QUANTITATIVE CAPACITIVE MEASUREMENTS OF VOIDAGE IN GAS-SOLID FLOWS

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by
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than that of the packed bed. Since Maxwell's equation tends to underpredict the voidage of a dense bed (see Section 4.1.1), the voidages may be approximately 3% greater than those calculated. However, these voidages are consistent with the behavior of a class A powder that exhibits particulate expansion in the emulsion phase.

In Fig. 4.7, a sudden compaction of the bed is clearly observed on the voidage trace. This event was simultaneously recorded on the videotape. It is characteristic of a stick-slip behavior that is often observed in narrow beds of powders showing degrees of cohesiveness. The detection of this event by the wall probe illustrates the exceptional sensitivity of this capacitance system. Within experimental error, the change of voidage associated with this event was consistent with the magnitude of the drop of the bed surface recorded on the videotape.

A similar trace was obtained with the parallel-plate probe (Fig. 4.8). The escape of bubbles, the slow collapse of the emulsion phase, and occasional stick-slip jumps were observed. However, as expected from its larger measurement volume, this probe recorded more dramatic voidage fluctuations during the bubble escape period.

4.2.2 High Temperature Tests

The high temperature capacitance probe was tested at a 20 MW utility demonstration CFB unit in Canada. The test was unexpectedly interrupted after the sensing surface separated from the probe head.

Capacitance data near the combustor's water-wall is presented in Fig. 4.9. The probe was inserted 46" into the bed, measured from the probe tip to the outer combustor wall with the probe penetrating approximately 1' into the bed. Figure 4.9 shows a drop in output voltage from 7.1 V in ambient air to 2.8 V in the combustor. This is consistent with the high density of solids expected in this region of the bed.

A low frequency oscillation of approximately 10 Hz is evident in Fig. 4.9. This may be a characteristic of the bed or it may be due to chatter of the probe head. Chatter causes the probe head to move within the lance, thus opening and closing the gap between the guard and ground halves.

Also evident in Fig. 4.9 are instabilities in the capacitance meter's output signal, demonstrated by abrupt jumps and drops in voltage. Voltages above the probe's voltage in air and below zero are physically unrealistic with respect to voidage measurements. Possible circumstances that may cause these instabilities include: a broken or loose connection, a short between the sensing, guard, and ground circuits, particle discharge on the sensing and guard surfaces, and charged particles within the probe's measurement volume. Since this data was recorded shortly before the sensing plate broke from the probe head, it is possible that a connection problem caused all or some of the instabilities. The high resistance measurements (discussed below) indicate that a short between the electrodes is unlikely. Electrostatic charging of particles may have contributed to the instabilities. However, problems with electrostatics were not detected by Kai and Furusaki during high temperature fluidized bed tests at approximately 367 °C [15].

Although limited data was collected, this test proved that the probe could withstand the harsh environment in the combustor. The probe was inserted 1 ft. deeper into the bed for materials testing. The ceramic insulators maintained a high resistivity in the bed. Measured resistances between the guard, ground, and sensing circuits ranged from 0.4 Mega-ohms to greater than 20 Mega-ohms, sufficient for operation of the capacitance meter. The probe surfaces

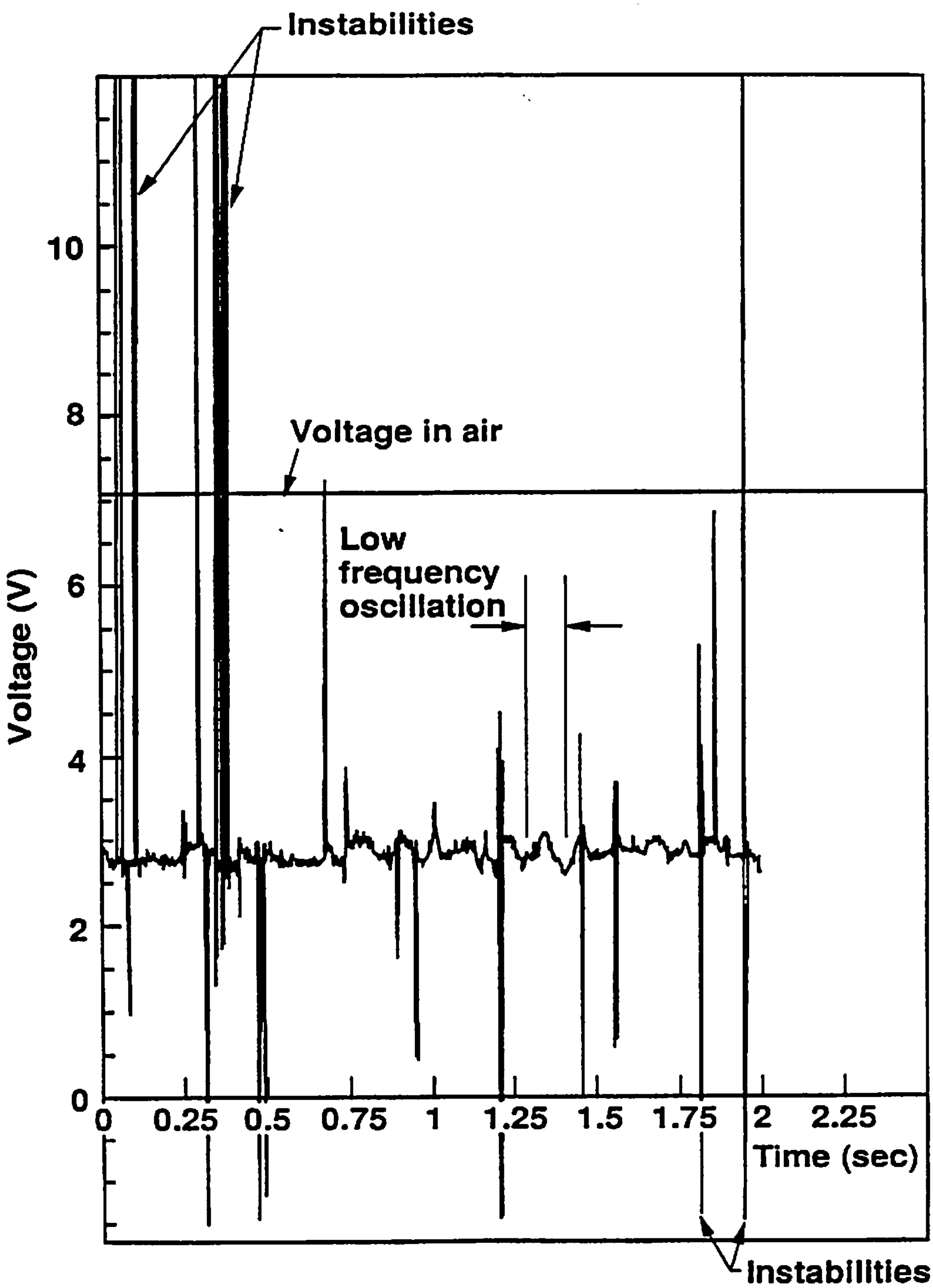

Figure 4.9. High temperature probe output near the water-wall region of the CFB. Capacitec's 4100-WB system was used for data collection. The settings were as follows: offset = 5.12 and gain = 883.6.

exhibited some oxidation which was less prominent directly above the air-cooling paths. Thus, the air was able to cool the probe head and lower the temperature of the ceramics and coaxial cable. The lance interior was kept well below the maximum operating temperature of the cables, as shown by little temperature difference between the inlet and outlet cooling water.

While writing this thesis, the probe head was re-designed to lock-in the sensing plate. The probe will be retested and used to record voidage profiles at different axial locations along the combustor.

CHAPTER FIVE
CONCLUSIONS

A new technique was presented for measuring voidage in gas-solid flows. Unlike its predecessors, the capacitance probes in this study provide *quantitative* voidage measurements at a fast sampling rate (2 kHz). Based on a guard circuit which nearly eliminates all stray and cable capacitances, these probes are sensitive enough to obtain accurate and repeatable capacitance measurements. Two configurations were studied: a parallel-plate arrangement and a non-intrusive wall probe in which all electrodes lay in the same plane. A high temperature probe was built for measurements of voidage in a circulating fluidized bed combustor.

The parallel-plate probe was tested by gradually submerging it in a bed of glass beads of known dielectric constant and packing coefficient. A modified form of Rayleigh's relation for conduction in a composite material provided the best fit to the measurements.

Approximations for the wall probe's capacitance and measurement volume were derived using complex variables. The predicted capacitance was in good agreement with the simple two-dimensional solution. Two different experiments, using glass beads and mineral oil, were performed to determine the size of the measurement volume. The results of the latter indicate a volume that extends above the probe to a distance 1.5 times the diameter of the ground surface. The effect of finite guard planes around the probe and of freely-charged surfaces in close proximity to the probe were examined.

The high temperature probe was designed and fabricated. It was demonstrated in a circulating fluidized bed combustor. Further tests in the combustor will soon be conducted to measure profiles of solid volume fraction.

REFERENCES

1. Almstedt, A.E. and Olsson, E., "Measurements of Bubble Behaviour in a Pressurized Fluidized Bed Burning Coal, Using Capacitance Probes," Proceedings of the 7th International Conference on Fluidized Bed Combustion, Philadelphia, 1982, pp. 89-98.

2. Almstedt, A.E., "Measurements of Bubble Behaviour in a Pressurized Bed Burning Coal, Using Capacitance Probes- Part II," Proceedings of the 8th International Conference on Fluidized Bed Combustion, Vol. II, Houston, 1985, pp. 865-877.

3. Biyikli, S., Tuzla, K., and Chen, J.C., "Particle Contact Dynamics on Tubes in the Freeboard Region of Fluidized Beds," AIChE Journal, Vol. 33, No. 7, July 1987, pp. 1225-1227.

4. Bottcher, C.J.S., "The Dielectric Constant of Crystalline Powders," Rec. Trav. Chim. Pays-Bas, Vol. 64, 1945, p. 47.

5. Botterill, J.S.M. and Teoman, Y., "Fluid-Bed Behaviour at Elevated Temperatures," Fluidization, eds. J.R. Grace and J.M. Matsen, Plenum Press, NY, 1980, pp. 93-100.

6. Catipovic, N.M., Fitzgerald, T.J., Jovanovic, G.N., and Levenspiel, O., "Cold Modeling of Fluidized Bed Combustors," microfiche EPRI-CS-1476, 1980.

7. Chandran, R. and Chen, J.C., "Bed-Surface Contact Dynamics for Horizontal Tubes in Fluidized Beds," AIChE Journal, Vol. 28, No.6, Nov. 1982, pp. 907-914.

8. Cheremisinoff, N.P., Instrumentation for Complex Fluid Flows, Technomic Publishing Co., Inc., Lancaster, PA, 1986, p. 83

9. Chiew, Y.C. and Glandt, E.D., "The Effect of Structure on the Conductivity of a Dispersion," Journal of Colloid and Interface Science, Vol. 94, No. 1, July 1983, pp. 90-104.

20. Meredith, R.E. and Tobias, C.W., "Resistance to Potential Flow through a Cubical Array of Spheres," Journal of Applied Physics, Vol. 31, No. 7, July 1960, pp. 1270-1273.

21. Meredith, R.E. and Tobias, C.W., "Conductivities in Emulsions," Journal of the Electrochemical Society, Vol. 108, No. 3, March 1961, pp. 286-290.

22. Meredith, R.E. and Tobias, C.W., "Conduction in Heterogeneous Systems," Advances in Electrochemistry and Electrochemical Engineering, Vol. 2 of Electrochemical Engineering, ed. C.W. Tobias, John Wiley and Sons, NY, 1962, pp. 15-47.

23. Merzkirch, W., Flow Visualization, Academic Press, NY, 1974, p.23.

24. Ozgu, M., Chen, J., and Eberhardt, N., "A Capacitance Method for Measurement of Film Thickness in Two-Phase Flow," Rev. Sci. Instrum., Vol. 44, No. 12, Dec. 1973, pp. 1714-1716.

25. Ozkaynak, T.F. and Chen, J.C., "Average Residence Times of Emulsion and Void Phases at the Surface of Heat Transfer Tubes in Fluidized Beds," Heat Transfer: Research and Application, AIChE Symposium Series, Vol. 74, No. 174, 1978, pp. 334-343.

26. Pearce, C.A.R., "The Electrical Conductivity and Permittivity of Mixtures, with Special Reference to Emulsions of Water in Fuel Oil," British Journal of Applied Physics, Vol. 6, April 1955, pp. 113-120.

27. Pearce, C.A.R., "The Permittivity of Two Phase Mixtures," British Journal of Applied Physics," Vol. 6, Oct. 1955, pp. 358-361.

28. Reitz, J.R. and Milford, F.J., Foundations of Electromagnetic Theory, 3rd Printing, Addison-Wesley Publishing Co., Inc., Reading, MA, 1960, p. 85.

29. Stubington, J.F., Barrett, D., and Lowry, G., "Bubble Size Measurements and Correlation in a Fluidized Bed at High Temperatures," Chem. Eng. Res. Des., Vol. 62, May 1984, pp. 173-178.

30. Tassicker, O.J., "The Temperature and Frequency Dependence of the Dielectric Constant of Power-Station Flyash," Staub-Reinhalt.Luft, Vol. 31, No. 8, Aug. 1971, pp. 23-28.

31. Tinga, W.R., Voss, W.A.G., and Blossey, D.F., "Generalized Approach to Multiphase Dielectric Mixture Theory," Journal of Applied Physics, Vol. 44, No. 9, Sept. 1973, pp. 3897-3902.

32. Turner, J.C.R., "Two Phase Conductivity: The Electrical Conduction of Liquid-Fluidized Beds of Spheres," Chemical Engineering Science, Vol. 31, 1976, pp. 487-492.

33. Werther, J., "Bubbles in Gas Fluidized Beds- Part I," Trans. Instn. Chem.Engrs., Vol. 52, 1974, pp. 149-159.

34. Werther, J., "Bubbles in Gas Fluidized Beds- Part II," Trans. Instn. Chem. Engrs., Vol. 52, 1974, pp. 160-169.

35. Werther, J. and Molerus, O., "The Local Structure of Gas Fluidized Beds- I. A Statistically Based Measuring System," Int. J. Multiphase Flow, Vol. 1, 1973, pp. 103-122.

36. Yaverbaum, L., Fluidized Bed Combustion of Coal and Waste Materials, Noyes Data Corporation, Park Ridge, NJ, 1977, p.1.

37. Yoshida, K., Fujii, S., and Kunii, D., "Characteristics of Fluidized Beds at High Temperatures," Fluidization Technology, Vol. 1, Keairns, D.L. ed., Hemisphere Publications, Washington, 1976, pp. 43-48.

38. Yoshida, K., Sakane, J., and Shimizu, F., "A New Probe for Measuring Fluidized Bed Characteristics at High Temperatures," Ind. Eng. Chem. Fundam., Vol. 21, No. 1, 1982, pp. 83-85.

39. Young, R.P., Dubard, J.L., and Sparkes, L.E., "The Effective Dielectric Constant of Dust Layers," Particulate Science and Technology, Vol. 5, 1987, pp. 105-114.

40. Yutani, N., Ho, T.C., Fan, L.T., Walawender, W.P., and Song, J.C., "Statistical Study of the Grid Zone Behavior in a Shallow Gas-Solid Fluidized Bed Using a Mini-Capacitance Probe," Chemical Engineering Science, Vol. 38, No. 4, 1983, pp. 575-582.

41. Zahn, M. and Rhee, S., "Electric Field Effects on the Equilibrium and Small Signal Stabilization of Electrofluidized Beds," IEEE Transactions on Industry Applications, Vol. IA-20, No. 1, Jan./Feb. 1984, pp. 137-147.

42. Zaretsky, M.C., Li, P., and Melcher, J.R., "Estimation of Thickness, Complex Bulk Permittivity and Surface Conductivity using Interdigital Dielectrometry," IEEE Int. Symposium on Electrical Insulation, June 5-8, 1988.