

First Year Annual Report on NSF/CRCO 9980325 Multiphase Transport Phenomena Curriculum Development

Charles A. Petty, Principal Investigator Michigan State University (Lead University), The University of Akron, The University of Tulsa

Performance Dates:	December 1999 through January 2001
Award Dates:	November 17, 1999 to November 16, 2001
First Year NSF Award:	\$250,000
Second Year Award:	\$250,000
NSF/REU Supplemental:	First Year, \$10,000
MSU, UT, & UA Cash Match:	\$125,000
MSU Supplemental:	\$16,000
Total Two-Year Project Cost:	\$651,000

1. Project Participants

Faculty & Postdoctoral Associates: Michigan State University

Charles A. Petty, Principal Investigator and Professor of Chemical Engineering
Mei Zhuang, co-Principal Investigator and Associate Professor of Mechanical Engineering
Marilyn J. Amey, Senior Associate and Associate Professor of Education
André Bénard, Senior Associate and Assistant Professor of Mechanical Engineering
Krishnamurthy Jayaraman, Senior Associate and Professor of Chemical Engineering
Steven M. Parks, Postdoctoral Associate
Shiwei (Michael) Shao, Postdoctoral Associate

Graduate Students: Michigan State University

Sang-Yoon Kang, Chemical Engineer (Faculty Advisor, K. Jayaraman)
Figen Lacin, Mechanical Engineer (Faculty Advisor, Mei Zhuang)
Dilip Kumar Mandal, Mechanical Engineer (Faculty Advisor, André Bénard)
Chinh T. Nguyen, Chemical Engineer (Faculty Advisor, Charles Petty)
Dogan Seyyar, Mechanical Engineer (Faculty, Advisor, André Bénard)
Michael W. Shafer, Chemical Engineer (Faculty Advisor, Dennis Miller)

Undergraduate Students: Michigan State University

Florin Radu Danca, Dean's Scholar in Chemical Engineering (Faculty Advisor, K. Jayaraman)
Dina A. El-dein, Dean's Scholar in Chemical Engineering (Faculty Advisor, Charles Petty)
Nicholas F. Lynn, Dean's Scholar in Mechanical Engineering (Faculty Advisor, Mei Zhuang)
Gregory Allen McColley, NSF/REU Scholar in Chemical Engineering (Faculty Advisor, K. Jayaraman)
Julie A. Richards, Dean's Scholar in Mechanical Engineering (Faculty Advisor, André Bénard)
Andrew R. Yoder, Dean's Scholar in Chemical Engineering (Faculty Advisor, Charles Petty)

Faculty: The University of Akron

George G. Chase, co-Principal Investigator and Professor of Chemical Engineering
Thomas D. Radcliff, Senior Associate and Assistant Professor of Mechanical Engineering
Edward A. Evans, Senior Associate and Assistant Professor of Chemical Engineering

Graduate Students: The University of Akron

Brian Raber, Chemical Engineer (Faculty Advisor, George Chase)
Hongmin Li, Mechanical Engineer (Faculty Advisors, Thomas Radcliff and Edward Evans)

Undergraduate Students: The University of Akron

Joshua Herron, Mechanical Engineer (Faculty Advisors, Thomas Radcliff and Edward Evans)
Seth Jentner, Chemical Engineer (Faculty Advisor, George Chase)
Michael T. Skeggs, NSF/REU Scholar in Chemical Engineering (Faculty Advisor, George Chase)

Faculty: The University of Tulsa

Ovadia Shoham, Senior Associate and Professor of Petroleum Engineering
Ram S. Mohan, Co-Principal Investigator and Assistant Professor of Mechanical Engineering
Siamack A. Shirazi, Senior Associate and Associate Professor of Mechanical Engineering
Keith D. Wisecarver, Senior Associate and Associate Professor of Chemical Engineering

Graduate Students: The University of Tulsa

Ferhat Metin Erdal, Mechanical Engineer (Faculty Advisor, Shiamack Shirazi)
Jin Wang, Chemical Engineer (Faculty Advisor, Keith Wisecarver)
Luis Gomez, Petroleum Engineer (Faculty Advisor, Ram Mohan & Ovadia Shoham)

Undergraduate Students: The University of Tulsa

Jose Severino, Petroleum Engineer (Faculty Advisor, Ram Mohan)

Other Technical Collaborators on the Project

Frederick Hall, UNIX Systems Analyst
Division of Engineering Computing Services
Michigan State University
Randy M. Russell, Web Curriculum Manager
Virtual University Technology Group
Michigan State University

NSF/CRCD Internet Course on Multiphase Transport Phenomena, Fall 2000 Student Participants (* non CRCD graduate students)

Florin Danca (Chemical, MSU)	Nick Lynn (Mechanical, MSU)
Dina El-dein (Chemical, MSU)	Gregory McColley (Chemical, MSU)
Alvin Goh* (Mechanical, MSU)	Chris Saffron* (Chemical, MSU)
Josh Herron (Mechanical, Akron)	Jose Severino (Petroleum, Tulsa)
Seth Jentner (Chemical, Akron)	Mike Shafer* (Chemical, MSU)
Frank Jere* (Chemical, MSU)	Mike Skeggs (Chemical, Akron)
Chee Lum* (Mechanical, MSU)	Jin Wang (Chemical, Tulsa)
	Andy Yoder (Chemical, MSU)

Industrial Advisors and Mentors

AEA Technology Engineering Software, Inc.
Jeffery P. Henning
Bethel Park, PA

Fluent Inc.
Barbara Hutchings and Ahmad H. Haidari
Lebanon, NH

Bechtel Technology and Consulting
Jon Berkoe
San Francisco, CA

ICEM CFD Engineering
Brigette Rosendall (now with Bechtel)
San Francisco, CA

Chevron Petroleum Technology Company
Gene E. Kouba (Mentor)
Houston, TX

Krebs Engineers
Mark E. Hoyack and Tim Olson (Mentors)
Tucson, Arizona

Dow Chemical
Paul Gillis
Freeport, Texas

Pharmacia Corporation
Mark Widman (Mentor)
Kalamazoo, MI

Dupont Central Research & Development
Karsten Keller
Wilmington, DE

The Procter & Gamble Company
Savas Aydore
Cincinnati, OH

Eastman Chemical Company
Kevin J. Fontenot (Mentor)
Kingsport, TN

The Trane Company
Ray Rite (Mentor)
La Crosse, Wisconsin

ExxonMobil Upstream Research Company
Stephen L. Lyons
Houston, TX

2. Activities and Findings

2.1 Major Activities: Project Milestones and Project Calendar

Pre-Award Activities

September 28, 1999: George Chase and Charles Petty meet with Mary Poats of NSF to discuss the possibility of an NSF award.

October 1999: Professor Marilyn Amey of the College of Education reviews the NSF/CRCRD proposal and agrees to join the project as an evaluator.

November 2, 1999: University/Industry pre-award breakfast meeting; Annual AIChE Meeting, Dallas, Texas; Attendees included Chase (Akron), Chen (AEA), Lyons (Mobil), Parks (MSU), Petty (MSU), Shao (MSU), and Wisecarver (Tulsa).

November 17, 1999: Notice received that the NSF/CRCRD two-year project will be fully funded: \$500,000 (NSF); \$125,000 (25% cash match from MSU/UA/UT); supplemental cash match of \$16,000 from MSU to support Professor Amey's participation.

First Quarter (December-February)

December 1999 -February 2000: MSU, UA, and UT faculty recruit undergraduate students for the first-year NSF/CRCO curriculum development project (six MSU students, three Akron students, and one Tulsa student).

December 14, 1999: Virtual University Technology Group at Michigan State University agrees to support the development of an NSF/CRCO Internet course on multiphase transport phenomena. This is a significant in kind contribution to the NSF/CRCO project. Participants at this meeting included: Paul Hunt (Vice Provost, Libraries, Computing, and Technology), Robert Church (Acting Vice Provost, University Outreach), Loraine Hudson (co-Director, Virtual University Team and Digital Information Group), Mei Zhuang (Mechanical Engineering), Charles Petty (Chemical Engineering), and Anthony Wojcik (Associate Dean of Research and Graduate Studies in the College of Engineering).

December 23, 1999: Draft of an Intellectual Property Agreement forwarded to The University of Akron and The University of Tulsa for administrative review.

January 2000: Michigan State University housing agrees to host the NSF/CRCO 2000 CFD Summer Camp, August 2000.

January 2000: The Division of Engineering Computing Services agrees to provide technical support and training for the CFD Summer Camp. This is a significant in kind contribution to the project.

January 19, 2000: Meeting with the Virtual University Technology Group to establish production schedule for the NSF/CRCO curriculum development project.

February 7, 2000: NSF/CRCO web site (<http://www.eng-mtp.vu.msu.edu/web/>) established by Randy Russell, Web-Based Curriculum Manager, Virtual University Technology Group. This web site, which supports the Internet course on multiphase transport phenomena, facilitates communication among the 43 or more NSF/CRCO faculty participants, students, and industrial participants (see Section 1) by providing photographs, telephone numbers, e-mail addresses, web page connections, and a WebTalk bulletin board.

February 11, 2000: Telephone conference call with UA and UT related to Intellectual Property Agreement.

February 2000: Proposal to the National Science Foundation for supplemental NSF/REU Fellowships; NSF/REU funds (\$10,000) available to support G. McColley (MSU) and M. Skeggs (Akron).

February 2000: Academic equipment grant proposal submitted to Sun Microsystems for ten Ultra 10 workstations; Sun Microsystems provides a two-for-one grant for workstation acquisition (five for MSU, three for Tulsa, and two for Akron).

February 2000: Petty meets new industrial participants at ASME/Petroleum Division ETCE 2000 Meeting in New Orleans; Fluent Inc. agrees to serve on advisory board.

February 2000: Request for first-year CFD design topics and industrial mentor volunteers. This is a significant in kind contribution to the NSF/CRCO project.

February 2000: First-year subawards issued to The University of Akron and The University of Tulsa.

Second Quarter (March-May)

March - May 11, 2000: Faculty participants develop material for May 11 Advisory Board Meeting.

March-May 2000: Steve Parks developed and tested a CFD educational transport phenomena problem with Yo Kim, an undergraduate honors college student at MSU. This CFD example problem was used as an instructional tool in the NSF/CRCD Summer Workshop (August 2000). The problem is also featured as an example on the NSF/CRCD web site (www.vu.msu.edu/preview/eng-mtp). Mr. Kim is now participating in the NSF/CRCD project as a graduate student.

March - May 2000: Faculty participants initiate nine academic case studies related to multiphase transport phenomena in support of the Internet course offering. Interim reports on these projects were presented at the May 2000 Industrial Advisory Board Meeting and the August 2000 CFD Summer Workshop. The titles and developers of these case studies are listed in Section 2.2.2.

May 11, 2000: Faculty Planning Session at Michigan State University (see Section 2.2.3 below).

May 12, 2000: Industrial Advisory Board Meeting at Michigan State University. Industrial Attendees included: Jeffery Henning, AEA Technology; Paul Gillis, Dow Chemical; Kevin Fontenot, Eastman Chemical; Stephen Lyons, ExxonMobil; Barbara Hutchings, Fluent; Brigitte Rosendall, ICM CFD Engineering (now with Bechtel); Mark Hoyack and Tim Olson, Krebs Engineers; Mark Widman and Doug Jonas, Pharmacia; and Ray Rite, Trane.

May 2000: Industrial case studies and industrial mentors selected for the first round of CFD design projects for undergraduates. These ongoing projects were launched during the CFD Summer Workshop in August. See Sections 2.2.4 and 2.2.5 for additional details.

May 2000: AEA Technology Engineering Software, Inc. trained the following postdoctoral and graduate student mentors in the use of CFX software: F. Erdal (Tulsa), F. Lacin (MSU), S. Parks (MSU), B. Raber (Akron), and M. Shao (MSU); Bethel Park, PA. This is a significant in kind contribution to the NSF/CRCD project.

Third Quarter (June- August)

June 2000: Ten Sun Microsystems Ultra 10 workstations ordered for the NSF/CRCD group (five to MSU; three to Tulsa; two to Akron). The workstations were delivered in September 2000.

June-July, 2000: S. Parks further developed and tested CFD training material for the CFD summer workshop with the assistance of F. Lacin, S. Shao, and undergraduate students at MSU (Danca, El-dein, Lynn, McColley, Richards, and Yoder).

July 19, 2000: Faculty submitted an NSF/IGERT pre-proposal in support of a continuation of the NSF/CRCD initiative on multiphase transport phenomena.

August 11-18, 2000: MTP/CFD Summer Workshop and MTP Symposium at Michigan State University (see Section 2.3 below).

August 16, 2000 to February 2001: CFD design projects were launched during the summer workshop. A brief abstract of each project is given in Section 2.2.5 below. A progress report will be placed on the web site for industrial review in February 2001. These projects will be further developed by graduate student/faculty closure teams and organized as CFD case study examples for the multiphase transport phenomena Internet offering July-August 2001.

Fourth Quarter (September-November)

September 25-28, 2000: Fluent, Inc. provided specialized CFD training for the following postdoctoral and graduate student mentors in the use of Fluent software: L. Gomez (Tulsa), F. Lacin (MSU), S. Parks (MSU), Hongmin Li (Akron), and M. Shao (MSU); Ann Arbor, Michigan. This was a significant in kind contribution to the NSF/CRCD project.

September 11-November 17, 2000: First offering of an Internet course on Multiphase Transport Phenomena (see Section 2.3 for additional details).

October 2-3, 2000: C. Petty and M. Amey attend NSF/CRCD Annual Meeting, Capital Hilton, Washington, D.C.

Fifth Quarter (December-February)

December 2000-January 26, 2001: Faculty participants prepare final NSF/IGERT proposal in support of a continuation of the NSF/CRCD initiative on multiphase transport phenomena.

January - February 2001: Randy Russell, the Web-Based Curriculum Manager assigned to the NSF/CRCD project by the Virtual University Technology Group at Michigan State University, has established a preview page for the NSF/CRCD project (www.vu.msu.edu/preview/eng-mtp). This web site provides a means to disseminate completed project results and to recruit students for 2002. It also provides password entry into the course Web site presently undergoing b-testing (<http://www.eng-mtp.vu.msu.edu/web/>).

February 2001: The results developed by the undergraduate design teams during the first year will be posted on the NSF/CRCD web site for industrial review.

Sixth Quarter (March- May)

March-May 2001: Chase, Mohan, Petty, Parks, and Zhuang will develop revisions to the MTP Internet Course. This material will be reviewed by industrial advisors, June 6-7.

March - May 2001: Faculty participants and graduate students will complete academic case studies. This material will be reviewed by industrial advisors, June 6-7.

March- June 2001: Graduate students and faculty teams will develop a second round of results for the industrial case studies initiated by the undergraduate teams during the first year. These CFD case studies will be placed on the preview NSF/CRCD web site by the end of June (see Section 2.2.6 for additional details).

Seventh Quarter (June- July)

June 1-3 & 7-8, 2001: Faculty Planning and Review Session at Michigan State University.

June 4 -5, 2001: NSF/CRCD CFD Summer Workshop at Michigan State University.

June 6-7, 2001: Industrial Advisory Board Meeting & NSF/CRCD Multiphase Transport Phenomena Symposium, Kellogg Center, Michigan State University.

June -July 2001: Faculty and graduate student mentors will organize the final draft of the MTP topical lectures for the NSF/CRCD Internet Course offering in July and August.

Eighth Quarter (August- October)

July 2 - August 16, 2001: NSF/CRCD Multiphase Transport Phenomena Internet Course (second offering by MSU University Outreach and MSU Virtual University Technology Group).

September-October 2001: Preparation of final project report to the National Science Foundation.

October 2001: C. Petty and M. Amey will attend the NSF/CRCD Annual Meeting, Washington, D.C.

2.2. Major Findings

2.2.1 Steve Parks developed and tested a CFD educational transport phenomena problem with Yo Kim, an undergraduate honors college student at MSU. This CFD example problem was used as an instructional tool in the NSF/CRCD Summer Workshop (August 2000). The problem is also featured as an example on the NSF/CRCD web site (www.vu.msu.edu/preview/eng-mtp). Mr. Kim is now participating in the NSF/CRCD project as a graduate student.

2.2.2 Faculty participants initiate nine academic case studies related to multiphase transport phenomena in support of the Internet course offering. Interim reports on these projects were presented at the May 2000 Industrial Advisory Board Meeting and the August 2000 CFD Summer Workshop. The results of these academic case studies will be posted on the NSF/CRCD web site in June 2000. The titles and developers of these case studies are listed below.

The University of Tulsa: "Multiphase Reactor Design", Jin Wang and Keith Wisecarver; "Swirling Flow Characterization in a Gas-Liquid Cylindrical Cyclone Separator", Luis Gomez, Ram Mohan, and Ovadia Shoham; "Computational Fluid Dynamics Simulations in a Gas-Liquid Cylindrical Cyclone Separator", Ferhat Metin Erdal and Siamack A. Shirazi.

The University of Akron: "Shape Factors for Converging Flow Through a Converging Permeable Disk", T. Thome, B. Raber, and G. Chase; "Heat Transfer During Solidification from Liquids and Gases", Hongmin Li, Thomas Radcliff, and Edward Evans

Michigan State University: "Particle Distribution in Pressure Driven Flows", Sang-Yoon Kang and K. Jayaraman; "Solid/Liquid Dispersion in a Pipe Bend", Shiwei (Michael) Shao and Charles Petty; "Flow Simulations within Catalytic Converters", Figen Lacin and Mei Zhuang; "Transient Heat Transfer Inside A Sealed Container", Dilip Mandal and Andre Benard.

2.2.3 Michigan State University hosted a faculty planning session on May 11, 2000. Participants included: Chase and Radcliff from Akron; Mohan, Shiamack, and Wisecarver from Tulsa; Amey, Benard, Parks, Petty, Shao, and Zhuang from MSU. The following five objectives for the two-year project were identified:

- Introduce undergraduate and first year graduate students to the fundamentals and limitations of multiphase modeling (Internet course on Multiphase Transport Phenomena, MTP).
- Introduce undergraduate and first year graduate students to CFD as a design and research tool.
- Give undergraduate and first year graduate students an opportunity to

work on industrial CFD design problems in multidisciplinary teams.

- Provide an opportunity for advanced undergraduate students to combine multiphase CFD knowledge with specific research experience in the laboratory (NSF/REU and MSU/Dean Scholars program).
- Develop a set of instructional case studies in the area of multiphase transport phenomena.

2.2.4

Michigan State University hosted an Industrial Advisory Board Meeting on May 12, 2000. Industrial participants included: Jeffery Henning, AEA Technology; Paul Gillis, Dow Chemical; Kevin Fontenot, Eastman Chemical; Stephen Lyons, ExxonMobil; Barbara Hutchings, Fluent; Brigette Rosendall, ICEM CFD Engineering (now with Bechtel); Mark Hoyack and Tim Olson, Krebs Engineers; Mark Widman and Doug Jonas, Pharmacia; and Ray Rite, Trane. The following Industrial case studies and industrial mentors were selected for the first round of CFD design projects. These ongoing projects were launched during the CFD Summer Workshop in August. The titles of these case studies are listed below:

Mixing of Suspensions in a Tank -- Pharmacia

Design Team A: Michael Skeggs (Akron) and Andrew Yoder (MSU)

Academic Mentor: Charles Petty (MSU)

Industrial Mentor: Mark Widman, Pharmacia Corporation

CFD Mentors: Shiwei (Michael) Shao (MSU), Chinh Nguyen (MSU)

Vendor Mentor: Jeff Henning, AEA Technology

Faculty Evaluator: K. Jayaraman (MSU)

Distribution of a Two-Phase Refrigerant to Heat Exchanger Tubes -- Trane

Design Team B: Dina El-dein (MSU), Nicholas Lynn (MSU), and Michael Schafer (MSU)

Academic Mentor: Mei Zhuang (MSU)

Industrial Mentor: Ray Rite, The Trane Company

CFD Mentors: Figen Lacin (MSU), Dilip Mandel (MSU)

CFD Vendor: Jeff Henning, AEA Technology

Faculty Evaluator: Andre Benard (MSU)

Slurry Bubble Column - Eastman Chemical Company

Design Team C: Joshua Herron (Akron), Gregory McColley (MSU), Jin Wang (Tulsa)

Academic Mentor: George Chase (Akron)

Industrial Mentor: Kevin Fontenot, Eastman Chemical

CFD Mentors: Hongmin Li (Akron) and Brian Raber (Akron)

CFD Vendor: Jeff Henning, AEA Technology

Faculty Evaluators: Edward Evans (Akron) and Keith Wisecarver (Tulsa)

Performance of a Large Tank Separator -- Chevron

Design Team D: Radu Dunca (MSU), Seth Jentner (Akron), and Jose Severino (Tulsa)

Academic Mentor: Ram Mohan (Tulsa)

Industrial Mentor: Gene Kouba, Chevron

CFD Mentor: Ferhat Erdal (Tulsa)

Vendor Mentor: Jeff Henning, AEA Technology

Faculty Evaluators: Siamack Shirazi (Tulsa), Ovadia Shoham (Tulsa)

Optimization and Comparison of Hydrocyclone Shapes-- Krebs Engineers

Design Team E: Luis Gomez (Tulsa), Steve Parks (MSU), and Hongmin Li (Akron)

Academic Mentor: Charles A. Petty (MSU)

Industrial Mentors: Mark Hovack and Tim Olson. Krebs Engineers

Vendor Mentor: Ahmed Haidari, Fluent

- 2.2.5 CFD design projects were launched during the summer workshop (August 16, 2000). A brief abstract of each project follows. A progress report will be placed on the web site for review in February 2001. These projects will be further developed by graduate student/faculty closure teams and organized as CFD case study examples for the multiphase transport phenomena Internet course offering, July-August 2001.

Mixing of Suspensions in a Tank -- Pharmacia

Design Team A: Michael Skeggs (Akron) and Andrew Yoder (MSU)

Maintaining a spatially uniform liquid suspension of solids in a batch tank during the filling state and the withdrawal stage is a challenging unit operation. This CFD design project will simulate the flow patterns of a suspension in a mixing tank that uses a vibrating mixer. The goal is to develop an understanding between the operating characteristics of the mixer and the spatial uniformity of the solid/liquid suspension.

Distribution of a Two-Phase Refrigerant to Heat Exchanger Tubes -- Trane

Design Team B: Dina El-dein (MSU), Nick Lynn (MSU), and Michael Schafer (MSU)

Good distribution of a two-phase refrigerant in heating, ventilating, and air conditioning (HVAC) systems is critical. In an HVAC system, the role of the header is to deliver an equal amount of refrigerant to each heat exchanger circuit without changing the ratio of vapor to liquid. This project will simulate the flow patterns within a vertical, cylindrical header with a single axial influent tube and multiple radial effluent tubes evenly spaced along the header. The focus of this study will be on the separation of the dispersed phase near the withdrawal tubes.

Slurry Bubble Column - Eastman Chemical Company

Design Team C: Joshua Herron (Akron), Gregory McColley (MSU), Jin Wang (Tulsa)

In a slurry bubble column, the energy needed for liquid blending and solids suspension is generated by the expansion of the sparged gas. The gas stream can be introduced as a point source through a pipe or ring distributor, or a perforated mesh. The objective of this project is to model a slurry bubble column to determine the effect of height/diameter ratio and gas load on the spatial distribution of the solid/gas/liquid suspension.

Performance of a Large Tank Separator -- Chevron

Design Team D: Radu Dunca (MSU), Seth Jentner (Akron), and Jose Severino (Tulsa)

A large (80,000 barrels) wet crude oil gravity separation tank is used to separate water from crude oil so the water can be safely returned to the environment. The feed stream may contain more than 20% water by volume. As more production wells are added and existing wells mature, the total flow rate and the ratio of water to oil in the feed stream increase. The oil/water dispersion is introduced into the tank through an array of pipes located near the bottom. A major challenge in the design is the prediction of the distribution of the oil and water dispersion over

the cross sectional area of the tank near the inlet manifold. The goal of this project is to estimate the performance of the separator as the flow rate and water cut increase.

Optimization and Comparison of Hydrocyclone Shapes-- Krebs Engineers

Design Team E: Luis Gomez (Tulsa), Steve Parks (MSU), and Hongmin Li (Akron)

The geometry of a hydrocyclone has a significant impact on the internal flow behavior and, thereby, the separation performance. Recent laboratory and field results developed by Krebs Engineers support the use of a new geometry for solid/liquid separations. The objective of this study is to simulate the internal flows within two different hydrocyclones to understand the influence of shape on solid/liquid separation. The study will focus on the conical section of the hydrocyclone.

2.2.6 March- June 2001: Graduate students and faculty teams will develop a second round of results for the industrial case studies initiated by the undergraduate teams during the first year. These case studies will be placed on the NSF/CRCD web site by the end of June 2001. The closure design teams are as follows:

- Design Team A*: Yo Kim (MSU) and Chinh Nguyen (MSU)
Mixing of Suspensions in a Tank -Pharmacia
- Design Team B*: Figen Lacin (MSU) and Dilip Mandel (MSU)
Distribution of a Two-Phase Refrigerant to Heat Exchanger Tubes -Trane
- Design Team C*: Hongmin Li (Akron) and Brian Raber (Akron)
Slurry Bubble Column - Eastman Chemical Company
- Design Team D*: Luis Gomez (Tulsa) and Jin Wang (Tulsa)
Performance of a Large Tank Separator -Chevron
- Design Team E*: Steve Parks (MSU) and Charles Petty (MSU)
Optimization and Comparison of Hydrocyclone Shapes -Krebs Engineers

2.3 Opportunities for Training and Development

- 2.3.1 AEA Technology Engineering Software, Inc. provided CFD training for the following postdoctoral and graduate student mentors in the use of CFX software: F. Erdal (Tulsa), F. Lacin (MSU), S. Parks (MSU), B. Raber (Akron), and M. Shao (MSU); Bethel Park, PA., May 2000.
- 2.3.2 Fluent, Inc. also provided specialized CFD training for the following postdoctoral and graduate student mentors in the use of Fluent software: L. Gomez (Tulsa), F. Lacin (MSU), S. Parks (MSU), Hongmin Li (Akron), and M. Shao (MSU); Ann Arbor, MI, September 2000. This was a significant in kind contribution to the NSF/CRCD project.
- 2.3.3 Michigan State University hosted a one-week MTP/CFD Summer Workshop and a one-day MTP Symposium during the period August 11-18, 2000. Faculty and student

participants included:

The University of Akron: George Chase, Brian Raber, Hongmin Li, Joshua Herron, Seth Jentner, and Michael Skeggs

The University of Tulsa: Ram Mohan, Ferhat Erdal, Luis Gomez, Jose Severino, and Jin Wang

Michigan State University: Marilyn Amey, Andre Benard, Florin Danca, Dina El-dein, K. Jayaraman, Sang-Yoon Kang, Figen Lacin, Nicholas Lynn, Dilip Mandal, Gregory McColley, Chinh Nguyen, Charles Petty, Steven Parks, Julie Richards, Dogan Seyyar, Shiwei (Michael) Shao, Andrew Yoder, and Mei Zhuang (preparation and evaluation only; on maternity leave in August).

Industrial Participants: Jeffery Henning, AEA Technology Software Inc.; Paul Gillis, The Dow Chemical Company; Kevin Fontenot, Eastman Chemical Company; Ahmad Haidari, Fluent Incorporated; Mark Hoyack and Tim Olson, Krebs Engineers; Mark Widman and Doug Jonas, Pharmacia Corporation.

MTP/CFD Summer Workshop Activities

Friday: Workshop Orientation and Laboratory Demonstrations
Saturday: Workstations; Web Site; Transport Phenomena Workshop-Part I
Sunday: Transport Phenomena Workshop-Part II
Monday: CFX Training-Part I
Tuesday: CFX Training-Part II & Lansing Lugnuts Baseball Game (evening)
Wednesday: Breakout Sessions with Industrial Mentors & NSF/IGERT discussion with the Dean of Engineering (evening)
Thursday: Symposium on Computational Analysis of Multiphase Problems & Picnic at Lake Lansing Park South (evening)
Friday: Student Design Team Presentations; Workshop Evaluation and Closure

2.4 Outreach Activities

An NSF/CRCD Internet course on Multiphase Transport Phenomena was offered during the period September 11- November 17, 2000. This experimental course was restricted to NSF/CRCD students and selected graduate students at MSU (three virtual contact hours per week for 10 weeks; 2 academic credits).

Student participants (* denotes graduate students, others are undergraduates): Florin Danca (Chemical, MSU), Dina El-dein (Chemical, MSU), Alvin Goh* (Mechanical, MSU), Josh Herron (Mechanical, Akron), Seth Jentner (Chemical, Akron), Frank Jere* (Chemical, MSU), Chee Lum* (Mechanical, MSU), Nick Lynn (Mechanical, MSU), Gregory McColley (Chemical, MSU), Chris Saffron* (Chemical, MSU), Jose Severino (Petroleum, Tulsa), Mike Shafer* (Chemical, MSU), Mike Skeggs (Chemical, Akron), Jin Wang* (Chemical, Tulsa), and Andy Yoder (Chemical, MSU).

The following topical lectures were offered. This material is presently undergoing revisions and will be open to non-CRCD student during the 2001 Summer Semester.

Topic I: Multiphase Transport Phenomena Fundamentals
September 11- September 29, 2000
Charles A. Petty, Steven M. Parks, and Mei Zhuang
Michigan State University

Background: Transport Phenomena and Computations (Summer Workshop)
Background: CFX 4.x Training (Summer Workshop)

Session I.1 Transport Phenomena: Single-Phase Fluids
Session I.2 Turbulent Transport Phenomena
Session I.3 Particle Dynamics
Session I.4 Transport Phenomena: Multiphase Fluids (Summer, 2001)
Session I.5 Multiphase Computational Fluid Dynamics (Summer, 2001)

Topic II: Gas-Liquid Two-Phase Flow Pattern Prediction
October 2 - October 20, 2000
Ram S. Mohan and Ovadia Shoham
The University of Tulsa

Session II.1 Applications
Session II.2 Flow Variables
Session II.3 Fundamental Phenomena
Session II.4 Flow Pattern Definitions and Classifications
Session II.5 Pressure Loss Calculations

Topic III: Flow in Porous Media
October 23 - November 10, 2000
George G. Chase
The University of Akron

Session III.1 Fundamental Equations
Session III.2 Defined Engineering Quantities
Session III.3 Isothermal Flows in Porous Media
Session III.4 Heat Conduction and Species Diffusion in Porous Media
Session III.5 Dispersion Effects in Flows Through Porous Media

3. Publications and Products

3.1 Presentations and News Events

"Multiphase Transport Phenomena Course Surges Beyond University Walls", EVENTS, No.147, College of Engineering, Michigan State University, February 2000.

"NSF/CRCO Multiphase Transport Phenomena: The Use of Commercial Computational Fluid Dynamic Tools to Support Engineering Design", presented by S. Parks and M. Shao, Michigan State University Faculty Computer Fair, March 29, 2000.

"NSF Combined Research Curriculum Development on Multiphase Transport Phenomena", presented by Charles Petty, North Central American Society for Engineering Education, Kellogg Center, Michigan State University, March 31, 2000.

"NSF/CRCO Multiphase Transport Phenomena Curriculum Development", presented by C. Petty, Poster Session on Frontiers in Chemical Education, Pasadena Room, AIChE Annual Meeting, Los Angeles, CA., November 13, 2000.

"NSF-CRCO Project on Multiphase Transport Phenomena", to be presented by R. Mohan, XXI Oklahoma AIAA ASME Symposium, The University of Tulsa, February 24, 2001.

"NSF/CRCO: Multiphase Transport Phenomena", to be presented by George Chase, 2001 ASEE Annual Conference & Exposition, Albuquerque, New Mexico, June 24 -27, 2001.

3.2 Web Sites

Randy Russell, the Web-Based Curriculum Manager assigned to the NSF/CRCO project by the Virtual University Technology Group at Michigan State University, has established a preview page for the NSF/CRCO project (www.vu.msu.edu/preview/eng-mtp). This web site provides a means to disseminate completed project results and to recruit students for 2002. It also provides password entry into the Internet course site presently undergoing b-testing (<http://www.eng-mtp.vu.msu.edu/web/>). The web site also facilitates communication among the 43 or more NSF/CRCO faculty participants, students, and industrial participants (see Section 1) by providing photographs, telephone numbers, e-mail addresses, web page connections, and a WebTalk bulletin board.

4. Contributions

The impact and significance of this NSF/CRCO project will be explained in the final report