A GRADUATE COURSE IN POLYMER PROCESSING

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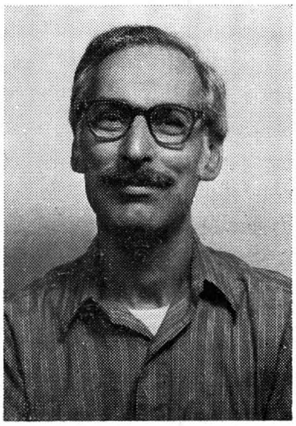
WHILE THE polymer-related industries hold a most significant position among chemical industries today, and while a large fraction of both B.S. and advanced degree holders in Chemical Engineering today find employment in some area of polymer production or fabrication, a relatively small number of ChE departments provide an opportunity for substantial course and research work in this field. Through its association with the Polymer Science and Engineering (PSE) Department of the University of Massachusetts, graduate students in ChE at U. Mass can elect from a large selection of polymer-related courses which make up the Ph.D. curriculum of the PSE Department. Many of these courses cover engineering aspects of the polymer field, and are taught by members of the ChE faculty who hold joint appointments with PSE. This article focuses on one such course: Polymer Processing.

TABLE 1
Major Course Offerings of the Polymer Science and Engineering Department

501	Introduction to Polymer Science
502	Polymer Science Lab
503	Polymer Synthesis Lab
589	Chemistry of Macromolecules
670	Applied Polymer Science
720	Viscoelasticity
721	Polymer Microscopy and Morphology Lab
731	Polymer Properties
733	Polymer Reactions Induced by Stress
734	Degradation and Stability of Polymers
735	Interaction of Radiation with Matter
736	Applied Spectroscopy of Polymers
737	Polymer Reactor Engineering
740	Magnetic Resonance of Polymers
742	Biopolymers
790	Organic Polymerization Reactions
792	Polymer Rheology
793	Polymer Processing
798	Physical Chemistry of High Polymers
799	Physical Chemistry of High Polymers II



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To put the course in the perspective of a broader program, Table 1 shows the total course offerings of the PSE Department. The Polymer Processing course is required of all PSE students, who normally take it in their second year of graduate study. ChE gradute students may elect the course at any time. Indeed, the nature of the course is such that senior ChE majors can and do take Polymer Processing as a technical elective. A typical class "mix" is 20-25 PSE graduate students, 6-10 ChE graduate students, and several

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seniors in the ChE department. In addition, we often have a few (2-4) industrial employed engineers who take the course.

Table 2 shows the major chapter headings of the text used in this course, a book which I wrote myself in response to needs I felt as a teacher for an appropriate text in this area. The book reflects a certain philosophy of education in this field which I have developed from my experiences in teaching, directing research, and consulting in the field of polymer fluid dynamics.

In many ways I regard this course to be one in applied fluid dynamics, with an emphasis on flow processes dominated by viscous effects. As such, it provides a useful follow-up to the usual undergraduate course in fluid dynamics, which offers a broad coverage of fluid flow analysis with, usually, minimal depth of study of problems involving highly viscous and non-newtonian fluids. In addition, the chapter on Heat and Mass Transfer (itself one hundred pages in length) provides an opportunity for reinforcement of the elements of convective transport phenomena usually touched on briefly in an undergraduate course.

Another goal of this course is the development of the student's skill in formulating engineering models of a process. Much of undergraduate education is occupied with learning to solve problems which have correct solutions. Thus it is clear that the derivative of sin x is cos x, and there is no room for debate about this. In this Polymer Processing course I try to emphasize the concept of modeling physical phenomena. The student must learn that while there can be clearly incorrect models, most engineering processes allow for many levels of modeling which, while not incorrect, do differ in sophistication, ease of application, and detail of correspondence to reality. The task in this course is to provide sufficient experience, through discussion and problem solving, that the student develops some facility and confidence in formulating a model that is appropriate to the goal at hand. It is very difficult to convince students that in some cases the best model to use is one that is so simple and sloppy that it appears, at first thought, that one might be ridiculed for even entertaining its use.

TABLE 2

Contents of "Fundamentals of Polymer Processing," by Stanley Middleman (Published by McGraw-Hill, 1977)

1. **Polymer Processing**
2. **Modeling Philosophy**
3. **Continuum Mechanics**
4. **Dimensional Analysis in Design and Interpretation of Experiments**
5. **Simple Model Flows**
6. **Extrusion**
7. **Calendering**
8. **Coating**
9. **Fiber Spinning**
10. **Tubular Film Blowing**
11. **Injection Molding**
12. **Mixing**
13. **Heat and Mass Transfer**
14. **Elastic Phenomena**
15. **Stability of Flows**

Another feature of this course arises from the unusual "mix" of student backgrounds that I must deal with. The bulk of the students are in the PSE program, and two-thirds of them are graduates of Chemistry programs. Thus, these students have seen no fluid dynamics, no transport phenomena, in many cases no mechanics at all. They have had a science education, they believe in science, and for them the concept of crude, approximate, models is often an alien, disturbing, and offensive concept. Thus, the course begins with discussion of the philosophy of modeling and then turns to development of the principles of mechanics as applied to the dynamics of viscous flow. A brief discussion of rheology is included here, since some of the students will not have done the full semester course we offer in that area.

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Following this introduction of fundamental concepts and tools, we turn to examining models for a wide range of idealized flow situations and then spend the bulk of the semester on applying these models to a variety of polymer flow processes. Paramount to developing a facility with modeling is examining the correspondence of a model to reality. Thus, the models are compared to industrial or laboratory data to the maximum extent possible. Below is a typical example from Chapter 13 of the text, in which several models are examined in the light of existing experimental data. The assumptions inherent in the models are reviewed, and then models which relax these assumptions are developed.

Example: Comparison of measured and predicted Nusselt numbers—Griskey and Wiehe present data for heat transfer to molten polyethylene pumped through a 3/8-in heated pipe. They present the data in terms of an "arithmetic average Nusselt number," shown plotted in Figure 1. Compare the data with theory.

We begin by constructing the theoretical curve in terms of the average Nusselt number Nu_a. For very small values of $U\pi R^2/\alpha_T L = wC_p/kL$ the Leveqque solution holds, and since the extent of heat transfer is not great, we expect that $\mathrm{Nu}_a = \overline{\mathrm{Nu}}$. If the Leveque equation is used for the local Nusselt number, and if integration is carried out to obtain the average, the result is found to be

$$\mathrm{Nu}_a = \overline{\mathrm{Nu}} = 1.61 \left(\frac{3n+1}{4n}\right)^{1/3} \left(\frac{4UR^2}{\alpha_T L}\right)^{1/3}$$

$$= 1.75 \left(\frac{3n+1}{4n}\right)^{1/3} \left(\frac{wC_p}{kL}\right)^{1/3} \tag{1}$$

It is much more tedious to carry out the same procedure using the Graetz infinite series solution, and instead we examine the limiting behavior at the extreme where the fluid is almost completely heated to the wall temperature. Under those conditions we find

$$q = -wC_p(<T> - T_o) = -wC_p(T_w - T_o)$$

and, it follows that

$$\mathrm{Nn}_a = \frac{2}{\pi}\frac{wC_p}{kL} \tag{2}$$

Figure 1 shows this asymptotic relation, as well as the Leveque limit [Eq. 1] for $n = 0.7$ (the value noted by Griskey and Wiehe). It is not very difficult to interpolate a smooth curve between the two asymptotic limits.

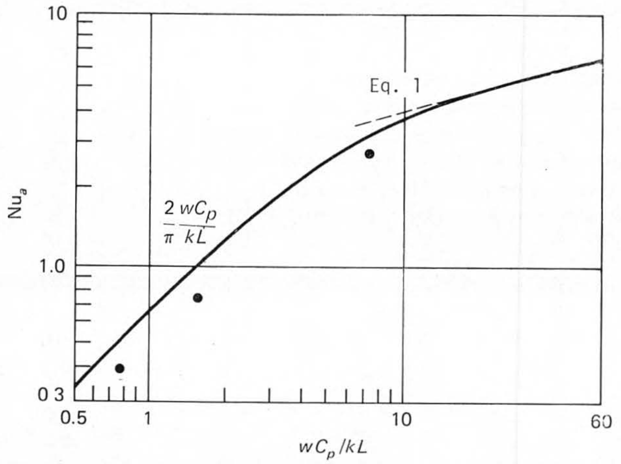

FIGURE 1. Data of Griskey and Weihe compared to theory (Eq. 1, using n = 0.7).*

The data of this example are seen to be in reasonably good agreement with the theory. Other sets of experimental data, obtained with polymer solutions, also bear out the general validity of the models presented above. We must recall, however, that the models are subject to certain assumptions which are not always met. In particular we have assumed:

1. The viscosity is independent of temperature.
2. The pipe wall is isothermal.
3. No viscous heat generation occurs.*

A second goal, and an important one, is development of a coherent set of principles of transport phenomena (fluid dynamics, heat and mass transfer) as applied to the design and analysis of highly viscous, often non-newtonian, systems.

The example continues with an examination of several additional models.

At present there is no laboratory experience associated with this course. However, we are presently building a Polymer Process Fundamentals Laboratory, and expect to integrate this facility into the graduate teaching program.

In summary, then, while this course is nominally one in the area of polymer transport phenomena, it serves several more general roles as well. Of greatest importance, I think, is the development of the capacity to examine a process, think about it in simple physical terms, and then produce a mathematical model of the process that represents the best compromise between simplicity of solution and application, on the one hand, and correspondence to reality, on the other. A second goal, and an important one, is development of a coherent set of principles of transport phenomena (fluid dynamics, heat and mass transfer) as applied to the design and analysis of highly viscous, often non-newtonian, systems. Finally, of course, the major polymer processes are discussed and illustrated, thereby providing an introduction to an area of engineering practice that is already of major importance, and that continues to grow. ☐

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*Reproduced by permission from Middleman, S., "Fundamentals of Polymer Processing", McGraw-Hill—1977.