where λ = latent heat of fusion of ice and $T_i = T_d$.

$$Q^{(m)} = w^{(m)} \lambda = -Q = h\,A\,(T_i - T_w)$$

$$w^{(m)} = \frac{h\,A}{\lambda}(T_i - T_w) = \frac{dm}{dt}$$

To solve this equation we need an expression for the area, $A = f(m)$, and a numerical value for ice is $\lambda_{ice} = 3.34 \times 10^5\ J{\cdot}kg^{-1}$

$$A_{sphere} = \pi D_o^2;\ V_{sphere} = \frac{\pi D_o^3}{6}$$

$$\text{Mass of sphere} = \rho V_{sphere} = \rho \frac{\pi D_o^3}{6} = m$$

The density of ice, $\rho_{ice} = 900\ kg{\cdot}m^{-3}$

$$m = \frac{\pi D_o^3 \rho}{6}, \qquad D_o = \left(\frac{6\,m}{\pi\rho}\right)^{1/3}$$

$$= \left(\frac{6 \times 10^{11}}{\pi \times 900}\right)^{1/3} = 596\ m$$

(This is a big iceberg and a deep port will be needed.)

$$A = \pi D_o^2 = \pi\left(\frac{6\,m}{\pi\rho}\right)^{2/3} = \pi^{1/3}\left(\frac{6\,m}{\rho}\right)^{2/3}$$

$$\frac{dm}{dt} = \frac{\pi^{1/3}\left(\frac{6\,m}{\rho}\right)^{2/3} h\,(T_i - T_w)}{\lambda} = m^{2/3}\beta$$

$$\frac{dm}{m^{2/3}} = \beta\,dt$$

All the terms on the right side are independent of time and the equation can be integrated. The initial condition of $m = m_o$ at $t = 0$ is obvious from the problem statement.

$$\int_{m_o}^{m} m^{-2/3}\,dm = \beta\int_{o}^{t} dt = \beta t$$

$$3\left.\frac{m^{1/3}}{}\right|_{m_o}^{m} = 3(m_o^{1/3} - m^{1/3}) = -\beta t$$

We see that $m_o > m$ and $T_w > T_i$ so both sides of this equation are positive. Rearranging

$$\frac{m_o^{1/3}}{m_o^{1/3}} - \frac{m^{1/3}}{m_o^{1/3}} = 1 - \left(\frac{m}{m_o}\right)^{1/3} = \frac{-\beta t}{3\,m_o^{1/3}}$$

$$\frac{m}{m_o} = \left[1 + \frac{\beta t}{3\,m_o^{1/3}}\right]^3$$

It is logical that as h, $(T_w - T_i)$, and t go up, the fraction remaining, m/m_o, goes down. Also as there is more ice initially, the ice is more dense, or it requires more heat to melt a unit mass; the fraction remaining will increase. Putting in actual numbers

$$t = 7\ \text{months} \times \frac{30\ \text{day}}{\text{month}} \times \frac{24\ \text{hr}}{\text{day}} \times \frac{3600\ \text{sec}}{\text{hr}}$$

$$= 1.81 \times 10^7\ s$$

$$\frac{m}{m_o} = \left[1 - \frac{\pi^{1/3}\,6^{2/3}\,70\,(15-0) \times 1.81 \times 10^7}{3 \times 900^{2/3} \times 3.34 \times 10^5\,(10^{11})^{1/3}}\right]^3$$

$\frac{m}{m_o} = [1 - 0.21]^3 = 0.49$, less than half remains but some ice does make it.

This calculation assumed that the area for heat transfer is equal to the total area of the sphere. Of course only 0.9 of the iceberg is under water; however the part above the surface is exposed to the air and to solar radiation which may approximately compensate.

The model is macroscopic. No boundary conditions are needed. And the model ends up as lumped parameter, unsteady, ordinary differential equation, and is deterministic. □

ChE book reviews

INDUSTRIAL CRYSTALLIZATION

Edited by J. W. Mullin,
Plenum Press, New York, 1976.
Reviewed by R. W. Rousseau,
North Carolina State University

This book is a collection of 44 papers on crystallization presented at the 6th Symposium on Industrial Crystallization held in September 1975. The papers encompass secondary nucleation, crystal growth kinetics, crystal habit modification, crystallizer design, and case studies of industrial crystallizer operations. A review paper leads off all but the last section; research results are presented in each section. The quality of the papers is not uniform but most are excellent.

Professor G. D. Botsaris begins the section on secondary nucleation with an excellent review; its only weak point is that much has happened in the field since the paper was written. Professor Botsaris discusses various nucleation models and areas where further research is needed. Particularly noteworthy in the remainder of the papers on secondary nucleation are those by Bujac and by Estrin and Youngquist. Bujac's paper presents an interesting experimental concept concerning the relationship between attrition and secondary nucleation. Estrin and Youngquist postulate in their paper that secondary nucleation and crystal growth are mechanistically coupled, a concept which is gaining in acceptance.

The review paper on crystal growth kinetics is by Professor P. Bennema, who systematically discusses the major theories of surface incorporation-controlled growth. The research areas emphasized

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BOOK REVIEW: Crystallization

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in this section include computer simulation of crystal growth, growth kinetics in various systems, and a particularly important paper by Janse and DeJong on growth dispersion. The key concept of growth dispersion is that crystals in a magma do not grow uniformily, and in developing a population balance this factor may be important in describing what is going on within the system. Janse and DeJong do a particularly good job in describing the phenomenon and its influence on crystal size distribution.

Professor R. Boistelle is the author of the review on crystal habit modification. Habit modification almost always requires a trial-and-error experimental program and, accordingly, there are few general models or concepts applicable to broad categories of solvent-solute combinations. A review of this subject is, therefore, seldom satisfactory. Professor Boistelle has nevertheless written a short, well organized and thoughtful review of the field. The research results presented in this section are excellent but most likely one must be interested in the specific system investigated in order to make use of the results.

The section on crystallizer design is outstandingly good, particularly the review presented by Professor J. W. Mullin. Professor Mullin gives a good state-of-the-art presentation of design requirements, basic crystallizer types and laboratory or pilot plant experiments required to obtain design data. He also presents a good list of research topics which should challenge crystallization researchers. Toussaint and Fortuin present an excellent discussion on the variables that play a key role in the design of draft tube and baffle crystallizers. Toyokura presents graphical design techniques and Asselbergs and DeJong discuss the relationships among mass, energy and population balances, heat transfer and other variables which affect crystallizer design. There are also papers on batch crystallizer design and crystal size distribution analysis.

No comprehensive review is attempted for the section on crystallizer operation and case studies. This section, however, should be very valuable for researchers who do not have direct access to in-plant experience with crystallizers and for those teaching crystallization operations. Among the manuscripts on operation characteristics are papers dealing with design models for transient behavior, stability, classification, fractional crystallization and direct contact cooling. Case studies on NaCl and KCl plants are presented.

In summary this book covers a broad field but gives in-depth coverage to selected topics. As with all compilations of research papers, the lack of a uniform set of nomenclature could cause the reader difficulty. It is not intended to be a teaching text; Professor Mullin's book *Crystallization* or the book by Randolph and Larson, *Theory of Particulate Processes,* are more useful for this purpose. Researchers and practitioners should find the book to be a useful compilation of relevant papers, reviews and experiences. □

ChE book reviews

THE NATURE AND PROPERTIES OF ENGINEERING MATERIALS

by Z. D. Jastrzebski. 2nd ed., Wiley, NY (1976).
Reviewed by James L. White
University of Tennessee

Most undergraduate chemical, mechanical, etc. engineering curricula contain courses in materials science. These are generally developments from early metallurgy courses in which the fundamentals of crystal structure, polymorphism, phase transformations and crystal deformation behavior has been introduced together with material on polymers and ceramics. At first the inclusion was token but has been increased through the years. This is, of course, reasonable in an age when the volume of polymers produced exceeds that of metals.

This book is typical of books of this type which aim towards a junior or sophomore level curriculum. A very wide range of topics are covered. It does have some excellent features not treated in much depth in most books of this type. The discussion of particulate matter and disperse systems is noteworthy. As with most books in this area, the treatment of material related to metals especially steel is much better done than that related to polymers and ceramics. Some of the contents of this and related books seem illogical. There is no discussion of refining metals from ores, but yet there is a full chapter on polymerization and a second on the chemistry of crosslinking. Certainly this is out of proportion. A major reason why books on materials science do not handle

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