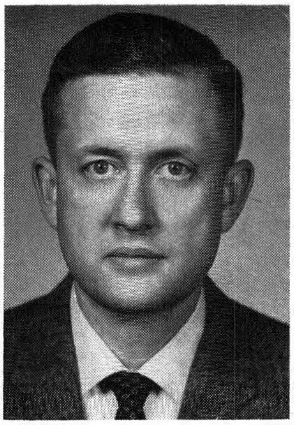
ChE views and opinions

TRANSPORT PHENOMENA: WE HAVE NOT GONE FAR ENOUGH

E. N. LIGHTFOOT
University of Wisconsin
Madison, Wisconsin 53706



Professor Lightfoot was educated at Cornell University, BChE and PhD. In 1953 he joined the Wisconsin department, became active in curriculum revision, and collaborated with Bird and Stewart on the text *Transport Phenomena.* His major research interests are in mass transfer and separation processes and in the appliction of transport phenomena to environmental and biomedical problems.

It is time to take a hard look at what used to be the field of unit operations, and, for most of us at least, it is time to make some fundamental changes. Our present practices overemphasize analysis as opposed to synthesis, and this imbalance seriously distorts both teaching and academic research. The solution to this problem is not to weaken analysis, as some have suggested, but to provide a more powerful and attractive framework for the synthesis aspect of unit operations, which is equipment design. It is also important to eliminate the artificial division between theory and practice, so common in the undergraduate teaching of physical rate processes, but this is a separate problem. Most attempts to combine the introduction of basic principles with examples of practical applications have been based on the elegant but purely descriptive framework of transport phenomena. They have thus aggravated one problem while trying to solve another.

The unit operations are a fundamentally heterogenous collection, and their organization into a single course sequence is an obsolete transition stage in the development of chemical engineering curricula. However the vigorous attempts of the last ten years to replace unit operations by much more systematically organized courses in transport phenomena have not been entirely successful. At Wisconsin, for example, of ten semester credits allotted for physical rate processes only four are devoted to transport phenomena. The remaining six credits are used for rather conservative courses on fluid flow and heat and mass transfer.

The department has consistently rejected suggestions that these ten credits be reorganized to a transport phenomena-based sequence in which introductory of basic theory is immediately followed by discussion of practical applications. I have been disappointed by this attitude in the past, but I now believe that there is a very sound basic objection to this otherwise attractive idea: a well taught course in unit operations was something more than a poorly organized course in transport phenomena. The something extra was an attempt to teach equipment design. The equations of change provide an effective basis for calculating the length of a heat exchanger given the radial dimensions, flow rates, and terminal temperatures. They are not sufficient for determining the configuration or coolant flow rate. They provide no basis for answering such questions as: how would you grind garnets to make sandpaper? They are purely descriptive.

We have overlooked equipment design in part because it was taught unsystematically, but also because of our current emphasis on sophistication and elegance. Synthesis can never be as elegant as analysis, and we can never develop as impressive a framework for equipment design as for transport phenomena. We can, however, improve greatly on our present performance.

We must first recognize that analysis and synthesis are fundamentally dissimilar and should be taught in a course sequence based on the organization of Transport Phenomena (Bird, Stewart, and Lightfoot) or similar texts, and it should proceed directly from fundamental principles to practical examples. The development of such a course sequence is relatively straightforward and should not be further discussed here*. The design aspects must be taught within a much more flexible framework, comparable to that recommended for process design in such references as Strategy of Process Engineering (Rudd and Watson). This framework does not now exist, and a very high priority should be given to its development.

Equipment design must, like process design, be based on a strategy and general principles rather than a set of generally applicable differential eqations. Problem definition is now the precise statement of equipment function. Thus in the sandpaper example above the grinding device must both reduce size and produce sharp-edged particles of compact shape. The remaining stages of the solution will generally require much more detailed physical information than used in conventional treatments of process design, and transport phenomena can be expected to play a key supporting role. The listing of alternative solutions will require an extensive knowledge of physical chemistry. Precedence ordering will now often require ordering of experiments or a mixture of experiments and computations, and it must be recognized that a systematic approach is useful even for very messy problems not amenable to extensive computation.

Development of an undergraduate course in equipment design is now being seriously considered at Wisconsin, and, I would expect, elsewhere. Detailed discussion of such a development is out of place here, but it does seem proper to point out that this type of a course will affect the rest of the curriculum. In addition to a sound background in transport phenomena we must be sure that the student has an adequate practical grasp of applied physical chemistry. I am not sure that this latter requirement is always met. It is also desirable to provide a more extensive historical background in both science and engineering than is now customary, to give perspective and also the faith necessary to successful innovation.

---

*This must, however, be done with care. The analogies and contrasts between the three transport processes must be emphasized and a proper balance maintained between theory and application. Simplicity must not be achieved at the price of misrepresentation.

LETTERS

Scenario for the 1970's — January 1, 1980

Sir: This is a report on the decade of the 1970's. Ten years ago, I note that I worried that the population explosion would come to a climax in the 1970's and that its manifestations would be a combination of mass starvation, catastrophic war, uncontrolled pollution, widespread epidemics and exhaustion of essential raw materials. Except for catastrophic war, these things have all happened but not in quite the way I had expected them.

Mass starvation we have certainly had. Back in 1970, we were used to hearing about starvation in India, Pakistan, China and Biafra. During the decade it continued in these countries on an ever increasing scale and to these were added Egypt, the rest of southeast Asia, Brazil, Mexico, Colombia, Venezuela, Peru, the central American countries and all of black Africa. For awhile in the early 1970's, new strains of rice and wheat held out a hope of reducing starvation, but population increases kept pace with the gains in food production. And by 1975 the annual increases in food production, which seemed so promising in the early 1970's, had slowed greatly so that food production remained static after 1975 in most countries, and even declined in some countries, for a variety of reasons.

It is estimated that during the decade, 200 million people starved to death. An accurate count was impossible. There were widespread epidemics in the poor countries, but they were so intermingled with starvation that it was impossible to obtain reliable data on deaths from starvation and from disease. Contrary to many predictions, the "have-not" countries did not blame the "haves" for the epidemics. Starving people apparently do not mind seeing their neighbors die of disease; it reduces the competition for food. Western medical teams won popular support for their unstinting efforts during the epidemics.

Air pollution in the U.S. got no worse in the bad places of 1970—Los Angeles, New York and Chicago—but it spread to many other metropolitan areas. Emission controls on gasoline engines and the widespread use of steam and electric cars has actually made Los Angeles a better place than in 1970. Low sulfur fuels and the development of public transportation improved the situation in New York, Chicago and San Francisco over what it was in 1970. Water pollution on the other hand is considerably worse than in 1970. Lake Erie is a lifeless sump. Lakes Michigan and Ontario are about as bad as Erie was in 1970. The open ocean itself is in poor condition being polluted world-wide and not just from the U.S.A. The Atlantic beaches from Boston to Virginia Beach are unsafe for bathing. A new major cause of death in the U.S. is poisoning from an accumulation of pesticide residues. This affects principally middle aged and older people. Marijuana is now legal and rivals tobacco in sales.

The fears concerning exhaustion of essential raw materials were largely unfounded. We now get 40% of our oil from offshore wells compared to 15% in 1970. In the past decade, we opened up vast deposits of low grade copper and iron. We collect and recycle almost all of the

(Continued on page 116)