5. Conclusions

Gamma-densitometry tomography (GDT) and electrical-impedance tomography (EIT) systems have been developed and applied to measure material distribution in two-phase and three-phase flows. Two bubble-column test beds, one at laboratory scale and one at industrial scale, have been employed to facilitate diagnostics development and validation. GDT and EIT have been applied to these test beds and related experiments, and comparisons have been made with techniques such as level rise (LR) and differential pressure (DP). When two techniques could be compared, fairly good to very good agreement has been observed.

GDT is the most mature technique and is now routine in application. It has successfully measured material distributions for gas-liquid flows in large steel-walled vessels. EIT is not as mature. While applied successfully to measure the distribution of a dilute suspension of small insulating glass spheres in water, EIT has not yet been completely successful in measuring material distributions in gas-liquid bubble-column flow. Several factors have been identified where significant improvements can be made. DP was found to be a reliable indicator of volumetrically averaged material-distribution properties for bubble-column flow, at least when these properties do not vary strongly in the vertical direction.

A. FEMEIT Files

The following files were used to generate one of the FEMEIT validation examples shown previously. Some files have had portions removed for brevity.

```
nodelm.dat
441
  1 0.996917E+00 0.784591E-01
  2 0.987688E+00 0.156434E+00
  3 0.972370E+00 0.233445E+00
(some lines removed for brevity)
439 0.919545E-01 -.919545E-01
440 0.130043E+00 0.000000E+00
441 0.000000E+00 0.000000E+00
800
  1   80    1  152
  2    1    2   81
  3    2    3   82
(some lines removed for brevity)
798  438  437  427
799  439  438  429
800  440  439  431
```

```
exinfo.dat
16
 1   5
 2  10
 3  15
 4  20
 5  25
 6  30
 7  35
 8  40
 9  45
10  50
11  55
12  60
13  65
14  70
15  75
16  80
```

```
exdata.dat
1   2 0.10000E+03
 0.62400E+03 0.00000E+00 0.23600E+03 0.26900E+03
 0.28400E+03 0.29300E+03 0.30000E+03 0.30600E+03
 0.31000E+03 0.31400E+03 0.31900E+03 0.32300E+03
 0.32900E+03 0.33700E+03 0.35200E+03 0.38500E+03
1   3 0.10000E+03
 0.77700E+03 0.38900E+03 0.10000E+01 0.27200E+03
 0.32000E+03 0.34300E+03 0.35900E+03 0.37300E+03
 0.38300E+03 0.39100E+03 0.39900E+03 0.40900E+03
 0.41900E+03 0.43500E+03 0.45800E+03 0.50600E+03
(some lines removed for brevity)
15  16 0.10000E+03
 0.24200E+03 0.27700E+03 0.29100E+03 0.30000E+03
 0.30700E+03 0.31200E+03 0.31800E+03 0.32200E+03
 0.32700E+03 0.33100E+03 0.33700E+03 0.34600E+03
 0.36000E+03 0.39400E+03 0.63100E+03 0.00000E+00
```

```
conpar.dat
0.8 0.1 1. 0.00001 0.00001 1.
50 4 4 2
0.3
0.3
0.
0.
0.99
0.03
```

```
parcon.dat
0.80000E+00  0.10000E+00  0.10000E+01  0.10000E-04  0.10000E-04  0.10000E+01
50    4    4    2
0.28613E+00 -.48785E-07   1
0.98310E-01 -.35085E-06   2
-.73243E+00 -.19771E-05   3
0.28811E+00 0.89886E-06   4
0.99000E+00
0.30000E-01
```

```
nodcon.dat
1 0.28613E+00 -.48785E-07
2 0.28613E+00 -.48785E-07
3 0.28613E+00 -.48785E-07
(some lines removed for brevity)
439 0.28613E+00 -.48785E-07
440 0.28613E+00 -.48785E-07
441 0.28613E+00 -.48785E-07
```

References

Adkins, D. R., Shollenberger, K. A., O'Hern, T. J., and Torczynski, J. R., 1996, "Pressure Effects on Bubble Column Flow Characteristics," in *ANS Proceedings of the 1996 National Heat Transfer Conference*, THD-Vol. 9, American Nuclear Society, LaGrange Park, IL, pp. 318-325.

Barber, C. D., Brown, B. H., and Freeston, I. L., 1983, "Imaging Spatial Distributions of Resistivity Using Applied Potential Tomography," *Electronics Letters*, Vol. 19, pp. 933-935.

Brown, G. O., Stone, M. L., and Gazin, J. E., 1993, "Accuracy of Gamma Ray Computerized Tomography in Porous Media," *Water Resources Research*, Vol. 29, No. 2, pp. 479-486.

Ceccio, S. L., and George, D. L., 1996, "A Review of Electrical Impedance Techniques for the Measurement of Multiphase Flows," *Journal of Fluids Engineering*, Vol. 118, pp. 391-399.

Crowe, C. T., Troutt, T. R., and Chung, J. N., 1996, "Numerical Models for Two-Phase Turbulent Flows," *Annual Reviews of Fluid Mechanics*, Vol. 28, pp. 11-43.

Deckwer, W.-D., and Schumpe, A., 1993, "Improved Tools for Bubble Column Reactor Design and Scale-Up," *Chemical Engineering Science*, Vol. 48, No. 5, pp. 889-911.

Devanathan, N., Moslemian, D., and Dudukovic, M. P., 1990, "Flow Mapping in Bubble Columns Using CARPT," *Chemical Engineering Science*, Vol. 45, No. 8, pp. 2285-2291.

Dickin, F., and Wang, M., 1996, "Electrical Resistance Tomography for Process Applications," *Measurement Science and Technology*, Vol. 7, No. 3, pp. 247-260.

Dudukovic, M. P., Devanathan, N., and Holub, R., 1991, "Multiphase Reactors: Models and Experimental Verification," *Revue de L'Institut Francais du Petrole*, Vol. 46, No. 4, pp. 439-465.

Dudukovic, M. P., Degaleesan, S., Gupta, P., and Kumar, S. B., 1997, "Fluid Dynamics in Churn-Turbulent Bubble Columns: Measurements and Modeling," in Symposium on Gas-Liquid Two-Phase Flows, edited by T. J. O'Hern, J. Bataille, U. S. Rohatgi, M. Shoukri, J. Navickas, I. Celik, American Society of Mechanical Engineers, New York, in press.

Duraiswami, R., 1993, "Bubble Density Measurement Using an Inverse Acoustic Scattering Technique," in *Cavitation and Multiphase Flow Forum*, FED-Vol. 153, edited by O. Furuya, American Society of Mechanical Engineers, New York, pp. 67-73.

Duraiswami, R., Sarkar, K., and Chahine, G. L., 1995, *2DynaEIT: A Boundary Element Code for Efficient Electric Impedance Tomography -- Theory and Test Cases*, Dynaflow Report 95012_1_SAND, Dynaflow, Inc., Fulton, MD.

Dyakowski, T., 1996, "Process Tomography Applied to Multi-Phase Flow Measurement," *Measurement Science and Technology*, Vol. 7, pp. 343-353.

Elghobashi, S., 1994, "On Predicting Particle-Laden Turbulent Flows," *Applied Scientific Research*, Vol. 52, pp. 309-329.

Fan, L.-S., and Tsuchiya, K., 1993, "Bubble Flow in Liquid-Solid Suspensions," in *Particulate Two-Phase Flow*, edited by M. C. Roco, Butterworth-Heinemann, New York, Chapter 23.

Fluid Dynamics International, 1996, *FIDAP Users Manual*, version 7.6, Fluid Dynamics International, Evanston, IL.

Herman, G. T., 1983, "The Special Issue on Computerized Tomography," *Proceedings of the IEEE*, Vol. 71, No. 3, pp. 291-292.

Hewitt, G. F., 1978, *Measurement of Two-Phase Flow Parameters*, Academic Press, London.

Howard, J. N., editor, 1985, *Applied Optics*, Vol. 24, No. 23.

Hua, P., and Woo, E. J., 1990, "Reconstruction Algorithms," in *Electrical Impedance Tomography*, edited by J. G. Webster, Adam Hilger, Bristol and New York, Chapter 10.

Ingber, M. S., Womble, D. E., and Mondy, L. A., 1994, "A Parallel Boundary Element Formulation for Determining Effective Properties of Heterogeneous Media," *International Journal for Numerical Methods in Engineering*, Vol. 37, pp. 3905-3919.

Jackson, N. B., Torczynski, J. R., Shollenberger, K. A., O'Hern, T. J., and Adkins, D. R., 1996a, "Sandia Support for PETC Fischer-Tropsch Research: Experimental Characterization of Slurry-Phase Bubble-Column Reactor Hydrodynamics," in *Proceedings of the First Joint Power and Fuel Systems Contractors Conference: Indirect Liquefaction*, Pittsburgh Energy Technology Center, Pittsburgh.

Jackson, N. B., Torczynski, J. R., Shollenberger, K. A., O'Hern, T. J., and Adkins, D. R., 1996b, "Hydrodynamic Characterization of Slurry Bubble-Column Reactors for Fischer-Tropsch Synthesis," in *Proceedings of the Thirteenth Annual International Pittsburgh Coal Conference*, Vol. 2: "Coal-Energy and the Environment," edited by S.-H. Chiang, University of Pittsburgh Center for Energy Research, Pittsburgh, PA, pp. 1226-1231.

Jaeger, H. M., Nagel, S. R., and Behringer, R. P., 1996, "Granular Solids, Liquids, and Gases," *Reviews of Modern Physics*, Vol. 68, No. 4, pp. 1259-1273.

Jamialahmadi, M., Branch, C., and Müller-Steinhagen, H., 1994, "Terminal Bubble Rise Velocity in Liquids," *Transactions of the Institution of Chemical Engineers*, Vol. 72, Part A, pp. 119-122.

Jones, O. C., Lin, J.-T., Ovacik, L., and Shu, H.-J., 1993, "Impedance Imaging Relative to Gas-Liquid Systems," *Nuclear Engineering and Design*, Vol. 141, pp. 159-176.

Joshi, J. B., Patil, T. A., Ranade, V. V., and Shah, Y. T., 1990, "Measurement of Hydrodynamic Parameters in Multiphase Sparged Reactors," *Reviews in Chemical Engineering*, edited by N. R. Amundson, and D. Luss, Freund Publishing House, London, pp. 73-227.

Kashiwa, B. A., Padial, N. T., Rauenzahn, R. M., and VanderHeyden, W. B., 1993, *A Cell-Centered ICE Method for Multiphase Flow Simulations*, Los Alamos Report LA-UR-93-3922, Los Alamos National Laboratory, Los Alamos, NM.

Kashiwa, B. A., and Rauenzahn, R. M., 1994, *A Multimaterial Formalism*, Los Alamos Report LA-UR-94-771, Los Alamos National Laboratory, Los Alamos, NM.

Knoll, G. F., 1979, *Radiation Detection and Measurement*, John Wiley & Sons, New York, p. 346.

Krishna, R., and Ellenberger, J., 1996, "Gas Holdup in Bubble Column Reactors Operating in the Churn-Turbulent Regime," *AIChE Journal*, Vol. 42, No. 9, pp. 2627-2634.

Kumar, S. B., Devanathan, N., Moslemian, D., and Dudukovic, M. P., 1994, "Effect of Scale on Liquid Recirculation in Bubble Columns," *Chemical Engineering Science*, Vol. 49, No. 24, Part B, pp. 5637-5652.

Kumar, S. B., Moslemian, D., Dudukovic, M. P., 1995a, "A γ-Ray Tomographic Scanner for Imaging Voidage Distribution in Two-Phase Flow Systems," *Flow Measurement and Instrumentation*, Vol. 6, No. 1, pp. 61-73.

Kumar, S., Vanderheyden, W. B., Devanathan, N., Padial, N. T., Dudukovic, M. P., Kashiwa, B. A., 1995b, "Numerical Simulation and Experimental Verification of the Gas-Liquid Flow in Bubble Columns," *AIChE Symposium Series*, Vol. 91, N. 305, pp. 11-19.

Lamarsh, J. R., 1983, *Introduction to Nuclear Engineering*, Addison-Wesley, Reading, MA, pp. 78-88, 472-488, 648-649.

Lapp, R. E., and Andrews, H. L., 1972, *Nuclear Radiation Physics*, Prentice-Hall, Englewood Cliffs, NJ, pp. 247-250.

Lin, J.-T., Jones, O. C., Ovacik, L., and Shu, H.-J., 1993, "Advances in Impedance Imaging Relative to Two-Phase Flow," *ANS Proceedings*, Thermal Hydraulics Division, Vol. 7, American Nuclear Society, LaGrange, IL, pp. 68-75.

Loh, W. W., and Dickin, F. J., 1996, "Improved Modified Newton-Raphson Algorithm for Electrical Impedance Tomography," *Electronics Letters*, Vol. 32, No. 3, p. 206.

MacCuaig, N., Seville, J. P. K., Gilboy, W. B., and Clift, R., 1985, "Application of Gamma-Ray Tomography to Gas Fluidized Beds," *Applied Optics*, Vol. 24, No. 23, pp. 4083-4085.

Mann, R., Dickin, F. J., Dyakowski, T., Williams, R. A., Edwards, R. B., Forrest, A. E., and Holden, P. J., 1997, "Application of Electrical Resistance Tomography to Interrogate Mixing Processes at Plant Scale," *Chemical Engineering Science*, in press.

Meyerhof, W. E., 1967, *Elements of Nuclear Physics*, McGraw-Hill, New York, pp. 91-103.

Moslemian, D., Devanathan, N., and Dudukovic, M. P., 1992, "Radioactive Particle Tracking Technique for Investigation of Phase Recirculation and Turbulence in Multiphase Systems," *Review of Scientific Instruments*, Vol. 63, No. 10, pp. 4361-4372.

Munshi, P., 1990, "A Review of Computerized Tomography with Application to Two-Phase Flows," *Sadhana*, Vol. 15, Part 1, pp. 43-55.

O'Hern, T. J., Torczynski, J. R., Ceccio, S. L., Tassin, A. L., Chahine, G. L., Duraiswami, R., and Sarkar, K., 1995a, "Development of an Electrical Impedance Tomography System for an Air-Water Vertical Bubble Column," in *Forum on Measurement Techniques in Multiphase Flows*, FED-Vol. 233, edited by T. J. O'Hern, A. Naqwi, C. Presser, and R. D. Skocypec, American Society of Mechanical Engineers, New York, pp. 531-537.

O'Hern, T. J., Torczynski, J. R., Shollenberger, K. A., and Ceccio, S. L., 1995b, "Electrical Impedance Tomography for Spatial Measurements of Gas Distribution in Multiphase Flows," *Bulletin of the American Physical Society*, Vol. 40, No. 12, p. 2004.

Pan, L., and Hewitt, G. F., 1995, "Precise Measurement of Cross Sectional Phase Fractions in Three-Phase Flow Using a Dual-Energy Gamma Densitometer," *ANS Proceedings*, Thermal Hydraulics Division, Vol. 8, pp. 71-78.

Press, W. H., Flannery, B. P., Teukolsky, S. A., and Vetterling, W. T., 1986, *Numerical Recipes: The Art of Scientific Computing*, Cambridge University Press, New York, Section 3.3, pp. 86-89.

Reda, D. C., Hadley, G. R., and Turner, J. R., 1981, "Application of the Gamma-Beam Attenuation Technique to the Measurement of Liquid Saturation for Two-Phase Flows in Porous Media," in *Instrumentation in the Aerospace Industry*, Vol. 27, *Advances in Test Measurement*, Vol. 18, Part Two, *Proceedings of the 27th International Instrumentation Symposium*, edited by K. E. Kissell, Instrument Society of America, Research Triangle Park, NC, pp. 553-568.

Savolainen, T., Kaipio, J. P., Karjalainen, P. A., and Vauhkonen, M., 1996, "An Electrical Impedance Tomography Measurement System for Experimental Use," *Review of Scientific Instruments*, Vol. 67, No. 10, pp. 3605-3609.

Shah, Y. T., and Deckwer, W.-D., 1983, "Hydrodynamics of Bubble Columns," in *Handbook of Fluids in Motion*, edited by N. P. Cheremisinoff and R. Gupta, Ann Arbor Science Publishers, Ann Arbor, MI, Chapter 22.

Shollenberger, K. A., Torczynski, J. R., Adkins, D. R., and O'Hern, T. J., 1995a, "Bubble Column Measurements Using Gamma Tomography," in *Fluid Measurement and Instrumentation*, FED-Vol. 211, edited by G. L. Morrison, M. Nishi, T. B. Morrow, and R. A. Gore, American Society of Mechanical Engineers, New York, pp. 25-30.

Shollenberger, K. A., Torczynski, J. R., Adkins, D. R., and O'Hern, T. J., 1995b, "Gamma Densitometry Tomographic Measurements of Void-Fraction Spatial Distribution in Bubble Columns," in *Frontiers in Industrial Process Tomography*, edited by D. M. Scott and R. A. Williams, Engineering Foundation, New York, p. 329.

Shollenberger, K. A., Torczynski, J. R., Adkins, D. R., O'Hern, T. J., and Jackson, N. B., 1997a, "Gamma Densitometry Tomography of Gas Holdup Spatial Distribution in Industrial Scale Bubble Columns," *Chemical Engineering Science*, in press.

Shollenberger, K. A., Torczynski, J. R., O'Hern, T. J., Adkins, D. R., Ceccio, S. L., and George, D. L., 1997b, "Comparison of Gamma-Densitometry Tomography and Electrical-Impedance Tomography for Determining Material Distribution in Liquid-Solid Flows," in *Cavitation and Multiphase Flow Forum*, edited by J. Katz and K. J. Farrell, American Society of Mechanical Engineers, New York, in press.

Taylor, L. M., and Preece, D. S., 1989, *DMC -- A Rigid Body Motion Code for Determining the Interaction of Multiple Spherical Particles*, Sandia Report SAND88-3482, Sandia National Laboratories, Albuquerque, NM.

Thompson, Kyle R., and Stoker, G. C., 1997, Private Communication, Sandia National Laboratories, Albuquerque, NM.

Torczynski, J. R., O'Hern, T. J., Adkins, D. R., Shollenberger, K. A., Mondy, L. A., and Jackson, N. B., 1994, "Sandia Support for PETC Fischer-Tropsch Research. Part A: Experimental Flows in Slurry-Phase Bubble-Column Reactors," in *Proceedings of the 1994 Coal Liquefaction and Gas Conversion Contractors' Review Conference*, edited by S. Rogers, P.-Z. Zhou, and K. Lockhart, Pittsburgh Energy Technology Center, Pittsburgh, pp. 449-456.

Torczynski, J. R., Shollenberger, K. A., O'Hern, T. J., and Adkins, D. R., 1995, "Tomographic Measurements of Volume Fractions in Multiphase Flows," *Bulletin of the American Physical Society*, Vol. 40, No. 12, p. 2004.

Torczynski, J. R., Adkins, D. R., Shollenberger, K. A., and O'Hern, T. J., 1996a, "Application of Gamma-Densitometry Tomography to Determine Phase Spatial Variation in Two-Phase and Three-Phase Bubbly Flows," in *Cavitation and Multiphase Flow Forum*, FED-Vol. 236, edited by J. Katz and K. J. Farrell, American Society of Mechanical Engineers, New York, pp. 503-508.

Torczynski, J. R., O'Hern, T. J., Shollenberger, K. A., Ceccio, S. L., and Tassin, A. L., 1996b, "Finite Element Method Electrical Impedance Tomography for Phase Distribution Determination in Multiphase Flows: Validation Calculations and Experiments," in *Cavitation and Multiphase Flow Forum*, FED-Vol. 236, edited by J. Katz and K. J. Farrell, American Society of Mechanical Engineers, New York, pp. 497-501.

Torczynski, J. R., Shollenberger, K. A., O'Hern, T. J., and Adkins, D. R., 1996c, "Gamma Densitometry Tomographic Measurements of Gas Distribution in a Large-Diameter Bubble Column," *Bulletin of the American Physical Society*, Vol. 41, No. 9, p. 1824.

Torvik, R., and Svendsen, H. F., 1990, "Modelling of Slurry Reactors. A Fundamental Approach," *Chemical Engineering Science*, Vol. 45, No. 8, pp. 2325-2332.

Toye, D., Marchot, P., Crine, M., and L'Homme, G., 1996, "Modelling of Multiphase Flow in Packed Beds by Computer-Assisted X-Ray Tomography," *Measurement Science and Technology*, Vol. 7, pp. 436-443.

Vest, C. M., 1985, "Tomography for Properties of Materials that Bend Rays: A Tutorial," *Applied Optics*, Vol. 24, No. 23, pp. 4089-4094.

Weast, R. C., editor, 1973, *CRC Handbook of Chemistry and Physics*, 54th edition, CRC Press, Cleveland, OH, p. B-133.

Webster, J. G., editor, 1990, *Electrical Impedance Tomography*, Adam Hilger, Bristol, UK.

Wilkinson, P. M., Spek, A. P., and van Dierendonck, L. L., 1992, "Design Parameters Estimation for Scale-Up of High-Pressure Bubble Columns," *AIChE Journal*, Vol. 38, No. 4, pp. 544-554.

Wolfram, S., 1996, *The Mathematica Book*, Cambridge University Press, Cambridge, UK.

Yang, Y. B., Devanathan, N., and Dudukovic, M. P., 1994, "Liquid Backmixing in Bubble Columns via Computer Automated Radioactive Particle Tracking (CARPT)," *Experiments in Fluids*, Vol. 16, No. 1, pp. 1-9.

Yorkey, T. J., Webster, J. G., and Tompkins, W. J., 1987, "Comparing Reconstruction Algorithms for Electrical Impedance Tomography," *IEEE Transactions on Biomedical Engineering*, Vol. BME-34, No. 11, pp. 843-852.

Zuber, N., and Findlay, J. A., 1965, "Average Volumetric Concentration in Two-Phase Flow Systems," *Journal of Heat Transfer*, pp. 453-468.

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MS 1324	6115	R.	J.	Glass, Jr.
MS 0749	6212	A.	P.	Sylwester
MS 0709	6212	N.	B.	Jackson (5)
MS 0841	9100	P.	J.	Hommert
MS 0828	9102	R.	D.	Skocypec
MS 0833	9103	J.	H.	Biffle
MS 0828	9104	E.	D.	Gorham
MS 0826	9111	S.	N.	Kempka, actg.
MS 0826	9111	C.	E.	Hickox (2)
MS 0826	9111	T.	J.	O'Hern (5)
MS 0834	9112	A.	C.	Ratzel (5)
MS 0834	9112	T.	W.	Grasser
MS 0834	9112	K.	A.	Shollenberger (5)
MS 0834	9112	J.	R.	Torczynski (5)
MS 0835	9113	T.	C.	Bickel
MS 0835	9113	D.	R.	Adkins (5)
MS 0827	9114	A.	S.	Geller, actg.
MS 0825	9115	W.	H.	Rutledge
MS 0836	9116	C.	W.	Peterson
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