

## **BIOGRAPHICAL INFORMATION**

***ROBERT S. BRODKEY***  
**Department of Chemical Engineering**  
**The Ohio State University**

Professor Robert S. Brodkey received his B.S. in Chemistry in 1950 and his M.S. in Chemical Engineering also in 1950 from the University of California, Berkeley. At the University of Wisconsin, he received his Ph.D. in Chemical Engineering in 1952, doing a study in freeze-drying. He spent 5 years with Standard Oil of New Jersey in their Esso Research and Engineering Company research facility. There he worked on diverse chemical and chemical engineering problems, including chemical synthesis (5 patents) and chemical process (5 patents). In 1957, he joined OSU as an Assistant Professor of Chemical Engineering, became Associate Professor in 1960, Professor in 1964 and Professor Emeritus in 1992.

His work has been primarily in the field of fluid mechanics with specialization in the areas of fundamental turbulent fluid flow (~40 publications), mixing (~25 publications), rheology (~15 publications), and two phase flow (~10 publications). Recently he has been involved in the application of image processing and analysis to problems in fluid mechanics (~10 publications). Some 30 additional publications, as well as textbooks and reviews, on a variety of fields have appeared in the literature. He is well known for his graduate text, *The Phenomena of Fluid Motions*, which was reprinted by Dover Publications in 1995. His undergraduate text, *Transport Phenomena: A Unified Approach*, (with H.C. Hershey) was published in 1988 by McGraw-Hill as part of their prestigious Chemical Engineering Series. The text has been translated into a two volume Greek edition.

Professor Brodkey received a "Senior U.S. Scientist Award" (1975) from the Alexander von Humboldt Foundation, a "Senior Fellowship in Science" (1972) from NATO, and the "Outstanding Paper of the Year Award" (1970) from the Canadian Society for Chemical Engineering. For the Fall of 1978, he received the Visiting Professorship award from the Japan Society for the Promotion of Science. He was selected to receive The Ohio State University's Distinguished Senior Research Award (1983) and a Senior Research Award (1983) from the College of Engineering of The Ohio State University. This latter award, which can be given every three years for work based on the preceding three years, was awarded again to Prof. Brodkey in 1986. During the summer of 1983 he was once again invited to visit Germany under the von Humboldt Senior U.S. Scientist Program. In 1985, he was awarded the Senior Research Award of the American Society of Engineering Education and elected a Fellow of the AIChE. In 1986, he received the Chemical Engineering Lectureship Award sponsored by 3M and given by ASEE. In 1987 he was elected a Fellow of the American Physical Society. He has also been made a fellow of the American Association for the Advancement of Science (1954) and of the American Institute of Chemists. In 1994, he held the W.W. Clyde Chair of Engineering at the University of Utah, received the 1994 North American Mixing Forum's award for Outstanding Research, and had two sessions at the San Francisco Annual AIChE meeting held in his honor for his 65th birthday. Another session on turbulence was held in his honor of his 70th birthday at the 1998 Annual AIChE meeting. In 2002, a symposium on "Turbulence in Chemical Processing" was held at USNCTAM-14 in his honor. Professor Brodkey

is still active in research, teaching, and departmental affairs, even though he has been appointed as an Emeritus Professor.

He has retired as vice-chair and treasurer of the US National Committee-Theoretical and Applied Mechanics (1995-1998). He formerly was the AIChE representative to the committee (1987-1995). He chaired the Scientific Committee of the XI-U.S. National Congress on Theoretical and Applied Mechanics that was held in May of 1990. He was a member of the ABET/AIChE Chemical Engineering Visiting Accreditation Panel and of the AIChE Fluid Mechanics Program Committee and the Mixing Area Committee. He was on the organizing committees for the Symposium on Turbulence, Rolla and the Beer Sheva Seminar on Magnetohydrodynamics and Turbulence (Israel). He is a member of a number of other honorary and professional societies such as Sigma Xi, AIChE, ACS, APS, AAM and AAAS and is listed in many of the standard biographical references.

In addition, he has presented nearly 100 invited seminars and lectures at Universities and establishments in the U.S. and in 13 countries overseas. He has given about 50 lectures at industrial research centers. Major invited papers were at the IX Symposium Nacional de Ingenieria Quimica, Monterey, Mexico (1984) and a special review lecture at the Coherent Structures in Turbulence Workshop, Austin, Texas (1986). He was a Keynote Speaker on "Image Analysis for Coherent Structures in Turbulence Research" at the international meeting on Experimental Methods in Heat Transfer, Fluid Mechanics and Thermodynamics that took place in Dubrovnik, Yugoslavia (1988) and a Plenary Lecturer on "Imaging and Chemical Engineering Research" at the 10th International Congress CHISA '90 that took place in Prague, Czechoslovakia. In the summer of 1999, he delivered the Plenary Lecture at Mixing 6 in Bradford, England.

Professor Brodkey has acted as advisor to nearly 45 Ph.D. students, with one still active in his degree work. He has been advisor to over 40 M.S. students.

## EDUCATION

Associate of Arts	San Francisco City College, February 1948
Bachelor of Chemistry	University of California, February 1950
M.S., ChE	University of California, September 1950
Ph.D., ChE	University of Wisconsin, November 1952

## TEACHING EXPERIENCE

3/92-present	Emeritus Professor, Department of Chemical Engineering, The Ohio State University
9/64-3/92	Professor, Department of Chemical Engineering, The Ohio State University
9/60-9/64	Associate Professor, Department of Chemical Engineering, The Ohio State University
9/57-9/60	Assistant Professor, Department of Chemical Engineering, The Ohio State University

## INDUSTRIAL EXPERIENCE

- 9/56-8/57           Esso Standard Oil Company, research chemical engineer. The development and design of modifications for a synthetic lubricating oil additives plant. Process involves alkylation, sulfurization, and neutralization.
- 11/52-9/56           Esso Research and Engineering Company, research chemical engineer. Chemistry of and bench scale production of chemicals by the high pressure oxo reaction. Polymerization of olefins at low pressure. Development of a synthetic butyl rubber latex.
- 6/50-9/50           E. I. Du Pont de Nemours and Co., chemical engineer. Research on the nature of drying synthetic polymers and pilot plant production.

## LONG TERM CONSULTING

Consultant to the field (industrial, government, and non-profit organizations) on problems involving turbulent motion, mixing, kinetics, rheology, two-phase flow, and other aspects involving fluid dynamics.

## HONORS

- Fluid Mechanics Symposium on "Turbulence in Chemical Processing" in Honor of Robert S. Brodkey at UNCTAM-14, Blacksburg, VA (2002)
- Fluid Mechanics Symposium in Honor of the 70th Birthday at the Miami Annual AIChE Meeting
- North American Mixing Forum Outstanding Research Award (1994)
- W.W. Clyde Chair of Engineering at the University of Utah (Fall 1994)
- Two Sessions at NAMF in Honor of the 65th Birthday at the San Francisco Annual AIChE Meeting
- Fellow of the American Physical Society (1987)
- Chemical Engineering Lectureship Award sponsored by 3M and given by the American Society of Engineering Education (1986)
- Senior Research Award, College of Engineering, Ohio State University (1983), repeat award based on preceding three years (1986)
- Fellow of the American Institute of Chemical Engineers (1985)
- Senior Research Award of the American Society of Engineering Education (1985)
- Fellow of the American Association for the Advancement of Science (1954)
- Fellow the American Institute of Chemists
- Alexander von Humboldt Senior U.S. Scientist Award, return summer visit (1983)
- The Ohio State University Distinguished Senior Research Award (1983)
- Senior Research Award, College of Engineering, The Ohio State University (1983)
- Visiting Professor Award of the Japan Society for the Promotion of Science, (1978)
- Alexander von Humboldt Senior U.S. Scientist Award (1975)

Expository Lecturer GAMM Conference, Goettingen (1975)  
Senior Fellowship in Science, NATO (1972)  
Outstanding Paper of the Year Award (1970), The Canadian Society for Chemical Engineering  
Highest Honors of the University of California  
Sigma Xi, Honorary Research  
Phi Lambda Upsilon, Honorary Chemistry  
Gulf Oil Fellow, University of Wisconsin  
Alpha Gamma Sigma, Honorary  
Phi Beta Delta, Honorary for International Scholars, founding member of Alpha Epsilon Chapter

#### TECHNICAL SOCIETY ACTIVITIES

##### Membership:

American Institute of Chemical Engineers, Fellow  
American Chemical Society  
American Physical Society, Fellow  
American Institute of Chemist, Fellow  
American Academy of Mechanics  
American Association for Advancement of Science, Fellow  
Society of Rheology  
Society of Engineering Science

##### Former Committee Activities

ABET/AIChE Chemical Engineering Visiting Accreditation Panel  
Beer Sheva Seminar on Magnetohydrodynamics and Turbulence, Organization Committee  
AIChE representative to the US National Committee-Theoretical and Applied Mechanics (1987-1995)  
Chairman, scientific committee of the XI-National Congress TAM held in 1990  
AIChE Fluid Mechanics Program Committee  
AIChE Mixing Area Committee  
Symposium on Turbulence, Rolla, Organization Committee  
Chairman of Program Committee, Secretary-Treasurer, Ind. Eng. Group, New Jersey Section ACS  
Chairman of Program Committee and of House Committee, Secretary, Central Subsection North Jersey Section ACS  
President, Vice-President, Program, New York Professional Chapter of Alpha Chi Sigma  
Member, National Bylaws Committee, Phi Lambda Upsilon  
Executive Committee Member, Central Ohio AIChE  
Member, Visiting Engineering Committee, ASEE  
Member, National Meetings Program Committee, Division IEC, ACS  
Reviewer for numerous professional journals

Chairman of the American Physical Society, Division of Fluid Dynamics annual meeting held in Columbus, Ohio, 1986

## **PUBLICATIONS**

### **A. Books and Reviews**

1. *Fluid Motion and Mixing*, Chapter 2 (110 pages) of *Mixing: Theory and Practice*, Vol. 1, Uhl and Gray Eds., Academic Press, Inc. (1966).
2. *The Phenomena of Fluid Motions* (730 pages), Addison-Wesley Pub. Co., (1967); 4th printing with revisions, The Ohio State University Bookstore (1984); Dover Publishing reprint of the 1st Edition with revisions (1995).
3. *Turbulent Motion, Mixing, and Kinetics*, Vol. 1, No. 2 of the Professional Development Lectures, West Virginia University, Kanawha Valley Graduate Center, Nitro, WV (1968).
4. *A Visual Study and Mass Transfer at the Wall in a Turbulently Flowing Liquid*, Vol. 1, No. 3, *ibid* (1969).
5. *Turbulence in Mixing Operations*, Ed. and Author of Chap. 2, Academic Press (1975).
6. *Transport Phenomena: A Unified Approach*, Mc-Graw Hill Book Co., (1988) with H.C. Hershey; Greek edition published (1990).
7. *Instructor's/Solution Manual to Accompany Transport Phenomena: A Unified Approach*, Whitlock Press, (1988) with H. C. Hershey.
8. *Full-Field, Time-Resolved, Vector Measurements*, Chap. 8, in *Instrumentation for Fluid-Particle Flow*, ed. S.L. Soo, Noyes Pubs. (William Andrew Publishing) NY (1999), with Y. Zhao.

### **B. Papers**

#### **Turbulence**

1. A Generalized Velocity Distribution for non-Newtonian Fluids, *AIChE J.*, **7**, 392 (1961), with J. Lee and R.C. Chase.
2. On the Brosko Relations for Turbulent Flow, *Appl. Sci. Res.*, **11A**, 109 (1962), with J. Lee.
3. Limitations on a Generalized Velocity Distribution, *AIChE J.*, **9**, 488 (1963).
4. A Visual Study of the Wall Region in Turbulent Pipe Flow, *J. Fluid Mech.*, **37**, 1 (1969), with E.R. Corino.
5. Turbulence Measurements in Shear Flow Liquid Systems, pg. 51, published in the *Proceedings of the Symposium on Turbulence Measurement in Liquids*, G.K. Patterson and J.L. Zakin, ed., Rolla, Missouri (1971), with M.C. Cohen, J.S. Knox, G.L. McKee, K.N. McKelvey, A.N. Rao, S. Zakanycz, and H.C. Yieh.
6. An Experimental Facility for the Visual Study of Turbulent Flows, pg. 127, *ibid*, with H.C.

- Hershey and E.R. Corino - Invited Lecture.
7. Continuous Flow Stirred Tank Turbulence Parameters in the Impeller Stream, *Chem. Eng. Sci.*, **27**, 137 (1972), with M.A. Rao.
  8. The Wall region in Turbulent Flow, *Engineering Societies Library*, 16 mm Sound Film (1972), with J. Friend and E.R. Corino.
  9. The Wall Region in Turbulent Shear Flow, *J. Fluid Mech.*, **54**, 39 (1972) with J.M. Wallace and H. Eckelmann.
  10. A Visual Study of Turbulent Shear Flow, *J. Fluid Mech.*, **61**, 513 (1973) with H.C. Hershey and S. Nychas (also see 12 below).
  11. Turbulent Kinetic Energy, Dissipation and Diffusion, *Phys. Fluids*, **16**, 2010 (1973) with J. Taraba, S. Nychas, and J. Wallace; also **17**, 2149-50 (1974).
  12. Short version of 10 published in *Zeitschrift fur Angewandte Mathematik und Mechanik*, **54**, #4, T137 (1974).
  13. Some Properties of Truncated Turbulence Signals in Bounded Shear Flows, *J. Fluid. Mech.*, **63**, 209 (1974) with J.M. Wallace and H. Eckelmann.
  14. A Visual Study of Turbulent Shear Flow, *Engineering Societies Library*, 16 mm Sound Film (1975) with J. Friend and S.G. Nychas.
  15. Optimization of Turbulence Models by Means of a Logical Search Algorithm, *Appl. Sci. Res.*, **27**, 321 (1973) with G.D. Huffman and C.D. Jones.
  16. Reynolds Stress and Joint Probability Density Distributions in the u-v Plane of a Turbulent Channel Flow, *Phys. Fluids*, **20**, 351 (1977) with J.M. Wallace.
  17. Strukturen in der turbulenten wandbegrenzten Stromung, *50 Jahre, Max-Planck-Institut Fuer Stroemungsforschung Goettingen 1925-1975*, (1976) with H. Eckelmann, S.G. Nychas and J.M. Wallace.
  18. Stereoscopic Photography of Shear Flow Turbulence, *Turbulence in Liquids, Proc. of the 4th Symp.*, page 345 (1977) Science Press, Princeton, N.J. with A.K. Praturi and H.C. Hershey.
  19. Stereoscopic Visual Studies of Complex Turbulence Shear Flows, *The International Symposium on Flow Visualization*, Tokyo, p. 45 (1977).
  20. Pattern Recognized Structures in Bounded Turbulent Shear Flows, *J. Fluid Mech.*, **83**, 673 (1977) with J.M. Wallace and H. Eckelmann.
  21. Vorticity and Turbulence Production in Pattern Recognized Turbulent Flow Structures, *Phys. Fluids Supl.*, **20** (2) S225 (1977) with S.G. Nychas, J.M. Wallace and H. Eckelmann.
  22. Mass Transfer at the Wall as a Result of Coherent Structures in a Turbulently Flowing Fluid, *Int. J. of Heat and Mass Trans.*, **21**, 593 (1978) with K.N. McKelvey, H.C. Hershey and S.G. Nychas.
  23. On the Mechanism of Turbulent Shear Flows, *Lecture Notes in Physics*, (H. Fiedler, ed.), **75**, 175, Springer-Verlag (1978) with E. Kastranakis, J.M. Wallace, W.W. Willmarth and B. Ghorashi.
  24. A Stereoscopic Visual Study of Coherent Structures in Turbulent Shear Flow, *J. Fluid Mech.*, **89**, 251 (1978) with A.K. Praturi.
  25. Flow Visualization and Simultaneous Anemometry Studies of Turbulent Shear Flows, *Workshop on Coherent Structure of Turbulent Boundary Layers*, (C.R. Smith and D.E. Abbott, eds.), pg. 28, Lehigh Univ., Bethlehem, PA (Nov. 1978).

26. Pattern recognition, a means for detection of coherent structures in bounded turbulent shear flows, *Proc. Dynamic Flow Conf.*, pg. 161, Marseille, France (Sept. 11, 1978) with H. Eckelmann and J.M. Wallace.
27. Coherent Structures in Turbulent Shear Flows - Impressions of Research in Japan, *Scientific Bulletin, ONR Tokyo*, **4** # 2, 28 (1979).
28. Coherent Structures in Turbulent Shear Flows, *J. Japan Society of Mechanical Engineering*, **83**, #736, 5 (March 1980).
29. Cross Correlation and Tracking for the Measurement of Particle Velocities, *I & EC Fund.*, **19**, 175 (1980) with G.B. Tatterson and J. Heibel.
30. Refinement of Pattern Recognition of Coherent Structures in Turbulent Shear Flows and a Comparison Between Detection Techniques, *Flow of Real Fluids, Lecture Notes in Physics*, **235**, 279, eds. G.E.A. Meier and F. Obermeier, (1985), with Y.G. Aouad, H. Valizadeh-Alavi and H. Eckelmann.
31. The Low-Turbulence/High-Efficiency Cyclone Separator Program: Curvilinear Boundary Layer Facility Results, Final report to U.S. Department of Energy, Office of Fossil Energy, issued through Battelle Columbus Division, October (1986) with M.L. Munson-McGee.
32. Image Processing and Analysis for Turbulence Research, *Chem. Engr. Educ.*, **20**, 202 (1986).
33. Development of a Shadow Tracking Laser Correlator for Three-Dimensional Velocity Measurements, *Proc. Conf. on Lasers in Fluid Mechanics*, paper 8.6, Lisbon, Portugal, July 7-9 (1986) with Kunle Ogunde.
34. A Visual Study of Pulp Floc Dispersion Mechanisms, *AIChE J.*, **33**, 279 (1987) with C. William Lee.
35. Towards Full Field Measurements of Instantaneous Visualizations of Coherent Structures in Turbulent Shear Flows, *Exp. Thermal and Fluid Sci.*, **3**, 74 (1990) with L. Economikos, C. Shoemaker, K. Russ, and D. Jones.
36. Further comments on a visual study of pulp floc dispersion mechanisms, *Tappi Journal*, **71**, No. 8, 137 (1988) with D. G. Wagle and C. William Lee.
37. Transition, Turbulence and Oscillating Flow in a Pipe; A Visual Study, *Exps. in Fluids*, **11**, 388 (1991) with L.S. Fishler.
38. Fully automated three-dimensional particle image velocimetry system applied to engine fluid mechanics research, Proceedings of Int. Seminar on Optical Methods and Data Processing in Heat and Fluid Flow, City University, London, Eng., April 2-3, 1992, with N. Trigui, Y. Guezennec and C. Kent.
39. Photogrammetric Calibration for Improved Three-Dimensional Particle Tracking Velocimetry (3-D PTV), *Proc. SPIE*, **2005**, 400-412 (1993) with C. Kent, N. Trigui, W-C Choi, and Y. Guezennec.
40. Algorithms for full automated three-dimensional particle tracking velocimetry, *Exps. in Fluids*, **17**, 209-219 (1994) with Y. Guezennec, N. Trigui, and C. Kent.
41. Averaged and Time-Resolved, Full-Field (Three-Dimensional), Measurements of Unsteady Opposed Jets, *Can. J. Chem. Engr.*, **76**, 536-545 (1998) with Yang Zhao
42. Experimental and Numerical Characterization of Viscous Flow and Mixing in an Impinging Jet Contactor, *Can. J. Chem. Engr.*, **76**, 546-555 (1998) with D.R. Unger and F.J. Muzzio.
43. Particle Paths in Three-Dimensional Flow Fields as a Means of Study: Opposing Jet Mixing

- System *Powder Technology*, **100/2-3**, pages 161-5 (1998) with Yang Zhao.
44. Laser Doppler Anemometry Measurements in an Index of Refraction Matched Column in the Presence of Dispersed Beads, *Int. J. of Multi-Phase Flow*, **26**, 1401-18 (2000) with S. I. Fort, L. Klaboch, M. Placnik and V. Vanecek.
  45. Motions of Dispersed Beads Obtained by Particle Tracking Velocimetry Measurements, *Int. J. of Multi-Phase Flow*, **26**, 1419-38 (2000) with S. Haam.
  46. McCreery, G. E., K. G. Condie, D. M. McEligot, J. C. Crepeau, R. Clarksean, Y. G. Guezennec and R. S. Brodkey, 1999. Flow visualization and velocity measurements in a model fuel storage canister. Paper 124, Global '99, International Conf. on Future Nuclear Sys., Jackson, Wyo., August-September.
  47. Nakamura, S. and R.S. Brodkey, 1999, "Computational and Experimental Study of the Fluid Flow in a Cylindrical Cavity with and Impeller Rotor at an Eccentric location," 3rd ASME/JSME Joint Fluids Eng. Conf. July 18-23, San Francisco (FEDSM99-7193).
  48. Brodkey, R.S., and Zhao, Y., "On the Representation of Complex Turbulent Flows: Representation of Large Data Fields on the Internet," *Ind. Eng. Chem. Res.*, **39**, 1743-1746 (2000).
  49. Nakamura, S. and R.S. Brodkey, 2000, "Direct and Large Eddy Simulation of the Three-Dimensional Unsteady Flow in the Counter-Jet mixing Vessel," *Proc. ASME Fluids Eng. Summer Conf.* July 11-15, Boston (FEDSM2000-11007).
  50. Nakamura, S. and R.S. Brodkey, 2000, "Computatioonal Flow Analysis ofr the Chemical Mixing Vessel with Impeller and Baffles," *Proc. ASME Fluids Eng. Summer Conf.* July 11-15, Boston (FEDSM2000-11207).
  51. Y. Zhao, R.S. Brodkey and S. Nakamura, 2002, Study of 3D Mixing Processes by Numerical and Experimental Approaches, 2002 ASME Fluids Engineering Division Summer Meeting, July 14-18, Montreal, Quebec, Canada (FEDSM2002-311697).

## Mixing

1. Light Probe for the Measurement of Turbulent Concentration Fluctuations, *Rev. Sci. Instrs.*, **34**, 1086 (1963), with J. Lee.
2. Turbulent Motion and Mixing in a Pipe, *AICHE J.*, **10**, 187 (1964), with J. Lee.
3. Turbulent Motion and Mixing in a Pipe, *AICHE J.*, **12**, 403, (1966).
4. Dye Injection at the Centerline of a Pipe, *AICHE J.*, **12**, 817, (1966), with J.P. Gegner.
5. Light Probe for the Measurement of Turbulent Concentration Fluctuations, *Rev. Sci. Instrs.*, **38**, 26 (1967), with J.O. Nye.
6. The Scalar Spectra in the Viscous-Convective Subrange, *J. Fluid Mech.*, **29**, 151 (1967), with J.O. Nye.
7. Mixing and Recycle for Analysis of a Continuous Flow Stirred Tank, *Chem. Eng. Sci.*, **27**, 2199 (1972), with M.A. Rao.
8. Turbulent Motion, Mixing, and Kinetics, Fluid Mechanics of Mixing, *American Society of Mechanical Engineers*, pg. 1, New York (1973), Invited Paper.
9. Turbulent motion, mixing, and kinetics in a chemical reactor configuration, *AICHE J.*, **21**,

- 1165 (1975) with K.N. McKelvey, H-C Yieh, and S. Zakanycz.
10. Turbulent Mixing Studies in a Chemical Reactor, pg. 225, in *Turbulent Mixing in Nonreactive and Reactive Flows*, edited by S.N.B. Murthy, Plenum Press (1975).
  11. Introduction and Chapter on Mixing in Turbulent Fields, pgs. 1 & 47, in *Turbulent in Mixing Operations*, edited by R.S. Brodkey, Academic Press, Inc. (1975).
  12. Schliern Measurements of Fine Scale Mixing, *Rozprawy Inzynierskie (Engineering Transactions)*, **25** #3, 469 (1976) with S. Zakanycz.
  13. Turbulent Motion, Mixing, and Kinetics, *Proceedings of the Levich Birthday Conf.*, Oxford, England, pg. 289 (1978).
  14. Stereoscopic Visualization of the Flows for Pitched Blade Turbines, *Chem. Eng. Sci.*, **35**, 1369-75 (1980), with G.B. Tatterson and H-H S. Yuan.
  15. Fundamentals of Turbulent Motion, Mixing and Kinetics, Invited Review, *Chem. Eng. Comm.*, **8**, 1-23 (1981).
  16. Evaluation of RAM Model for Cleveland, Ohio, Part II, *J. of the Air Pollution Control Association*, **34**, 371 (1984), with R. Hodindossi.
  17. Reactor Selectivity Based on First Order Closures of the Turbulent Concentration Equations, *AIChE J.*, **31**, 111 (1985) with J. Lewalle.
  18. Fundamentals of Turbulent Mixing and Kinetics, Chapter 2 in *Mixing of Liquids by Mechanical Agitation*, J.J. Ulbrecht and G.K. Patterson, eds., Gordon and Breach (1985).
  19. Exchange of letters on Reactor Selectivity, *AIChE J.*, **32**, 1056 (1986) with T. Heeb.
  20. Turbulent Mixing with Multiple Second Order Chemical Reaction, *AIChE J.*, **36**, 1457 (1990), with T.G. Heeb.
  21. Move Mixing Technology Into the 21st Century, *Chem. Eng. Prog.*, **45** (6), 45 (1991) with G.B. Tatterson and R.V. Calabrese.
  22. Local wall heat transfer coefficients using surface sensors, Proceedings of the 7th European Conf. on Mixing, Brugge, Belgium, September 18, 1991 with J. Fasano and S.J..
  23. Local Heat Transfer in a Mixing Vessel Using Heat Flux Sensors, *Ind. Eng. Chem. Res.*, **31**, 1384 (1992), with S.J. Haam and J.B. Fasano.
  24. Multiphase Local Heat Trasfer in a Mixing Vessel, *AIChE Symp. Series*, No 286, **88**, 93 (1992), with S.J. Haam and J.B. Fasano.
  25. Local Heat Transfer in a Mixing Vessel Using a High-Efficiency Impeller, *Ind. Eng. Chem. Res.*, **32**, 575 (1993), with S.J. and J.B. Fasano.

## **Rheology**

1. Measurement of the Flow of Molten Polymers Through Short Capillaries, *J. Appl. Polymer Sci.*, **7**, 399 (1963), with A.P. Metzger.
2. A Kinetic Interpretation of non-Newtonian Flow, *J. Appl. Phys.*, **33**, 2269 (1962), with D.A. Denny.
3. Translating Terms for non-Newtonian Flow, *Ind. Eng. Chem.*, **54** # 9, 44 (1962).
4. A Kinetic Approach for Polymer Solution Data, *AIChE J.*, **14**, 61 (1968), with H.T. Kim.
5. Thixotropic Behavior of a Colloidal Suspension, *5th Int. Cong. on Rheology*, Kyoto, **2**, 267 (1970), with L.G. Jones.

6. A Kinetic Interpretation of time-Dependent Polymer Rheology Data, *5th Int. Cong. on Rheology*, Kyoto, **4**, 141 (1970), with W.E. Lewis.
7. Modifications of an R-16 Weissenberg Rheogoniometer, *Trans. Soc. Rheol.*, **14**, 555 (1970), with K.H. Lee, L.G. Jones, and K. Pandalai.
8. Time-dependent Polymer Rheology Under Constant Stress and Under Constant Shear Conditions, *Trans. Soc. Rheol.*, **15**, 627 (1971), with K.H. Lee.
9. Time-depending non-Newtonian Behavior of Viscoelastic Materials, *Rheol. Acta*, **13**, 745 (1974) with P.D. Jachimiak and Y.S. Song.
10. Development of an Extrusion Rheometer Suitable for On-line Rheological Measurements, *Polymer Eng. Sci.*, **15**, 583 (1975) with P. Springer and E. Lynn.
11. The Effects of Extrusion on the Molecular and Rheological Properties of General Purpose Polystyrene, *Polymer Eng. Sci.*, **15**, 588 (1975) with P. Springer and E. Lynn.
12. A Visual Study of the Dynamics of Polymer Extrusion, *J. Rheology*, **22**, 135, (1978) with M.Y. Anastas and R.E. Lynn.
13. Time Domain Rheological Properties of Thin Materials Utilizing Frequency Analysis, *Advances in Rheology*, **3**, 147 (1984). 9th Int. Cong. on Rheology, Acapulco, Mex.
14. Rheological Properties of Slurry Fuels, *J. Rheology*, **29**, 147 (1985) with S.F. Lin.
15. Visual Rheological Studies of Slurries and Emulsions, *Proc. 2nd Conf. of European Rheologist*, Prague, June 17-20, (1986) with Soon-Man Cha and J.L. Zakin, *Rheol. Acta*, **26** (sup.), 169 (1988).

### **Two Phase Flow**

1. An Analysis of Geometry and Pressure Drop for the Horizontal, Two-Phase Annular Flow of Water and Air in the Entrance Region of a Pipe, *Chem. Eng. Sci.*, **19**, 261 (1964), with L.A. Jacowitz.
2. Prediction of Flow Patterns in Horizontal Two-Phase Pipe Flow, *Can. J. Chem. Eng.*, **48**, 21 (1970), with D.E. Saunders and J.N. Al-Sheikh. **Paper received Outstanding Paper of the Year Award.**
3. A Mathematical Model for Heat Transfer in a Packed Bed and a Simplified Solution Thereof, *AIChE J.*, **18**, 623 (1972), with D.S. Kim and L.E. Gates.
4. High Speed Photography of Stock Transport in a Disk Refiner, *TAPPI*, **62** #3, 55 (1979), with T.S. Fox and A.H. Nissan.
5. Pulp Transport in the Disk Refiner, in *Paper Science and Technology - The Cutting Edge*, 143, Appleton, Wis. (1980) with T.S. Fox and A.H. Nissen.
6. Inside a disk refiner, *TAPPI*, **65** #7, 80 (1982), with T.S. Fox and A.H. Nissan.
7. A note on Particle-liquid Mass Transfer in a Fluidized Bed of Small Irregular-shaped Benzoic Acid Particles, *Chem. Eng. Sci.*, **40**, 1797 (1985), with G.C. Shen and C.J. Geankoplis.
8. Comments on the buoyancy of a particle in a fluidized suspension, *Chem. Eng. Sci.*, **42**, 1269 (1987), with L.-S. Fan and L. S. Han.
9. Fluid to Particle Heat Transfer to Single Particles and in a Fluidized Bed, *Int. J. Heat and Mass Trans.*, **34**, 2327 (1991) with D.S. Kim and W. Sidner.

10. Computer Simulations of the Rupture of a Gas Bubble at a Gas-Liquid Interface and its Implications in Animal Cell Damage, *Chem. Eng. Sci.*, **49**, 2301 (1994) with Miguel A. Garcia-Briones and Jeffrey J. Chalmers.

### **Other Papers**

1. Heat Transfer in Condensation, Effect of Temperature Variation Around a Horizontal Tube, *Ind. Eng. Chem.*, **44**, 2962 (1952) with L.A. Bromley.
2. Radiant Freeze Drying, Summaries of Doctoral Dissertation, *University of Wisconsin*, **14**, 471 (1954).
3. Safety Problems in the Study of Hazardous Reactions, *Ind. Eng. Chem.*, **48**, 223 (1956), with J. Steward and R.G. Newberg.
4. Article above abstracted, translated and reprinted in *Tenish Tidskrift*, Nov. 20, 1956, pg. 1014.
5. New Areas in Chemical Engineering with Emphasis on Petrochemicals, *News in Engineering*, **31** (June 1959).
6. Nuclear Chemical Engineering Research, *News in Engineering*, **32**, 3 (1960), with C.E. Dryden.
7. Fluidized Calcination of Simulated Aluminum-type Wastes, *Ind. and Eng. Chem.*, **52**, 795 (1960), with J.D. Jackson, H.A. Sorgenti and G.A. Wilcox.
8. Forced Convection from a Horizontal Cylinder, *AIChE J.*, **7**, 531 (1961), with E.R. Purves.
9. Evaluation of a 6-inch Oldershaw Distillation Column, *News in Engineering*, **33**, 15 (Nov. 1961).
10. Heat and Momentum Transfer in Laminar Flow: Helium, Initially at Plasma Temperatures, *AIChE J.*, **9**, 49 (1963), with R.J. Wethern.
11. Water Desalination in a Fluidized Bed., *Ind. and Eng. Chem.*, **56**, 34, (April 1964), with J. Kanyok.
12. Areas of Specialization in Chemical Engineering, *Chem. Eng. Prog.*, **63**, # 10, 21 (1967).
13. Transport Phenomena at the Liquid-Vapor Interface of Mercury Using a Radioactive Tracer, *Prog. in Heat and Mass Transfer*, **6**, 195 (1972), with K.R. Wylie.
14. Meandering in the Southwest, *News in Engineering*, **44**, #2 (1972).
15. A Distributed Micro-Mini Computer Combination for On-line Acquisition, *Proc. Int. Conf. on Use of Micros in Fluid Eng.*, London, England, June, 1983.
16. Underground Detection Using Differential Heat Analysis, *Archaeometry*, **26**, 21 (1984), with S.M. Benner.
17. Analysis of the free-fall behavior of liquid-metal drops in a gaseous atmosphere, *Materials Processing in the Reduced Gravity Environment of Space*, ed. R.H. Doremus and P.C. Nordine., (1987) with J. Kevin McCoy, Alan J. Markworth, and E.W. Collings. *Mat. Res. Soc. Symp. Proc.*, **87**, 163 (1987).
18. Cooling and solidification of liquid-metal drops in a gaseous atmosphere, *J. Mat. Sci.*, **27**, 761 (1992) with J. Kevin McCoy, Alan J. Markworth and E.W. Collins.
19. Formation and Characterization of Paper Pulp Floccs, *Chem. Eng. Sci.*, **46**, 2997 (1991) with S.V.S. Jagannadh and H. Jordan.

### C. Patents

1. U.S. 2,814,639, Dimethylol-Tricyclodecanol Esters and Process, with J.H. Bartlett and P.V. Smith. Jr.
2. U.S. 2,839,580, Preparation of Diethyl Ketone, with V.L. Hughes.
3. U.S. 2,846,464, Oxo Synthesis of Alcohols.
4. U.S. 2,875,244, Dicarboxylic Acids from Dicyclopentadienes, with J.H. Bartlett.
5. U.S. 2,876,264, Plasticizer Alcohols by Oxo Process, with W.E. Catterall, W.F. Fischer, and E. Arundal.
6. U.S. 2,936,295, Thermal and Mechanical Stable Latices of Isoolefin-Multiolefin Rubbery Polymers and Process for Preparing Same, with A.L. Miller.
7. U.S. 2,955,094, Stable Isoolefin-Multiolefin Rubbery Latices Prepared with Ortho-Phosphoric Acid and Organic Sulfate Salts, with A.L. Miller.
8. U.S. 2,973,309, Stable Butyl Latices, with J. Rehner, Jr.
9. U.S. 2,976,271, Propylene Polymerization, with S.B. Lippincott, R.M. Thomas, H.T. Oakley, and R.F. Leary.
10. U.S. 3,293,539, Gem Dimethylol Alicyclic Esters, with J.H. Bartlett, P.V. Smith, Jr., and H.K. Wiese.

### INVITED LECTURES AND SEMINARS

University of Arizona (3)  
Brown University  
California Institute of Technology  
Carnegie-Mellon University  
Case Western Reserve University (3)  
University of Cincinnati  
Colorado State University  
University of Connecticut  
University of Houston  
University of Kentucky  
University of Illinois (2)  
Iowa State University (2)  
University of Iowa, Hydraulic Research Inst.  
University of Kentucky  
Louisiana State University (2)  
University of Massachusetts  
University of Michigan (2)  
Michigan State University  
University of Mississippi  
University of Missouri-Rolla

University of Nebraska  
Northwestern University (2)  
Notre Dame University (2)  
The Ohio State University (2)  
Purdue University (2)  
Rensselaer Polytechnic Institute  
Rice University  
University of Rochester (2)  
University of Southern California  
University of Texas  
Tri-State University  
The University of Utah  
Washington University, St. Louis (2)  
West Virginia University  
Technical University of Prague, Czechoslovakia  
Max-Planck-Institut fuer Stroemunsforschung, Germany (4)  
Universitat Karlsruhe, Germany  
Ruhr University, Bochum, Germany  
Imperial College of London, England  
University of Cambridge, England  
University of Sheffield, England  
Technical University of Delft, Holland  
Indian Institute of Science, Bangalore  
Indian Institute of Technology, Delhi (2)  
Indian Institute of Technology, Madras  
Korean Institute of Science and Technology (KIST), Seoul  
The Hebrew University, Jerusalem, Israel  
University of Hiroshima (3)  
Ehime University, Matsuyama  
Tohoku University, Sendai  
Institute of Space and Aeronautical Science of Tokyo University  
National Institute for Environmental Studies, Tsukuba  
Tokyo Institute of Technology  
Yokohama National University  
Tokai University, Hiratsuka  
Institute of Mechanical Engineers of Japan, Tokai Division, Nagoya  
Gifu University  
Kyoto University (2)  
Osaka University  
Kobe University  
Kyushu University, Fukuoka  
Kyushu Institute of Technology, Kita Kyushu  
University Edinburgh, Scotland

Technical University, Zurich, Switzerland

Invited Lectures at Many Industrial Companies and Organizations

Idaho National Energy Laboratory

Institute of Paper Chemistry (2)

Toledo Section, AIChE

Dayton Section, AIChE (2)

Research Technical Presentations and Professional Meetings

### SPECIAL INVITED LECTURES

Louisville Rheology Conference, Martin Sweets Company, Inc.

Mixing Conference, Engineering Foundation Research Conference

Symposium on Turbulence Measurements in Liquids, University of Missouri

Special Turbulence Symposium American Physical Society, Washington meeting

Expository Lecturer, GAMM Conference, Goettingen, West Germany

Institute Conference on Physical Chemistry and Hydrodynamics, Professor Benjamin Levich

Birthday Conference, Oxford, England

Short Course on Mixing - University of South Carolina

Turbulence Symposium, Society Chemical Engineers of Japan, Okayama

Heat Transfer Society of Japan Workshop, Tokyo

Workshop of Coherent Structure of Turbulent Boundary Layers, Lehigh University, Bethlehem, Pennsylvania

International Symposium of Papermachine Headboxes, McGill University, Montreal, Canada

IX Symposium Nacional de Ingenieria Quimica, Monterrey, Mexico

Coherent Structures in Turbulence Workshop, Special Review Lecture, Austin, Texas

Keynote address presented at the Experimental Methods in Heat Transfer, Fluid Mechanics and Thermodynamics Symposium at Dubrovnik, Yugoslavia.

Plenary lecture on Image Processing and Analysis at 10th Int. Congress CHISA '90, Prague, Czechoslovakia.

Where Should Mixing go: A Biased View, Invited plenary lecture at the Mixing VI Conference held in Bradford, England, 1999.

### GRADUATE STUDENTS ADVISED

42 Ph.D. students

46 M.S. students

### LIST OF GRANTS

Heat Transfer in Fluidized Beds (1957-1962) \$60,000 (AEC).

Turbulent Motion and Mixing (3 separate grants covering the period from 1957 to 1970) \$120,000

(NSF).

Visual Study of Wall Region in Turbulent Flow (1962-1965) \$55,000 (NSF).

Rheology of Fluids (1964-1967) \$60,000 (NSF).

Rheology of Fluids (1964-1967) \$35,000 (NASA).

Interface Condensation in Liquid Metals (1966-1970) \$30,000 (NSF).

Visual Study of the Boundary Region Including Transition (1969-1974) \$40,000 (NSF).

Stereoscopic Visual and Anemometry Studies of Coherent Motions in Turbulent Shear Flows (1978-1981) \$167,000 (NSF).

A Kinetic-Elastic Approach for Time-Dependent Rheological Data, (1978-1982) \$122,000 (Wright Patterson Air Force Base Grant - Air Force Aero Propulsion Lab).

Motions in Turbulent Shear Flows; Significance for Mass Transfer and Drag Reduction (1980-1982) \$30,000 (American Chemical Society, Petroleum Research Fund).

Fiber Characteristics in a Turbulent Field (1980-1982) \$92,000 (International Paper Company).

Low Turbulence/High Efficiency Cyclone Separator, (1983-1985) \$47,000 (Battelle and DOE).

Image Processing and Analysis Facility (1984) \$42,000 (Victor and Erna Hasselblad Foundation of Sweden).

Image Processing and Analysis Facility (1984) \$50,000 (ARCO Foundation).

Image Processing and Analysis (1987) \$30,000 (National Science Foundation).

Image Processing and Analysis Workshop (1987) \$23,000 (National Science Foundation).

Mixing and Heat Transfer in Vessels (1988 -) \$50,000 (Chemineer).

Low-Velocity, Full-Field Velocity Measurements During Crystallization (1989-1991) \$50,000 (NASA-Lewis)

Multiphase Research on Analysis and Verification of Solid-Liquid Flow (1990-1993) \$39,968 (NSF-International Programs), co-PI with Ivan Fort.

Image Processing and Analysis of the Flow Field in an Experimental Simulation of an Internal Combustion Engine (1991 - 1995 ) \$130,000 (with Mechanical Engineering) (Ford Motor Co.), co-PI with Yann Guezennec.

Influence of Particles on Turbulence Characteristics and the Dispersion of Particles in Flow (1994-1997) 212,900 Czech Crown, Grant Agency of the Czech Republic, co-PI with Vaclav Vanecek and Ivan Fort.

Environmentally Benign Chemical Synthesis and Processing Program (1995-1997) \$85,000 OSU part, NSF, co-PI with Fernando J. Muzzio.

Void Structures in Composite Woven Structures (1995-1997) (\$200,000) NSF, co-PI with James Lee.

Flow Visualization of Forced and Natural Convection in Internal Cavities (1997-2000) \$80,000 University of Idaho with Y. Guezennec.

Validation of DNS, Development of LES, and CFD Modeling of an Opposed Jet Mixer Based on Time-Resolved, Full-Field, Velocity Vector Measurements And the Extension to Impeller Driven Mixing Vessels Viewed from a Rotating Frame of Reference (1999-2001) . \$60,000 ACS-PRF.

Using Time-Dependent Mixing in Stirred Vessels to Optimize Mixing Processes and to Minimize Waste in Reactive Systems (1999-2002) \$70,000 NSF Combined GOALI Environmental and Equipment Grant with J.J. Chalmers and Y. Guezennec.