NSF CRCD: Multiphase Transport Phenomena

G. Chase, E. Evans
The University of Akron

C. Petty, M. Zhuang, K. Jayaraman, A. Benard, M. Amey
Michigan State University

R. Mohan, O. Shoham, S. Shirazi, K. Wisecarver
The University of Tulsa

Abstract

Faculty at three universities are collaborating in a unique approach to teaching multiphase transport phenomena (MTP). This MTP curriculum development program draws on the research experiences from nine laboratories at Michigan State University, The University of Akron, and the University of Tulsa. The objective of the program is to teach undergraduate and graduate students practical use of multiphase computational fluid dynamics (CFD).

The impact of multiphase flow research on solving practical engineering problems is an integral part of the learning experience. Industrial participants in the project provide specific design problems related to emerging technologies. Specific projects suggested by the industrial sponsors for the first cycle are: Performance of a large tank separator (Chevron), Optimization of design and operation of degassing tanks (Dow Chemical), Optimization and Comparison of hydrocyclone shapes (Krebs Engineers), Mixing of suspensions in a tank during the filling stage (Pharmecia), and Distribution of a two-phase refrigerant to heat exchanger tubes (The Trane Company), Design of a Slurry Bubble Column (Eastman Chemical Company).

Students are taught the fundamentals of CFD at a 1-week intensive short course in the summer. In the Fall semester the student take a web based course on multiphase transport phenomena theory and applications. Also in the Fall semester the students are assigned to teams to work on design problems posed by sponsor companies and apply their skills in CFD.

The results of the first cycle of this project are presented in this paper. Lessons learned and suggestions for improvement are discussed.

I. Introduction

Courses on transport phenomena associated with multicomponent, single-phase fluids play a major role in training undergraduate and graduate students in chemical, mechanical, and petroleum engineering. However, like thermodynamics and other multidisciplinary courses, these academic offerings have been developed separately within each engineering discipline in order to emphasize applied problems encountered in each field. So far, student training on transport phenomena for *multiphase fluids* has been limited to specialized courses and workshops. Consequently, important advances in multiphase flow research and analysis tend to remain isolated within a discipline. Moreover, access to post graduate courses on multiphase transport phenomena and particulate processing remains a difficult challenge for most graduates. Therefore, the objective of this NSF/CRCD initiative is to bridge the gap between traditional training in fluid mechanics, heat transfer, and mass transfer received by most engineers within their individual discipline and the need for additional specialization and training in the area of multiphase transport phenomena.

Recent significant advances in multiphase flow research have been achieved due to the availability of laser-based flow instrumentation, inexpensive computing systems, and improved computational protocols. These enabling technologies, which were unavailable thirty years ago, have opened up new possibilities for developing next generation compact separators and other technologies for many applications including, but not limited to, oil and gas production *downhole*, plastic recycling, biotechnology, and micro-gravity separation in outer space. Thus, this curriculum development project aims to develop and implement a multi-institutional curriculum on *multiphase transport phenomena* (MTP) that builds on the existing course offerings in the participating departments. The *new MTP course* will be designed to 1) train students from different engineering backgrounds in the use of *multiphase computational fluid dynamics* (MCFD); 2) introduce students to state-of-the-art experimental techniques employed to validate multiphase transport models; and, 3) teach students how to critically analyze and interpret CFD results. The MCFD offering will eventually be integrated into the existing coursework structure and degree requirements of the participating departments. Modular educational packages appropriate for undergraduate instruction and/or entry level graduate instruction will be developed as complementary material to more traditional courses on transport phenomena.

II. Need for a Multiphase Transport Phenomena Curriculum

Multiphase transport phenomena research is of industrial and national importance. Advances in oil and gas production, composite material processing, bioremediation of soils, plastic recycling, modern biotechnology reactors and separators, high-performance filtration devices, nuclear fuel reprocessing, and efficient automotive fuel utilization represent a few disparate engineering problems that rely on a basic fundamental understanding of multiphase transport phenomena.

This curriculum development initiative aims to address a need to bridge an educational gap between undergraduate training in transport phenomena of single-phase fluids and transport phenomena of multiphase fluids. Moreover, a significant gap is developing on the use of conventional transport phenomena principles and computational fluid dynamic tools. CFD has opened up the possibilities of analyzing in the classroom complex flows in complex geometries unimagined ten to twenty years ago. Students need further training to effectively use modern CFD codes and to understand how CFD results can be used as an innovative process design tool as well as a diagnostic tool. Thus, the broad goals of this initiative stem directly from ongoing research and educational programs at MSU, Akron, and Tulsa. The proposed multi-disciplinary, multi-institutional curriculum development project will integrate different teaching paradigms associated with different professional groups. Although it may be difficult to clearly define the final product of this project, it will clearly be different than current instructional approaches.

III. Participants

The participants in this project come from industry and academia. The three universities include Michigan State University (the lead institution), The University of Akron, and University of Tulsa. Students and faculty come from several disciplinary areas of Chemical Engineering, Mechanical Engineering, and Petroleum Engineering. Industrial participants come from AEA Technology Engineering Software Inc., Bechtel Technology and Consulting, Chevron Petroleum Technology Company, The Dow Chemical Company, DuPont Central Research & Development, Eastman Chemical Company, ExxonMobile Production Company, Fluent Incorporated, ICEM CFD Engineering, Krebs Engineers, The Procter & Gamble Company, and The Trane Company.

IV. Goals of the Project

The overall goal of this effort is to develop and implement a Multiphase Transport course across the three different professional disciplines at the three different universities. Eight educational needs for advanced undergraduate and beginning graduate engineering students are identified. The structure of this curriculum is our attempt to address these needs. These needs are:

1) Training in fundamentals of multiphase transport phenomena;
2) Training in the development of multiphase model formulation, interpretation, and experimental validation;
3) Training in the fundamentals of numerical methods that support current state-of-the-art commercial CFD codes;
4) Training in the implementation of CFD codes;
5) Training in the use of CFD codes for non-turbulent flows of single phase fluids;
6) Training in the use of CFD codes for turbulent flows of single phase fluids;
7) Training in the application of multiphase CFD codes; and
8) Training in the integration of CFD tools into the design process.

V. Organization of the Program

The Program is organized into three major parts: one-week of intensive CFD and transport training (referred to as "bootcamp"), a web based course on multiphase transport, and an interdisciplinary/interuniversity design project. The description given here is how we ran the program last year. At the end of this paper we discuss changes that we are considering.

i. Bootcamp

Bootcamp was conducted at MSU in August of 2000. The bootcamp had periods of intensive training interspersed with socializing activities. Approximately 20 undergraduate and graduate students participated along with 5 faculty and 6 industrial mentors. The students were given a review of single-phase transport phenomena, practical hands-on experiments to introduce students to concepts in single and multiphase material properties, and a period of intense training on the use of AEA Technology Engineering Software Inc.'s CFX4 software. The software is operated on unix work stations and a brief instruction was given on how to operate, log-on, and use the unix operating systems. At the end of the software training the students understood the fundamentals and had experience in setting up and executing solutions to simple computational problems.

At the bootcamp the students were assigned to their design teams. The students met with the industrial mentors that suggested the project ideas for their teams. These meetings allowed the students and the industrial mentors to decide upon the scope and set the expectations on the projects.

Part of the training at the bootcamp included a discussion on the state-of-the-art of CFD software, its limitations, and interpretation of results. These discussions were provided by AEA Technology Inc. and by Fluent Inc.

At the end of the bootcamp each of the design teams presented their plan of how they were going to solve the problems proposed by the industrial mentors. The students were given instruction on how to interact through email or the WebTalk bulletin board at the MSU web site to work on their projects and to discuss course material.

ii. Web course

The purpose of the web course is to provide the students with more in-depth fundamental knowledge of how to model multiphase systems. The web course is divided into three areas:

1) Multiphase Transport Phenomena Fundamentals by C. Petty and M. Zhuang,
2) Gas-Liquid Two-Phase Flow Pattern Prediction, by R. Mohan and O. Shaham,
3) Flow Through Porous Media, by G. Chase

The web course is organized such that as students read the material they send answers to assigned questions to the instructors.

iii. Design Projects

Six design projects were proposed by industrial mentors: Performance of a Large Tank Separator (Chevron), Optimization of design and operation of degassing tanks (Dow Chemical), Optimization and Comparison of Hydrocyclone Shapes (Krebs Engineers), Mixing of Suspensions in a Tank During the Filling (Pharmecia), and Distribution of a Two-Phase Refrigerant to Heat Exchanger Tubes (The Trane Company), Design of a Slurry Bubble Column (Eastman Chemical Company).

The students were divided into five three-student design teams. One of the teams is actually working on two projects at the same time. Four of the teams have one student at each of the three universities and one team is made up of students only from MSU. Two graduate students at each university assist the design team students on their projects as well as the faculty as academic mentors. The teams also have assigned an industrial mentor. Most of the communication between the teams is via email or the web bulletin board. At the time of writing this paper the design projects are not yet completed.

As an example, Figure 1 is a simplified sketch of the Large Tank Separator to separate oil from water. The separator is a large diameter tank with a pipe array as a gas flow distributor at the bottom of the tank.

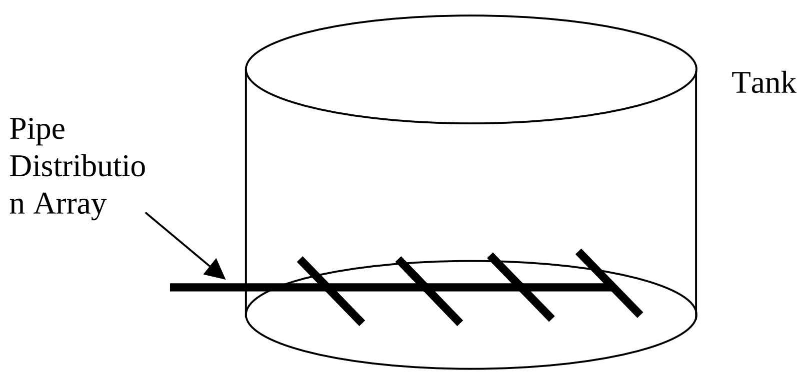

Figure 1. Tank with pipe array.

The pipes in the pipe array are perforated on the bottom with holes for the fluid to pass through and into the tank. Setting up the numerical grid to model the holes requires a fine grid structure around the holes. Such a fine grid structure is impractical for modeling long pipe lengths. As a compromise to allow a coarser grid structure, the bottom of the pipe is modeled as a porous structure, as shown in Figure 2. A calculated speed profile showing the locations of the highest speed of the fluid (irregardless of the velocity direction) is shown in an isometric view in Figure 3.

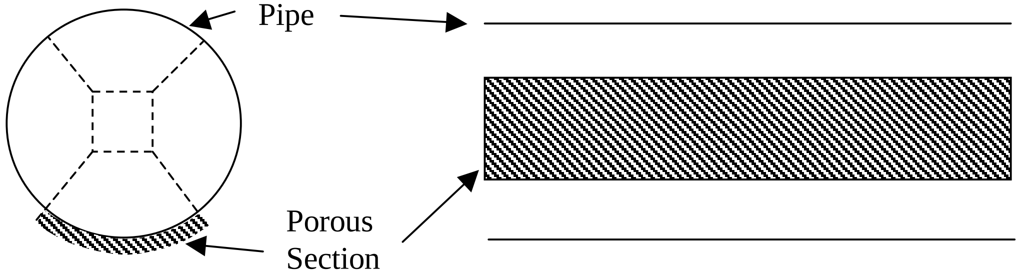

Figure 2. Pipe with porous section at bottom of pipe.

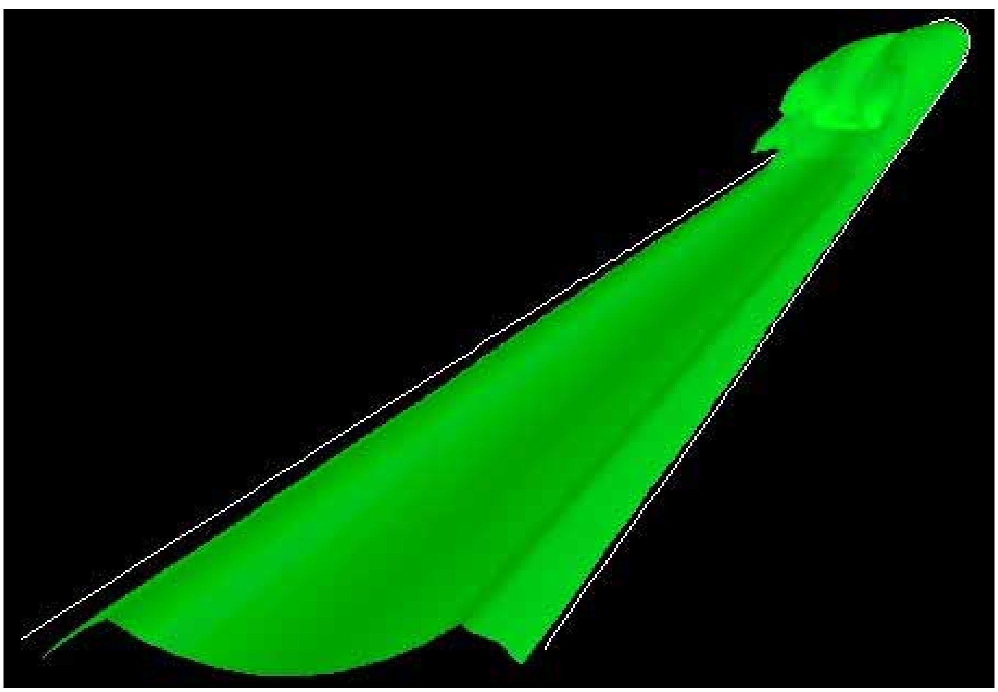

Figure 3: Isometric view of speed profile in the pipe for single phase water flow

VI. Assessment/Evaluation

The project was supported by on-going assessment and evaluation processes. A pre- and post-bootcamp assessment was conducted, along with a mid-week evaluation during the camp. Expectations of the students for learning outcomes, team development and teamwork, and on-line capabilities and on-line work were assessed and monitored throughout the bootcamp. Industrial expectations for the overall design project, perception of return on investment, and utility of participation was assessed at the end of the bootcamp. During the on-line course, a mid "term" assessment was conducted. Students commented on learning gains over the course material, time investment in the on-line experience and design project, comfort with on-line learning environments, and general satisfaction with the various aspects of the project. A final standardized on-line course evaluation was also used, in compliance with MSU faculty guidelines. Because of the perceived centrality of the Webtalk bulletin board for intra-team and class participation, content analyses of the on-line postings were also conducted. Themes and patterns about nature, content, frequency of communication were developed that have implications for on-line student teams, design projects and curriculum design. Final project assessment will also be conducted with students and industry mentors.

VII. Lessons learned

This project is still in progress, and full evaluation is not yet complete. Some of the tentative results and comments are provided here.

The students feel the curriculum is demanding but gives them an experience that is unique compared to their contemporaries. They have suggested that the web course be assigned during a different semester from the design project. We are considering moving the bootcamp to June, with the design project during the summer and the web course in the fall. Actually, the web course could be taught any time to the students because the design projects thus far suggested by the industrial participants do not require the in-depth web course material. However, the web course is an important part of the curriculum to provide students a greater understanding for interpretation of the CFD modeling results.

The faculty found the first year's curriculum also to be challenging. Writing the web courses required a significant effort for the first drafts. Future drafts will require refinements to make the courses more user interactive.

The first year Akron and Tulsa did not have the computer workstations setup until late in the Fall semester. This caused delays in starting the design projects. For future offerings of the curriculum this should not be a problem. Also, not unexpected, we found the design team made up of students only from MSU made the fastest progress on the design project, partly because of the availability of the computers and partly because face-to-face communications can be more effective on a project such as this.

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Biographical Information:

GEORGE CHASE
George Chase is a Professor of Chemical Engineering at The University of Akron. He also as director of a Coalescence Research Consortium, has served as director of the Microscale Physiochemcial Engineering Center, and has served as the Chairperson of the American Filtration and Separations Society. Dr. Chase was the 1999 Johansen-Crosby Visiting Chair Professor at Michigan State University. Dr. Chase received his BS in Chemical Engineering in 1978 and PhD in 1989 both from The University of Akron.

ED EVANS
Edward A. Evans is an Assistant Professor of Chemical Engineering at The University of Akron. Dr. Evans has initiated a crystal growth research effort in which models are developed to improve deposition processes. Dr. Evans is the advisor for the undergraduate Chemical Engineering Car Team from the University of Akron. Dr. Evans received his BA in Engineering from Dartmouth College in 1991 and his PhD in Chemical Engineering from Case Western Reserve University in 1998.

CHARLES PETTY
Charles Petty is a Professor of Chemical Engineering at Michigan State University. Dr. Petty received his B.S. in 1966 and Ph.D. in 1970, both from The University of Florida. His research interests include hydrodynamic and reactor stability theory; solid-fluid separations; and turbulent transport phenomena. Dr. Petty is the Primary Investigator on the NSF CRCD grant upon which the work reported in this paper is based.

MEI ZHUANG
Mei Zhuang is an Associate Professor of Mechanical Engineering at Michigan State University. She is a member of the the NSF Center for Sensor Materials and the CFD Laboratory at MSU. She is also involved in joint research through partnerships with industry. Dr. Zhuang received her MS in Aeronautics in 1986 and PhD in 1990 both from Caltech.

ANDRE BENARD
Andre Benard is an Assistant Professor of Mechanical Engineering at Michigan State University. His research interests include heat transfer, materials processing, fuel cells, composite materials, phase change processes, modeling complex transport phenomena, viscoelastic flows, finite elements, and wavelets. He received his B. Eng. from Universite de Sherbrooke, M.Sc. at Ecole Polytechnique de Montreal, and Ph.D. at University of Delaware.

KRISHNAMURTHY JAYARAMAN
Krishnamurthy Jayaraman is Professor of Chemical Engineering at Michigan State University. He received the Withrow Distinguished Scholar Award in the College of Engineering at Michigan State University for 1999. He holds a Ph.D. in Chemical Engineering from Princeton University. His research interests and expertise are in the area of polymer processing and rheology, particularly in the context of two-phase systems such as rubber modified thermoplastic blends, fiber reinforced polymer composites and polymer nanocomposites. Dr. Jayaraman has developed several educational modules and case studies in design for courses and industry workshops, illustrating the dependence of molded part performance on processing conditions through the microstructure in the part.

MARILYN AMEY
Marilyn Amey is an associate professor of educational administration who teaches courses in higher, adult, and lifelong education. She is interested in leadership issues, postsecondary governance and administration issues, faculty concerns including improving teaching and learning, and community college contexts. Her current research involves work on department chairs; dual career couples in the academy, and early career community college faculty.

RAM MOHAN
Ram S. Mohan is a professor of Mechanical Engineering at the University of Tulsa. He received his Ph.D. and M.S.

Degrees in Mechanical Engineering from the University of Kentucky, and his B.Sc (Engg.) degree in Mechanical Engineering from the University of Kerala, India. He currently serves as the associate director of Tulsa University Separation Technology Projects (TUSTP), supported by several oil companies, U.S. Department of Energy and Oklahoma Center for the Development of Science and Technology (OCAST). Dr. Mohan is a member of the Society of Petroleum Engineers, American Society of Mechanical Engineers, Society of Manufacturing Engineers and American Society for Engineering Education. He currently serves as the Symposium Chair of the Manufacturing and Services Symposium for Energy Sources Technology Conference and Exposition (ETCE-2001) of ASME.

OVADIA SHOHAM
Ovadia Shoham is Professor of Petroleum Engineering at the University of Tulsa. He received his Ph.D. degree in Mechanical Engineering from Tel Aviv University and his M.S. and B.S. degrees in Chemical Engineering from the University of Houston and the Technion in Israel. He served as the associate director and the director of research of the Tulsa University Fluid Flow Projects for 10 years. He is a member of the Society of Petroleum Engineers and the American Institute of Chemical Engineers. He was a member of the SPE Production Operation Technical Committee (1990-1992 and 1998-2000) and served as a member of the planning committee of the SPE Forum Series on Multiphase Flow in 1992.

SIAMACK SHIRAZI
Siamack Shirazi is Associate Professor of Mechanical Engineering at The University of Tulsa. Shirazi teaches and conducts research in the areas of CFD for multiphase flow, erosion/corrosion and multiphase separation. He is the Director of the Tulsa University Sand Management Projects (TUSMP) and the Principal Investigator of the Erosion/Corrosion Research Center (E/CRC). Dr. Shirazi received his BS, M.S. and Ph.D in Mechanical Engineering (1981, 1983, and 1989, respectively) all from The University of New Mexico, Albuquerque, NM.

KEITH WISECARVER
Keith D. Wisecarver is an Associate Professor of Chemical Engineering at the University of Tulsa. He also serves as Co-PI of the Fundamentals of Delayed Coking DOE/Joint Industry Project. Dr. Wisecarver is a registered Professional Engineer in Oklahoma, and is actively involved in research related to multiphase reactor design and modeling.