to Measure the Velocities of Sound in a Solid," submitted to *Journal of the Acoustical Society of America* (1996).