where h_{room} is the heat transfer coefficient for the inside (or roomside) boundary layer, and h_{out} is the heat transfer coefficient for the outside boundary layer.

Rearrangement and addition as before gives

$$(\theta_{room} - \theta_{out}) = \frac{q}{A}\left(\frac{1}{h_{room}} + \frac{t_g}{k_g} + \frac{1}{h_{out}}\right)$$

or

$$q = \frac{(\theta_{room} - \theta_{out})A}{\left(\frac{1}{h_{room}} + \frac{t_g}{k_g} + \frac{1}{h_{out}}\right)} \tag{9}$$

The outside heat transfer coefficient will be dependent on wind speed and window position, which need to be determined, but the exact mode of heat transport (*e.g.*, the balance between convection and conduction) is unimportant and of scientific, not engineering, interest. The rate of flow of heat per unit area per unit temperature difference is

$$\frac{q}{A(\theta_{room} - \theta_{out})}$$

This is, of course, the overall heat transfer coefficient, U, and from the above equation its relationship to the individual coefficients is seen to be of a reciprocal nature

$$\frac{1}{U} = \frac{1}{h_{room}} + \frac{t_g}{k_g} + \frac{1}{h_{out}} \tag{10}$$

It may be pointed out that this is analogous to the summing of electrical resistances; the term on the left-hand side is the overall resistance to heat transfer and those on the right are the individual resistances.

DISCUSSION

It may be noted that the assumption of a stagnant layer of air between the panes of the double glazed units was also an oversimplification. The circulation currents within the enclosed space reduce the insulating effect. In order to reduce this loss of insulating power, certain manufacturers fill the space with inert gases which are several times denser than air. Frame construction also influences heat loss, and the final overall heat transfer coefficients range from 2.0 to 3.5 $Wm^{-2}K^{-1}$ for double glazed units. This compares favorably with the 7 $Wm^{-2}K^{-1}$ of typical single glazed windows, but the difference is not as dramatic as students and others first suppose.

The pedagogic value of the example is not limited to the introduction of the overall heat transfer equation. There is the opportunity to develop (a) students' understanding of natural convection by considering in greater detail the physical process occurring in the enclosed cavity between the panes, and (b) their appreciation of forced convection by considering the effect of wind speed upon the outside film heat transfer coefficient.

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NOMENCLATURE

A	area
h	film heat transfer coefficient
k	thermal conductivity
q	heat flux
t	thickness
U	overall heat transfer coefficient
x	distance
θ	temperature

Subscripts

1,2	refers to slabs as shown in Figure 2
cold,hot,i	refers to cold-side, hot-side, and interfacial positions as shown in Figure 2
g	glass
gi	glass-room interface
go	glass-outside interface
out	outside
room	room-side ❐

ChE book reviews

INTRODUCTION TO PHYSICAL POLYMER SCIENCE

by L.H. Sperling

John Wiley & Sons, One Wiley Dr., Somerset, NJ 08873; $39.50 (1986)

Reviewed by
F. Rodriguez
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This textbook is written at the level of the senior or beginning graduate student who has had no previous courses in polymers. It is presumed that a course in organic polymer chemistry will follow.

Recognition of the importance of polymers for chemists and chemical engineers has yet to be acknowledged in many departments. However, the

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different simplification of Eq. (7):

$$\ell n\left(\frac{1}{F}\right)=\ell n\left(1+\frac{N_o}{P_o}\right)+\left(\mu^{+}p\right)t \tag{9}$$

where the slope yields p. N_P can then be calculated using the following results from Seo and Bailey [6]

$$p=1-\frac{\ell n(2-\delta)}{\ell n(2)} \quad \text{and} \quad \delta=2^{1-N_P} \tag{10}$$

The experimental measurement for N_P is quite labor intensive.

SUMMARY

This lab can provide an introduction to microbiological techniques, mathematical modeling, and statistical methods while studying a problem of current importance in biotechnology. As previously mentioned, two handouts are available from the authors: one describes the mathematical and experimental procedures in detail, and the other is the pre-lab handout for the students. Over the past three years, this laboratory has evolved into the present form and continues to be enhanced from the student input which is requested in their written reports.

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REVIEW: Physical Polymer Science

Continued from page 135.

American Chemical Society has taken action. The ACS Committee on Professional Training has issued guidelines for "approved degree programs" [*Chem. & Eng. News*, p 49, May 1, 1989]. In addition to a core curriculum of elementary, organic, and physical chemistry, the approved program in chemistry/polymers calls for two semesters of polymer science (physical and organic), laboratory work, and an advanced course.

Sperling has written a textbook which fits the ACS criterion admirably. In general, the topics covered are those suggested for a course in Physical Chemistry of Polymers in a syllabus issued by the Joint Polymer Education Committee of the ACS (*Polymer Education Newsletter*, Spring, 1989). Since the book presupposes no previous knowledge of polymers beyond the usual undergraduate organic and physical chemistry courses, the first chapter is a brief introduction on polymerization which mainly serves to supply a vocabulary of basic polymer terminology.

In the first third of the book, a chapter on chain structure and configuration includes discussion of some methods of characterization. This is followed by chapters describing concepts of molecular weight as well as solution and phase behavior.

The remainder of the book emphasizes properties of bulk polymers. This includes chapters on crystallinity, classes, and rubber elasticity. Viscoelasticity and mechanical behavior (failure tests) complete the coverage.

The ACS Syllabus for a course in Physical Chemistry of Polymers is rather broad and includes some topics not covered in Sperling's book. Many chemical engineers would probably have been exposed to rheology in other courses so the omission of non-Newtonian flow (at the level of the power-law and the Ellis model, for example) can be overlooked. The ACS syllabus also suggests topics in polymer processing (molding, extrusion, *etc.*) which are beyond the scope of the present book.

In this day when most polymer books tend to be collections of papers presented at meetings, a textbook with a single author is something of a novelty. The unified viewpoint and consistency of treatment in this book should make it very convenient to use as a text. Each chapter concludes with a "Homework" section containing both numerical and essay-type questions which are useful for self-study or as class assignments. In addition to the many specific references in each chapter, there are suggestions for general reading, most of which are authored (rather than edited) books. The language of the text is quite easily understood and the general organization is neat and consistent.

In addition to the chemistry/polymers topic, approved curricula in specialty areas of chemistry/biochemistry and chemistry/education also have been adopted by ACS. It is noteworthy that in commenting on the usefulness of these new options, M.J. Caserio of the ACS Professional Training Committee is quoted as saying, "...90% of the graduates in chemistry who enter the job market will find themselves working in some area dealing with macromolecules." Those of us who labor in the polymer vineyards of chemical engineering have been saying the same thing about our graduates for many years. This book is a welcome addition to the expository literature for teachers and students in the field of macromolecules. ❐