ChE educator

MORTON M. DENN

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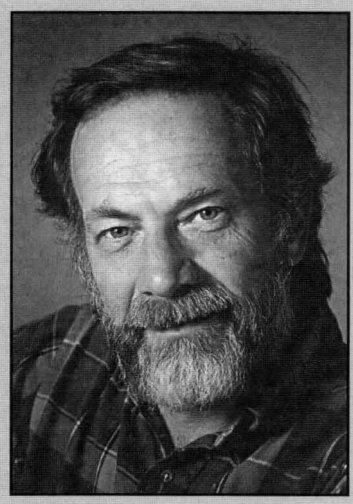
Morton Denn is a household name in modern chemical engineering circles, not only because of his many research accomplishments and service to our profession, but also because of the influence his books and classroom teaching have had on the education of young chemical engineers. In this paper, we, three of his former and current colleagues who span roughly three generations of chemical engineering academics, will highlight some of Mort's research accomplishments and provide perspective on some of his enduring contributions to chemical engineering education.



Now ▲

and . . .

then (circa 1971), sans beard.

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Mort was born and raised in Paterson (New Jersey), close to the city of New York. He got his first taste of "chemical engineering" in 1957 during a six-month stint as a laboratory assistant making foamed plastic boat bumpers and fishnet floats for the Linen Thread Company. This taste of chemical engineering served to whet Mort's appetite for the subject, and he later chose to major in chemical engineering at Princeton University.

An incident during his junior year at Princeton may have helped shape Mort's concise style of writing (it is difficult to find an extraneous phrase in articles and books written solely by Morton M. Denn). A laboratory report, graded by Michel Boudart, was returned to Mort liberally covered with red ink. He was humiliated that a native French speaker could find so much fault with his English and vowed that he would henceforth write in such a way that it would never happen again. Reading his textbooks and knowing of his exemplary work as editor of *AIChE Journal* and the *Journal of Rheology*, most would agree that he has succeeded.

Mort worked on his senior thesis with Bill Schowalter, a newly arrived Assistant Professor at the time. They aimed to carry out an experimental study of normal stresses in polymer solutions (people were still not convinced normal stresses were real in those days). Mort often remarks that after that experience it is a wonder that either of them ever did experiments again, despite the fact that *both* the data points were good ones. Meanwhile, he read tensor analysis and basic rheology papers with Schowalter and his students and developed a strong interest in the mathematical analysis of physical problems relevant to chemical engineers. This would be the underlying theme in much of Mort's early research and the pedagogy in his books.

Mort decided to pursue graduate studies in Minnesota. He was interested in mathematics in chemical engineering, and Richard Wilhelm had told him to go there. Also, in the summer of 1961, Mort had worked at the Dupont Engineering Research Laboratory in Wilmington with Alan Foss (later a faculty colleague at Berkeley), Jon Olson (later a colleague at Delaware), Steve Whitaker, and the late Forest Mixon. These "experienced" coworkers told him that Rutherford Aris was the hot item in applied mathematics in chemical engineering, so Mort arrived in Minnesota with the goal of becoming an Aris student. As a result, Aris agreed to become the thesis advisor of yet another student who would later become one of the leaders of our profession.

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Mort's thesis focused on optimization of systems with interconnecting structures, a problem that had been causing real difficulties but which proved to be "relatively straightforward" (Mort's view) when put into the proper format.

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Just prior to completing his thesis, Mort learned from Schowalter (who was spending a sabbatical leave at Minnesota) that Metzner at Delaware was looking for a postdoctoral coworker in the area of non-Newtonian fluid mechanics. He applied for, and was offered, the job. At Delaware he continued to spend time working on optimization problems and explored a newfound interest in optimal control.

After one year as a postdoctoral scholar, Mort joined the faculty at the University of Delaware. Interestingly, he had a joint appointment: 75% in computer science and 25% in chemical engineering. Three years later he moved full time into chemical engineering since he found his interests and those of the computer science department were not moving in the same direction. Mort was also promoted to tenure in 1968 (in just three years!). Once, when he and Henry Weinberg were asked "How did you fellows get tenure so quickly in those days? Were you just so much better, or was it easier?" even before the irrepressible Weinberg could say anything, Mort replied without hesitation, "Both!"

What do we know about the young Mort Denn, and what fostered his ability to make incisive decisions with such apparent ease? Some insight may be gained through a story his father related at the annual AIChE meeting in 1977 when Mort received the Professional Progress Award. Mort had invited his parents to attend the ceremony, and when he was absent from the table for a few minutes, the conversation turned to the clarity with which Mort is able to analyze societal as well as professional issues and at what age these attributes may have developed. His father responded just as definitively as Mort usually does with the following story:

> *At a very early age. I remember an occasion when Morton had just passed his thirteenth birthday and General Eisenhower, running for election, scheduled a campaign appearance in our home town. By pressing the local Republican officials I was able to arrange for the General's motorcade to change its itinerary sufficiently to enable a brief stop at our store. I wanted our son to meet this famous hero of World War II—perhaps a once-in-a-lifetime opportunity. All was arranged; Morton came to the store at the appointed time, but was less than enthralled when I explained to him, for the first time, what I had in mind. The motorcade arrived and I stepped outside to meet the general, but when he and I entered the store, Morton was nowhere to be found!. Clearly, he had taken full control of his own destiny by age thirteen and was ready to proceed incisively with developing it as he saw fit and with minimum outside interference.*

The period from 1965 to 1977 was a remarkably productive period in Mort's career. He continued working on optimization of distributed parameter systems, and many of the papers he wrote during this period were among the first in that area. But his most insightful and lasting contributions were made in the field of rheology and non-Newtonian fluid mechanics. The following examples, taken from the broad range of problems that Mort worked on, make clear the impact of his research in the first dozen years of his career.

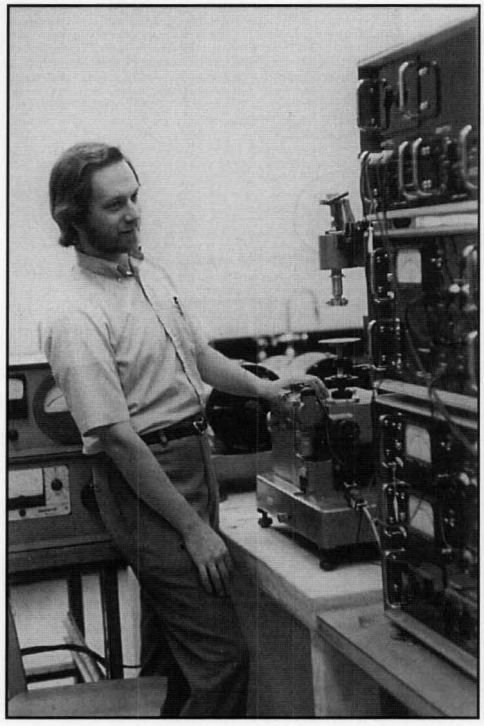
In 1970, Mort and one of his students, James Ultman addressed an issue that has since turned out to have deep implications for polymer flow and transport behavior.[1] They were studying heat transfer from cylinders submerged in flowing polymer solutions. The experimental data of David James showed some rather unusual behavior, which they ascribed to the fact that the relevant transport equations changed from elliptic to hyperbolic (thus allowing discontinuities) when certain pertinent variables acquired values that exceeded a certain threshold. While the implementation was not done rigorously by Ultman and Denn, this idea has proved to be wide-ranging in its applicability to transport phenomena in polymeric liquids, and Dan Joseph and coworkers[2] applied the idea rigorously to a variety of situations in the 1980s.

In 1971, Pino Marrucci and Mort published a paper on stretching of viscoelastic fluids that is characteristic of much of Mort's work in the first decade of his career— incisive, with profound implications, and yet mathematically simple. They analyzed the stretching of a rod of viscoelastic material.[3] Marrucci was a former student of Gianni Astarita in Naples, and as we have noted earlier, Mort had started work on non-Newtonian fluids as Art Metzner's postdoc. Astarita and Metzner[4] had published an analysis of some experiments based on the notion that the stress saturated as the stretching rate increased. Marrucci and Denn showed that this analysis was flawed, as it considered only the slow stretching rate asymptote; consideration of the fast stretching rate asymptote quickly showed the real physics. One can only imagine the pleasure the two youngsters derived from correcting their mentors' analysis. This paper with Marrucci, together with Mort's earlier work on boundary layers for elastic fluids, had an impact far beyond the difficulty of the

analysis because it led to deep physical insights. Both papers are widely cited and used as examples in textbooks.

◀ ***Mort and David Boger in the bush, late 1970s.***

Mort, circa 1972, at the University of Delaware: How do you operate a Weissenberg rheogonimometer with the plates six inches apart? ▼



In the late 1960s and early 1970s, Mort wrote a series of theoretical and experimental papers on Taylor-Couette instabilities in dilute polymer solutions[5] that set the stage for a lot of subsequent work on flow stability. These papers emphasized, for perhaps the first time, the extreme sensitivity of certain flows to second-order rheological effects. Mort still regrets the fact that he missed the interesting case of the zero Reynolds number oscillatory instability that has been exploited extensively by Muller (now a Berkeley colleague), Larson, and Shaqfeh in the early 1990s.[6] As he ruefully points out, the analysis for this case is there in his student Sun's thesis, but in a form that did not reveal the interesting physics.

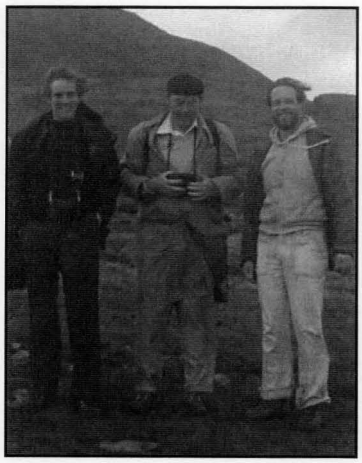
The mid-70s marked the beginning of Mort's research on the simulation of polymer processing operations, especially melt spinning, where his work with students and collaborators has defined the state of the art. The spinning work spanned twenty years, starting with an unpublished MS thesis of Glen Zeichner (co-advised with Art Metzner and Byron Anshus), followed by a seminal 1975 paper with Petrie and Avenas,[7] through a comprehensive book chapter[8] to a very recent paper on dynamics and disturbance propagation.[9] This period also marked the beginning of a productive collaborations with Jim Wei on the modeling of coal gasification reactors.

In addition to making seminal contributions to non-Newtonian fluid mechanics and stability, during this period Mort also wrote three of his five books. They cover a rather wide range of subjects: two are concerned with his stability and optimization interests, and one is a textbook for the first course in chemical engineering.[10] Perhaps the most popular textbook that Mort has written is *Process Fluid Mechanics,*[11] used in many chemical engineering departments around the world for undergraduate (and graduate) instruction.

Starting in 1965, the Delaware chemical engineering department initiated a project to redesign the six-credit introductory sophomore courses in industrial stoichiometry. Mort and TWF Russell devoted six years of effort to this task, and the final product was a totally new approach to the traditional first course in chemical engineering. The history of this course's development (and the resulting textbook) was outlined in an issue of this journal over twenty-two years ago.[12]

Some conclusions drawn by the authors that have stood the test of time and many years of classroom teaching by others are the "Denn-Russell rules":

- *Since chemical engineering departments require students to take freshman courses in mathematics, physics, and chemistry, it's incumbent upon them to use this material effectively in the introductory major course in chemical engineering.*
- *A crucial part of chemical engineering is the design, planning, and interpretation of experiment, and this must be introduced early in the curriculum.*
- *To analyze experiments properly and to use the results for effective process or product design, it is essential that one be proficient in chemical engineering analysis. This is distinctly different from applied mathematics.*
- *There are two critical issues in chemical engineering analysis that must be effectively learned. The first is the ability to look at any physical situation and to develop the mathematical description; the second is the ability to compare model behavior with experiment and to draw conclusions.*
- *Students at the freshman or sophomore level have great difficulty obtaining the mathematical descriptions or model equations, and a key component of analysis is the presentation of logical procedures to obtain the correct equation.*



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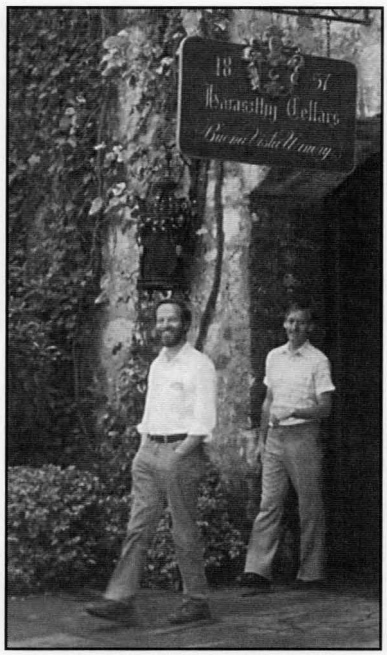
Mort with Bob Bird and Bruce Finlayson on Ben Lomond during a break between morning and afternoon sessions at a 1981 conference.



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Mort and Jan Mewis, wine tasting at one of the area vineyards, 1981,

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in 1986, Mort accepts the Bingham Medal from the Society of Rheology.

- *To teach chemical engineering analysis effectively, one should begin with studies of liquid-phase reacting systems. With such systems, one can show students a direct relationship between laboratory experiment, mathematical modeling, and simple reactor and process design.*
- *In the context of teaching chemical engineering analysis, students must be introduced to rate of reaction and rate of mass transfer, the two cornerstones of chemical engineering.*
- *Analysis is a necessary, but not sufficient, skill for chemical engineers.*

Mort left a rich legacy of discussions with faculty, administrative officials, the Board of Trustees, and perhaps others, in Delaware. One concerns Mort's appointment as chairman of the newly instituted university-wide senate Committee on Promotions and Tenure. The new provost had decided that the University of Delaware could not really qualify for admission to the circle of respected research universities as long as faculty who were of indeterminate quality and motivation were promoted to advanced status. Some departments had excellent criteria for promotion at that time, but others had rather slipshod criteria and procedures. The provost was anxious to see this ambivalence corrected, and the senate wisely chose Mort to carry the flag for this purpose. Mort denies the accuracy of the following recollection, but we do believe the salient points to be correct.

Evidently, in prior years (before the establishment of the senate committee) some department chairmen submitted rather informal and incomplete files directly to the administration in support of promotion requests, confident that in those days of rapid enrollment growth every warm body was sorely needed to meet teaching needs. One chairman, late to submit his document, had it carried to Mort's department where it was simply popped into the appropriate mailbox. When Mort found the shoddy file, he hastily scribbled a note to the chairman who had tendered the offending dossier—a note to the effect that it was apparent that this chairman did not have his office functioning at the level he would wish since "some junior clerk must have sent me this mess before you had a chance to consider it." Subsequent submissions, from all departments, were carefully prepared!

THE MOVE TO BERKELEY

In the late 1970s, Mort decided to leave Delaware. This decision was not based on any professional dissatisfaction with the University of Delaware. He simply wanted to live in an urban setting. While several distinguished universities tried to recruit him, he chose the University of California at Berkeley, joining the faculty in 1981. The diversity and academic excellence that characterizes Berkeley, together with the cultural opulence and natural beauty of the Bay Area, proved to be the determining factors.

Upon arriving at Berkeley, Mort established a polymers and composites research program in conjunction with the Lawrence Berkeley National Laboratory. This is now a vibrant program with a principal focus on anisotropic polymers and polymer-surface interactions that has many principal investigators working on diverse problems ranging from field-theoretic descriptions of the statistical physics of polymers to issues pertinent to large-scale processing. Mort runs the program like a benevolent dictator.

The emphasis of Mort's research at Berkeley has shifted toward more experimental work. In the 1980s, there were two parallel efforts in his group:

large-scale computations of viscoelastic fluid flows and complementary experimental work. The computational work was done largely in collaboration with Roland Keunings (now Professor at The Catholic University of Louvain). Many interesting things emerged from the Denn laboratory in these years, but perhaps the most comprehensive and exciting studies concerned the flow of fiber suspensions[13] and viscoelastic jet breakup.[14] Theoretical and computational work on the rheology of fiber suspensions involved a synergistic collaboration with David Boger in Melbourne, whose group did the complementary experiments. Computational and analytical work done in Mort's group, combined with pre-existing experiments, solved many aspects of the viscoelastic jet-breakup problem.

Mort developed a very strong interest in the rheology and fluid mechanics of liquid crystalline polymers, a subject that is still a central focus of study in his laboratory. He made the decision in the late 1980s to abandon, for the moment, computational and theoretical work in this area and to focus exclusively on experimental work, because he strongly believed that there were many issues in this field that were not understood even phenomenologically. As such, he decided that complex algorithm development was not fruitful until some of the relevant questions were understood at the simplest physical and phenomenological level. Mort also decided that such an understanding could only be obtained via well-designed experiments. Over the past few years, Mort's lab and those of others have produced experimental data that (in Mort's view) have begun to provide the phenomenological understanding of liquid crystalline polymer rheology that he believed was missing five years ago.

The study of extrusion instabilities has been a major focus of Mort's research for years.[15] During the past decade he has emphasized the role of the material of construction of the extrusion die on melt flow, particularly phenomena associated with failure of the no-slip boundary condition. Mort's innovative work in this area has combined adhesion theory, rheology, and surface spectroscopes ranging from XPS to ATR/FTIR in an effort to understand how surface chemistry and physics affect flow. He has had the satisfaction in recent years of seeing enough activity generated by his contributions (*e.g.*, a paper on adhesion and slip in polymer melts,[16] that he views as his most significant work of the decade) that his own papers have become secondary sources.

In his early years at the University of Delaware, Mort worked with a small number of students and sometimes with single investigators in various parts of the world; there were few collaborations involving joint supervision of students. The greater emphasis on state-of-the-art experiments, and perhaps the character of the Berkeley campus, have led to much more collaborative work in recent years. He collaborates extensively with Jeff Reimer in using NMR spectroscopy to probe polymer structure. He has also collaborated with Clay Radke, Alex Bell, David Soane, Miquel Salmeron, and Susan Muller.

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TEACHING AND PROFESSIONAL ACTIVITIES

The Berkeley years have also seen Mort giving much of his effort and time to professional service and mentoring junior faculty in the department. In the late 1980s and early 90s, the Berkeley department had an eclectic group of young faculty (mostly assistant professors) doing exciting research as well as conceiving and teaching new courses. They were also a feisty bunch and respectfully challenged some of the existing ways of doing things. Mort, at least fifteen years senior to the oldest member of this group of renegades, was the leader of the pack. He took time out to mentor many of these young faculty, even if their research areas were quite different from his own. It is perhaps fair to say that the success this group of now not-so-young faculty has realized can be partly attributed to the supportive and intellectually dynamic environment created by Mort and a few other senior faculty at Berkeley. Today, Mort continues to play a supportive role to the next generation of untenured faculty at Berkeley.

Over the years, Mort has served the chemical engineering profession in a variety of ways. For six years (1985-91) he was the sole editor of the *AIChE Journal,* and he worked hard to streamline the journal's operation. It is fair to say that when he handed the baton to Matt Tirrell, the *Journal* had regained its stature as one of the flagship journals of our profession.

Mort has served on innumerable review panels, editorial boards, and national committees of the AIChE, National Research Council, and other organizations. He is not just a warm body when it comes to these activities. He spends time to consider the various issues, he does his homework, and he contributes actively to the task at hand. His thoughts on the evolution of the profession of chemical engineering[17] reveal that he worries about deep issues pertaining to the future of our profession. His article, "The Identity of Our Profession," may be controversial, but no one would deny that it is thoughtful.

Mort served as department chairman at Berkeley for three years (1991-94). He is very interested in curriculum development and modification and continues to serve as the conscience of the department in this regard. After stepping down from the chairmanship, we all expected Mort to take a breather and concentrate purely on teaching and research; however, this plan seems to have gone awry, as he has now taken over as editor of the *Journal of Rheology.*

Mort and Vivenne at home, 1995.

Mort's former students and postdocs are profitably employed in industry, academia, and national laboratories. Perhaps a sign of the fact that he is "maturing" is the many former students and postdocs who are now in academia. These include Benny Freeman (NC State), Alejandro Rey (McGill), Jim Ultman (Penn State), Rakesh Jain (Harvard), Roland Keunings (C.U. Louvain, Belgium), Davide Hill (Notre Dame), Wen-Ching Yu (former dean of engineering at Tunghai University, Republic of China), Bob Fisher (UConn), Doug Kalika (Kentucky), Glenn Lipscomb (Toledo), Doug Bousfield (Maine), Rakesh Jain (Harvard), and S.J. Lee (Seoul National University, Korea).

Mort's remarkable achievements as a teacher, a researcher, and a responsible member of the profession have been recognized through a multitude of awards and honors, including a Guggenheim Fellowship, the Professional Progress and William H. Walker awards of the AIChE, the Bingham medal of the Society of Rheology, a Fullbright Lecture, and the Chemical Engineering Lectureship Award of the American Society for Engineering Education. In 1986 Mort was elected to the National Academy of Engineering.

Mort has a policy of introducing his seminars with a brief exposition of how his work complements that of his colleagues and how it was intended to contribute to wider departmental goals of teaching and research. This act of unselfish and unusual devotion to his colleagues is not one that he discusses, but it has been brought to our attention by faculty from other institutions who have heard his presentations. This devotion—to his profession, to his students, to his department—is a thread running through all his activities.

Mort continues to serve the profession and the chemical engineering department at Berkeley by his exemplary standards in research and teaching, by generously giving of his time to mentor young faculty, and by looking after the *Journal of Rheology.* Mort is happily married to Vivienne Roumani-Denn, head of the Berkeley Earth Sciences and Map Library. Mort and Vivienne enjoy living in the Bay area and often welcome young faculty and their families to their home for a pleasant evening and panoramic bay views. They have six children between them: Matthew (practicing law in Wilmington), Susannah (works for the District Court in San Francisco), Rebekah (writes for Gannett papers in Westchester County, NY), Aryeh (a financial analyst for Smith-Barney in New York), Dania (a student at UCLA), and Natan (a student at Berkeley High School). The chemical engineering faculty at Berkeley are glad that Mort's thoughful voice will be around in the coming years to help face and overcome the challenges that await us.

ACKNOWLEDGMENTS

We thank colleagues at Berkeley and Delaware for sharing some of their recollections and thoughts regarding Morton M. Denn.

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