Larry Duda: Biography and Scientific Achievements

Larry Duda was born and raised in Donora, PA, a small steel mill town 20 miles down the Monongahela River from Pittsburgh. He was born into a family in which most of the males went to college on football scholarships. Although Larry did not succeed in that path, he obtained an academic scholarship to enter Case Institute of Technology. Starting as a rather mediocre student hampered by a poor high school background and a dyslexia problem that he did not recognize at that time, Larry began to excel as soon as he confronted his first chemical engineering course in stoichiometry. He discovered his forte as a problem solver.

Larry entered the University of Delaware as a graduate student and was particularly stimulated by research and the interactions with such chemical engineering greats as Bob Pigford, Art Metzner, Jack Gerster, Kurt Vohl, etc. Stimulation was also provided by an outstanding group of graduate students who were in Delaware at that time. In addition to learning how to do research under the tutelage of Art Metzner, he honed his tennis game, helped integrate restaurants in Delaware, and met his future wife, Margaret Barbaleck.

In 1963, Larry joined the Process Fundamentals Group of the Dow Chemical Company in Midland, MI, where his long and successful collaboration with Jim Vrentas began. In Midland, Larry and Marge very quickly established a family, and in less than 3 years, had four children (twins John and David, Paul, and Laura). During the Dow days, Larry and Jim's basic work in the area of diffusion of polymers was initiated. They were at Dow during the golden days when great advancements were made in polymer science, led by such individuals as Turner Alfrey and Ray Boyer. Naturally, in that environment, Duda and Vrentas were drawn into considering problems associated with polymer production and processing. In addition to the overall impact of Jim Vrentas, other individuals such as Turner Alfrey and Art Metzner (as a Dow consultant) continued to impact Larry's professional development.

Although Larry's career at Dow had reached new heights in the late 1960s, he decided to move to academia in order to more freely pursue his research interests. In the last years at Dow, Larry made his most successful impact on the company through his work on designing insulation systems for the trans-Alaskan pipeline and the patented system consisting of insulation and a latent-heat-storage component to keep the pipeline from melting the permafrost during the short Alaskan summer.

Larry left Dow for Penn State in 1971, and for the past 30 years, he has devoted most of his energies to the development of the Department of Chemical Engineering at Penn State. He served as the Department Head for 17 years, reconstructing the department by recruiting new faculty, enhancing the department's research activities in emerging areas of biotechnology

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and computer simulations, and vastly improving the research visibility of the department. The 16th rank given to the department in the most recent national survey published by U.S. News and World Report is a direct consequence of Larry's leadership of the department.

Throughout his career, Larry has made significant contributions to the solution of numerous industrial chemistry and chemical engineering problems. The unifying threads through his research are the important role played by transport processes, the involvement of polymeric materials, the attempt to bring order and quantification to complex areas dominated by qualitative studies, the emphasis on translating the results from fundamental studies into implementable engineering solutions, and the strong record of developing collaboration with colleagues.

Larry's work in collaboration with Jim Vrentas represents a unique advancement in our understanding of how small molecules migrate through rubbery and glassy polymers. The results obtained have a significant impact on a number of problems relating to the engineering of materials: the interaction of solvents and thin polymer films during the fabrication of semiconductor devices, the design of controlled-release systems for medical applications, the design of polymer membranes for separations, and the environmental impact of polymer and polymer composites associated with the migration of water and other low-molecular-weight penetrants.

Central to these technological applications is the free-volume theory developed by Vrentas and Duda in which the viscous behavior of polymeric melts is coupled to the diffusional behavior in binary solutions. The theory allows for the prediction of diffusion coefficients as a function of temperature and concentration from viscosity and thermodynamic data obtained for essentially pure-component systems. Duda and Vrentas also extended the statistical mechanical theories of dilute polymer systems to develop methods for predicting diffusion coefficients in the limit of high solvent concentrations. The free-volume theory has been shown to be applicable for temperatures up to at least 80 °C above the glass transition temperature and for concentrations as high as 70 (or more) wt % solvent. The theory is also capable of predicting anomalous abrupt changes in the diffusivity observed in the vicinity of the glass transition temperature. Duda and collaborators have also extended the free-volume theory to consider the diffusion of metal atoms in polymers and gases in glassy polymers.

Another major contribution resulting from Larry's work is directed toward the measurement of diffusion coefficients in polymer−solvent systems at the elevated temperatures that are characteristic of the conditions realized in polymerization reactors and in subsequent processing operations. He has developed a simple and easy-to-use high-temperature sorption apparatus that has been adopted by several industrial groups. This technique has become the workhorse for polymer−solvent diffusion studies; since its inception, it has produced over half of the high-temperature ($T > 100$ °C) diffusion data available in the literature. Another important contribution is the development of an oscillatory sorption experiment specifically designed to study the coupling of diffusional transport and molecular relaxation, which is unique to polymer−solvent systems. This is the only experimental technique available that permits an unambiguous investigation of such phenomena. Most recently, in collaboration with Ron Danner, Duda has employed the inverse gas chromatography technique to measure diffusion coefficients in polymer systems at infinitely dilute solvent concentrations over a broad temperature range. The technique has recently been extended to include finite solvent concentrations and multicomponent systems and to investigate processes involving fibers. The diffusion theories and experimental techniques have been applied to the solution of many practical problems including the production and stability of polymer foams and polymer and carbon fibers, as well as various household polymer commodities.

In recent years, Duda has developed models for many polymer solution processes using his fundamental theories of molecular diffusion as the basis. He has developed detailed physicochemical and transport models to describe the drying of polymer solutions to produce polymer films and coatings and the devolatilization of polymers including the use of additives to enhance impurity removal and extraction with supercritical fluid. Recently, Duda has worked on extending theories developed to describe molecular diffusion in synthetic polymers to treat mass transfer in other macromolecular systems such as food materials and petroleum pitch. He has also examined the influence of ultrasonics on mass transfer in polymer membranes.

Throughout the 1970s and early 1980s, one of Larry's major focuses has been the flow of polymer and surfactant solutions in porous media, in the context of enhanced oil-recovery applications. A porous media viscometer was developed to simulate the conditions that occur during the flooding of oil reservoirs. This experimental apparatus is elegant in its simplicity of design and operation and has been used to demonstrate the influence of adsorption, polymer molecule entrapment, and inaccessible pore volume on the permeability of reservoir sandstone. Further, Duda's work provided the first experimental and theoretical demonstration that the conventional capillary model is inadequate for describing the flow of purely viscous non-Newtonian polymer solutions in porous media because of the excess pressure drop associated with the expansion and contraction regions of such media.

Also during the 1970s and 1980s, Duda recognized how fundamental principles of chemical engineering can be successfully applied to bring order to the traditionally empirical and largely proprietary field of tribology and lubrication. This gave birth to Larry's collaborative research with Elmer Klaus. The most important outcome of this research is the development of a microreactor technique to study the thermal and oxidative degradation of lubricants under conditions that simulate automotive engine tests, heavy-duty diesel engine performance, electrical-power-generating equipment, and gas turbine engines. The test has been adapted by over 15 industrial research groups as a way to minimize costly engine tests and has been successfully used as the primary technique to study the performance of lubricant additives as well as the catalytic effects of metal surfaces on lubricant degradation. Presently, this test is being evaluated as a possible ASTM test for the oxidative stability of greases. Other significant results from the micro-oxidation studies include the development of copper compounds as antioxidants and the identification of the mechanisms by which oxidation inhibitor molecules are preferentially oxidized in a lubricant base stock.

Another important result from this research is the development of a novel lubricant delivery system for applications at elevated temperatures. In this system, a lubricant film is formed on a hot surface from homogeneous vapor phase. The lubricant-forming vapor is adsorbed on the solid surface and reacts to form the lubricant film. This new lubricant system is being evaluated for applicability in diverse areas including the lubrication of an adiabatic ceramic engine and the lubrication of metal-forming operations. Duda's work has also led to the development of methods for the rheological characterization of lubricants, greases, and sealants under extreme conditions of temperature, pressure, and shear rate. His later work has concentrated on reducing the environmental impact of lubricants through such means as reducing emissions from diesel engines utilizing vapor-phase lubrication and also using vegetable oils and other environmentally benign fluids as lubricant base stocks.

The strong industrial importance of Duda's research is reflected in the listing of companies that support his current research. These include Dow Chemical, Dow Corning, BASF, DSM, Bayer, and Exxon Mobil in the area of devolatalization; 3M, Imation, and Avery-Dennison for the studies on films and coatings; and Conoco, Elf Atochem, DuPont, and Dow Chemical in support of the modeling of polymer solution processing. Duda has also maintained an extensive consulting relationship with a number of chemical companies.

Exploiting his background as a researcher with extensive ties to the industry, Duda has been serving as an active voice of and spokesman for academic interests to industry. He has served as a member of the Council for Chemical Research (CCR) for more than 10 years, including on its Governing Board and the Executive Committee of the Governing Board. He has served on the CCR Committee on Industrial College Relations and as CCR Liaison Man with the NSF. He has also been active on the Academic Advisory Council of Dow Chemical. He has served on the Managing Boards of the Center for Process Safety and the Center for Waste Reduction Technologies and in the Council of the American Institute of Chemical Engineers.

At Penn State, Duda has been a teacher of great impact. His success as a teacher is defined not simply by his classroom lectures, but more importantly by his close work with undergraduate and graduate students in their research. He has advised nearly 75 masters' and 50 doctoral students at Penn State. Duda has also been unusually active in guiding undergraduate students in their research projects. Over 80 students have worked with him on their honors research projects, and many of them have eventually gone on to graduate schools, inspired by their research experience. Duda has clearly demonstrated to his students and colleagues how one can carry out fundamental research that leads directly and tangibly to industrially significant results.

Duda's work has been recognized by many national awards. He is the co-recipient of the William H. Walker Award (with Jim Vrentas) and the Warren K. Lewis Award, both from the American Institute of Chemical Engineers. He also received the Charles M. A. Stine Award from the Materials Division of the AIChE. He was given the Chemical Engineering Division Lecturer Award by the American Society of Engineering Education. He has also been elected to the National Academy of Engineering. The most recent of these awards is the recognition from the American Chemical Society in the form of the E. V. Murphree Award in Industrial and Engineering Chemistry. At Penn State, Duda has been recognized by numerous teaching and research awards, including the Premier Research Award given by The Pennsylvania State Engineering Society and the Outstanding Professor Award given by Penn State undergraduate students in chemical engineering.

Despite his numerous awards, Duda remains a simple man, actively pursuing research, maintaining close contacts with his undergraduate and graduate students on a daily basis, rejoicing at the successes that his children have achieved personally and professionally, and always remaining at the side of his wife Marge as she pursues ever changing interests as a fiction writer, world traveler, international photographer, travelogue writer, and jewelry designer, among others. Larry and Marge are also devoted grandparents of four grandchildren who have come to claim a major share of their time. It is a pleasure to have this special issue of Industrial and Engineering Chemistry Research honor the achievements of Larry Duda.

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