U.S. Department of Energy

Final Report

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

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EXECUTIVE SUMMARY

The principle objective of the project was 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 accomplished during the first three years of DOE funding was devoted to the development of a rigorous theory for acoustic wave propagation through solid-liquid (S-L) and solid-gas-liquid (S-G-L). In the first funding period we developed an acoustic probe for S-G-L suspensions that has resulted in a theory, supported by our experiments, to describe small amplitude acoustic wave propagations in dilute suspensions (Norato, 1999; Spelt et al., 1999, 2001; Norato et al. 2002). The theory agrees well with experimental data of sound attenuation over a wide range of particle sizes, frequencies, and weight percent solids. We have also completed theoretical and experimental investigation on the effect of entrained gas bubbles on the attenuation. This analysis permits us to determine the S-L weight percent in the presence of bubbles.

The work accomplished during the second three years of DOE funding, including the no cost time extension, was to develop and demonstrate the application of the acoustic monitor on a flow loop through which a S-L and S-G-L suspension is flowing. Toward this objective a flow loop was constructed at Syracuse University, the acoustic monitor was constructed and tested, electronics and signal analysis software necessary to operate the monitor was developed, and tests were conducted on the flow loop to demonstrate the capability of the monitor to measure solids in S-L and S-G-L slurries in real time. The acoustic monitor is shown to have a rapid response time of 0.5s. For S-L slurries measurements in-line over the range of 0.5 to 7.25 weight percent, the percent average absolute relative deviation (AARD) is 11% for acoustic monitor measurements plotted against in-line sample port measurements. These results are for ceramic microspheres (G-800). Similar results were observed for kaolin-bentonite (KB) slurries where an AARD of 5% was achieved for a comparison of solids weight percent in the range of 3.0 to 7.0 weight percent. The acoustic monitor and associated software also shows capability to measure solids weight percent in S-G-L slurries of ceramic spheres and kaoline-bentonite. Slurries of G-800 at about 1.0 solids weight percent can be measured at 3% AARD and slurries of KB at about 7.0 solids weight percent can be measured at 4% AARD with gas concentrations increasing from 0.005 to 0.1 volume percent in the flow loop. This project resulted in the successful demonstration of the Syracuse Acoustic Monitor (SAM) to measure low concentrations of solids in S-L and S-G-L slurries.

The results of this project have relevance to the DOE mission of mobilizing, transporting and processing solid-liquid slurries by providing a reliable and safe monitor of solids concentration in these slurries. Significant impact is expected for application as an accurate, safe and reliable monitor which is non-invasive to quantify across site transfers of dilute and concentrated slurries from storage tanks to processing facilities for high level waste treatment. Application is also expected for process stream monitoring to concentrate solids in nuclear waste slurries processing. A continuation project will demonstrate this latter application.

4. PERSONNEL SUPPORTED

Principal Investigator:Prof. Lawrence L. Tavlarides, Syracuse University
Co- Principal Investigator:Prof. Ashok Sangani, Syracuse University
Co-Investigator:Dr. Margaret Greenwood, PNNL
Post-Doctoral Student:Dr. Peter Spelt, currently at Imperial College,
London, UK
PhD Student:Dr. Michael A. Norato, currently at Westinghouse
SRTC
M.S. Student:Mr. Mark Hedges, currently at Kionex, Inc.
M.S. Student:Mr. Eric Dievendorf, currently at Blauslow, Bach
and Lee, Inc.
Research Associate:Mr. Alexander Shcherbakov, on leave for Institute
for Superhard Materials, Kiev, Ukraine

5. PUBLICATIONS

- 5.1. Norato, M.A. "Acoustic Probe for the Characterization of Solid-Gas-Liquid Slurries," Ph.D. Thesis, Syracuse University, May 1999.
- 5.2. Hedges, M., "Ultrasound Characterization of Low Volume Fraction Solid-Liquid Slurries," M.S. Thesis, Syracuse University, January, 2001.
- 5.3. Spelt, P.D.M., Norato, M.A., Sangani A.S., and Tavlarides, L.L., "Determination of Particle Size Distributions from Acoustic Wave Propagation," Physics of Fluids, Vol. 11, ns 1065-1080 (1999).
- 5.4. Spelt, P.D.M., Norato, M.A., Sangani A.S., Greenwood, M.S., and Tavlarides, L.L., "Attenuation of Sound in Concentrated Suspensions: Theory and Experiments," J. of Fluid Mechanics, 420, 1-36 (2001).
- 5.5. In preparation from Norato's Thesis.
- 5.6. In preparation from Hedges' Thesis.
- 5.5. Dievendorf, E. "Acoustic Monitor for Real-Time Analysis of Solids Concentrations in Solid-Gas-Liquid Slurry," M.S. Thesis, Syracuse University, May 2004.
- 5.8. In preparation from Dievendorf's Thesis.

6. PATENTS

- 6.1. Tavlarides, L.L., Norato, M., Shcherbakov, A., Sangani, A., “Acoustic Monitor for Solids Measurements in Solid-Liquid and Solid-Gas-Liquid Slurries,” U.S. Patent Application in preparation, 2003.

7. FUTURE WORK

Future work is in progress to complete the project through support by Office of Science (BER), U.S. Department of Energy, Grant No. DE-FG02-03ER63658. The proposed work includes: refinement of the software for accurate and rapid data analysis of solid-liquid-gas slurries; demonstration of the acoustic monitor for SRS surrogate slurries; development of a metal (or ceramic) housing for the monitor; testing the redesigned unit under filtration operation; and modification of the acoustic monitor to a more compact pulse-echo configuration for in-tank placement.

8. REFERENCES

- 8.1. Norato, M.A., Spelt, P.D.M., Sangani, A.S., Tavlarides, L.L., "Effects of Entrained Gas Bubbles on the Measurement of Ultrasound Attenuation in Slurries," Ultrasonics, Submitted, 2002.
- 8.2. Norato, M.A., “Acoustic Probe for the Characterization of Solid-Gas-Liquid Slurries,” Ph.D. Thesis, Syracuse University, May 1999.
- 8.3. Spelt, P.D.M., Norato, M.A., Sangani, A.S., and Tavlarides, L.L., “Determination of Particle Size Distributions from Acoustic Wave Propagation,” Physics of Fluids, Vol. 11 ns, 1065-1080 (1999).
- 8.4. Spelt, P.D.M., Norato, M.A., Sangani, A.S., Greenwood, M.S., and Tavlarides, L.L., “Attenuation of Sound in Concentrated Suspensions: Theory and Experiments,” J. of Fluid Mech. Vol. 430, 51-86 (2001).

9. PRESENTATIONS

- 9.1. L.L. Tavlarides, P. Spelt, M.A. Norato, M. Greenwood, A. Sangani, "Acoustic Probe for Characterization of Solid-Gas-Liquid Slurries," US DOE EMSP National Workshop, April 24-27, 2000, Atlanta, GA.
- 9.2. L.L. Tavlarides, "Acoustic Probe for Solid/Gas/Liquid Suspensions," DOE-TFA FY 2001 Midyear Review, Salt Lake City, UT, March 12-16, 2001.
- 9.3. M. Hedges, A.S. Sangani, L.L. Tavlarides, "Ultrasonic Characterization of Low Volume Fraction Solid-Liquid Slurries," MIXING XVIII – 18th Biennial Conference on Mixing, Pocono Manor, PA, June 24-29, 2001.
- 9.4. A.V. Shcherbakov, J.S. Lee, E. Dievendorf, A. Sangani, L.L. Tavlarides, "An Ultrasonic Monitoring System for Real-Time Measurement of Solid Concentrations in Solid-Gas-Liquid Slurries," AIChE 2002 Annual Meeting, Indianapolis, IN, Nov. 3-8, 2002.
- 9.5. E. Dievendorf, O. Shcherbakov, A.S. Sangani, L.L. Tavlarides, "Acoustic Monitor for Solids Measurements on Solid-Gas-Liquid Slurries," XIX Mixing Conference, Lake Placid, NY, June 15-20 2003.
- 9.6. L.L. Tavlarides, O. Shcherbakov, E. Dievendorf, A.S. Sangani, "Acoustic Monitor for Solid-Liquid Slurries Measurements at Low Weight Fractions," 226th ACS National Meeting and Expo, New York City, NY, September 10, 2003. – Invited
- 9.7. L.L. Tavlarides, O. Shcherbakov, E. Dievendorf, A.S. Sangani, "Acoustic Monitor for Slurries Measurements at Low Weight Fraction," AIChE 2003 Annual Meeting, San Francisco, CA, November 19, 2003.