STRESSING INDUSTRIAL IMPLICATIONS IN A POLYMER ENGINEERING COURSE

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A POLYMER ENGINEERING course generally covers three main areas: the nature and chemical manufacture of polymeric resins, their properties and their processing into finished parts. To achieve good academic standards, the basic objectives of such a course must be the satisfactory coverage of fundamental and quantitative aspects of polymer engineering. It is felt, however, that students should also develop a good practical feel for common polymeric materials and processes, should learn about the industrial aspects of the field and should be given the opportunity to apply the acquired knowledge in a creative manner. The need for these important additional objectives has long been stressed by practicing engineers.

To achieve these additional objectives, a polymer engineering course with original features has been developed. The discussion of these features can only be done in the context of the conventional aspects of the course and it is felt that these aspects of a university-taught polymer engineering course have not been sufficiently described in the literature. The conventional aspects of the present course will therefore be described and illustrated with specific examples and it is expected that this will invite constructive criticism from practicing engineers and open useful discussions.

The additional objectives were pursued by introducing several special activities. To permit useful references in the subsequent detailed coverage of the course material, a qualitative introductory survey of all three areas of polymer engineering was presented first. Demonstrations and discussions of samples of polymeric resins and parts were used extensively throughout the course.

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The use of technical journals and of our own extensive collection of commercial literature was promoted through special assignments. Team projects involving the study of the manufacture of certain polymeric parts and the selection of suitable commercial resins and processing equipment led to very effective technical visits of corresponding industrial plants and discussions with their engineers.

While the concept of the activities introduced to fulfill the additional objectives may well have been used elsewhere, it is felt that since their successful implementation rests on a careful organization it is desirable to discuss organizational details and specific examples. Once again it is expected that this will arouse the interest of practicing engineers and that their comments will lead to further improvement of the efficiency of these activities.

MODIFICATION FOR GRADUATE LEVEL

THE COURSE DESCRIBED here is primarily intended as an undergraduate course for students in the last two years of the undergraduate curriculum. In view of the wide range of topics involved it is felt that the course could not easily be upgraded as a full-fledge graduate course. A modified version, however, could serve as an introductory graduate course followed, in a comprehensive polymer engineering graduate program, by the following sequence of courses:

- **Advanced chemical engineering of polymers concentrating on physical chemistry and reactor design which would be particularly suited to ChE or chemistry students.**
- **Advanced physical processing of polymers with emphasis on phase transitions and heat, mass and momentum transfer in the fluid state which would be particularly suited to chemical and mechanical engineering students.**
- **Advanced engineering properties of polymers with emphasis on the physical structure and mechanical and transport properties in the solid state which would be particularly suited to chemical and mechanical engineering students.**

For some students the course will be their one and only formal training in polymer engineering as full-time students. Some of these will never become directly involved with polymers, while others will work in this field in industry and will further their knowledge through day-to-day experience and, possibly, continuing education. Other students will enter graduate schools where they will receive further extensive academic and research training. It is felt that all of them have a common need which is the acquisition of a sufficient basic background to benefit from the reading of specialized technical and scientific literature in the field of polymer engineering.

It could be feared that the introduction of additional objectives, however useful they may be, must lead to an undesirable reduction in the coverage of the basic objectives. Every effort was made to avoid this and it is felt that success rested on two factors which will be emphasized in the paper:

- **High motivation in the special activities which increased the work input.**
- **Thorough organization of both basic and additional objectives which enhanced the efficiency.**

The selection of the course basic program and the depth of coverage are influenced by a number of factors including the following:

- **Feedback information, recommendations or requests from industry, the main user of graduates, in the form of personal communications, published surveys, etc. [1] to [5].**
- **The instructor's experience or knowledge of other similar courses or textbooks, his own ideas, interests and intuition [6].**
- **The student's background.**
- **The student's interest.**

A questionnaire was used at the very beginning of the course to obtain information on the last two points. Fifty-five percent of the students answered that they had no background in polymers, about four percent had acquired some background through courses, fifteen percent through industrial employment and twenty-six percent through personal interest. Fifteen percent of the students indicated a primary interest in the properties and use of polymeric materials, thirty-seven percent in the production of polymeric resins and forty-eight percent in their transformation into finished products.

The total duration of the course was about fourteen weeks (one semester) with three one-hour class meetings per week.

Some details of the course basic program (parts I, II and III) are given in table I. It would be too long to describe its content in detail but a good measure of the depth of coverage will be provided by the examination of a few representative problems assigned to the students.

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No comprehensive typed course notes were handed in by the instructor; students wrote their own notes on the material covered in class and a limited amount of typed notes was handed in in special cases only. It was felt that in view of the number of assignments, students should not be held responsible for fundamental material not covered in class.

TABLE I

POLYMER ENGINEERING

Course Outline

COMPREHENSIVE INTRODUCTION
(about two weeks or 13 %)
- General Structure of Polymers
- Classes of Polymeric Materials
- Effect of Temperature on Physical State
- Applications and Testing
- Processing Techniques

PART I: STRUCTURE, CHEMICAL PROCESSING
(about four weeks or 29%)
- Chemical Structure, Physical Chemistry
- Polymerization and Copolymerization Principles
- Polymerization Techniques (Bulk, Solution, Suspension, Emulsion)

PART II: PHYSICAL PROPERTIES
(about four weeks or 29%)
- Physical States: Amorphous, Semi-crystalline
- Special Cases: Copolymers, Plasticizers, Fillers . . .
- Mechanics (Static)
- Temperature Effects
- Time Effects (Viscoelasticity)
- Time—Temperature Superposition
- Melt Rheology

PART III: PHYSICAL PROCESSING
(about four weeks or 29%)
- Basic (Extrusion, Injection Molding, Film Blowing, Fiber Spinning)
- Others (ex: Blow Molding, Thermoforming . . .)
- Special Techniques

A supporting textbook [7] was selected which represents a good compromise for quality and cost. Its purpose was to offer equivalent or supplementary information on much of the fundamental material (theoretical treatments, examples, references, etc.). Its contents (Table II) do not match the course outline (Table I), however, particularly in the area of processing.

Other more expensive textboks cover large parts of the course program [8] to [11]. Three classical advanced texts [12], [13] and [14] specifically relate to parts I, II and III respectively.

PROBLEM SETS ASSIGNED

A TOTAL OF about thirty *problems* distributed among seven weekly problem sets was assigned, allowing a variety of aspects to be dealt with. Six examples, representative of several aspects are given in appendix II.

- Problems A, B, C and D, relative to part I of the course, form a sequence dealing with basic aspects of the polymerization of polymethylmethacrylate which must be understood before proceeding to engineering applications. Emphasis is placed on the generation of relationships rather than isolated results in order to enhance discussion. Scaled graph paper was supplied in order to guide students and save them time (see Figure 1).
- Problem E, relative to part II of the course illustrates in a concrete manner the application of fundamental concepts and data of visco-elasticity and time-temperature superposition to the solution of an engineering problem of vibrations and heat build-up.
- Problem F is relative to part III of the course. While most problems on this part led to numerical results, problem F involves the analytical application of fundamental concepts to a problem similar to but simpler than the screw extrusion case discussed in class.

Students had to submit even incomplete solu-

TABLE II

FUNDAMENTAL PRINCIPLES OF POLYMERIC MATERIALS FOR PRACTICING ENGINEERS

by S. L. ROSEN

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tions according to the established schedule but, after the discussion of the problems in class, they could upgrade their marks by resubmitting improved solutions. The exercise proved valuable as a preparation for the tests.

ASSESSMENT THROUGH TESTS

PERFORMANCE TESTING is an inevitable part of the course. Properly devised testing is in fact very useful to the students in providing an incentive for thorough study and understanding of the material and a check for progress and achievement of stated objectives. It is also useful to the instructor in assessing the efficiency of his teaching in general and of specific methods or techniques in particular. The relative weights were distributed in the following way: homework assignments and problem sets, fifteen percent; tests, sixty percent and design project, twenty-five percent.

Each of the three *tests* on parts I, II and III of the course outline consisted of two separate exercises.

Short answers had to be provided in a restricted space in thirty to forty-five minutes for five to ten *closed book (and notes) questions*. Questions B, C and D given in appendix I are representative examples of these largely basic and qualitative questions.

- **Question B implies a sufficient knowledge of the four polymerization techniques to undertake a comparison.**
- **Question C, in addition to an understanding of the consequences of copolymerization, stresses the use of graphical representation which is so common in scientific and technical papers.**
- **Question D intends to verify that basic definitions are sufficiently well known and understood to be applied to a simple practical situation.**

Students could not use textbooks but had access to their personal course notes and their solutions to the assignments and problem sets for the second exercise. It consisted of two or three *"open notes" problems* similar in scope and difficulty to those in problem sets. The time available, however, was restricted to between sixty and ninety minutes and the effort was necessarily strictly personal.

COMPREHENSIVE INTRODUCTION

MANY BASIC ASPECTS of the rather special nature, behavior and processing of polymeric materials are generally largely unknown to students entering a polymer engineering course despite the fact that they have been in contact with such materials in everyday life for years. Polymer engineering courses usually start with a very brief introduction and move on to fundamental engineering material.

It was felt that it is not convenient to go through the sequence of fundamental engineering topics without a good qualitative preview of the whole field. It is difficult, for instance, to discuss

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the advantages and disadvantages of polymerizing a material as a thin powder or in bulk without reference to the use of powders or pellets in various processing techniques. It is equally difficult to justify the study of the visco-elasticity of polymer melts without reference to film blowing, blow molding or thermoforming processes. In the discussion of fundamental questions, it is also very desirable to be able to refer to specific objects whose constitutive materials and manufacturing processes have been introduced earlier.

The *comprehensive introduction* (see Table I) was a thorough preview of most of the course material with emphasis on qualitative and practical aspects. It accounted for about two weeks or thirteen percent of the course and was found by the students to be very useful and motivating. The following are a few representative examples of material covered.

- **After monomers, monomeric units and polymeric molecules are defined, the basic difference between homopolymers and the various types of copolymers is illustrated with examples.**
- **Polyvinyl chloride, polystyrene, polymethylmethacrylate, etc. are described as non-crystallizing thermoplastics while epoxies and unsaturated polyesters are described as catalyst-curing rigid thermosets.**
- **Tensile, impact, fatigue, tear and abrasion tests are described and shown to serve different purposes.**
- **Main features and applications of the film blowing process are discussed with the help of diagrams.**

Throughout the comprehensive introduction, very extensive and systematic use was made of hundreds of polymeric *samples* which the instructor has collected. Samples were demonstrated and discussed in class which frequently led to fruitful out of class discussions. A list of samples related to polyvinyl chloride is given in Table III with a list of other selected examples; they illustrate the comprehensiveness and the variety of the samples. If such demonstrations are limited to the comprehensive introduction, they can be rapidly forgotten and serve only part of their purpose; instead, samples were shown, when appropriate, throughout the course. This practice proved largely worth the time involved and was extremely well received by the students.

INTRODUCTORY ASSIGNMENTS

IT WAS FELT that very early in the course students should become aware of the industrial and commercial aspects of polymer engineering. In particular they should know about trade publications, commercial and technical literature, the economics of the field, etc. *Introductory assignments* were designed to provide an organized and practical framework for achieving these objectives

TABLE III
EXAMPLES OF SAMPLES DEMONSTRATED AND DISCUSSED IN CLASS

Samples related to Polyvinyl chloride PVC

- unplasticized PVC (powder, pellets)
- plasticizer (liquid dioctyl phtalate DOP)
- plasticized PVC (10%, 20%, 30% DOP) powdered and roll-milled
- plastisol
- rigid PVC extrudates
- plasticized PVC sheets (flat and embossed)
- PVC coated fabrics
- plasticized PVC tubing (plain and braid-reinforced)
- plasticized PVC electric wire insulation
- injection molded electric plug insulation
- injection molded automotive trimming
- PVC-based blow molded bottles
- rotation molded dolls

Other selected examples

- Automobile tire
- Compression molded fiber-reinforced plastic FRP automobile bumper
- Laminated FRP skis
- Injection molded Polyurethane ski boot
- Injection molded automobile interior door pannel
- Extruded foamed elastomer automobile seal
- Injection molded integral skin rigid foam typewriter cover
- Compression molded baby bottle nipple
- Phenolic automobile distributor cap
- Cast polyurethane foam automobile arm rest

while motivating the students and reducing to a minimum nonproductive searching time.

The first introductory assignment dealt with polymeric materials and the second one with processing equipment. Two lists of polymers and processes are given in Table IV; entries in the second group are somewhat less well known than those in the first group. Students were asked to choose three entries in each group and gather information corresponding to questions appearing on forms. In order to set clear limits to the amount of work involved, students were given one blank form for each polymeric material or processing equipment which provided limited space for answering each question, this also allowed the easy comparison or reproduction of these data forms.

Sources of information recommended to the students were two-fold. Physical sciences and engineering libraries have most of the trade publications listed as references [15] to [27] as well as many relevant handbooks. Commercial literature is not normally easily accessible however. Prior to this course, the instructor obtained from over a hundred North American or European companies the material for a very extensive commercial literature file (advertising brochures, technical data sheets, specification sheets, price lists, etc.) which was placed in a mobile filing cabinet; the file was located in a room accessible to the students for the duration of the course. The file was also a primary source of information for the design projects to be discussed later.

Early testing was carried out after the comprehensive introduction using closed book (and notes) questions. It was felt that some essential material should be remembered for later reference in the course but emphasis was placed on the determination of answers by deductive reasoning rather than strict memorization. Question A (see appendix I) is a representative example of such questions. Student's response confirmed the expectations.

DESIGN PROJECTS

STUDENTS IN GROUPS of two (teams) were asked to study the industrial production of a polymeric object of their choice referred to here as an item (a list of items is given in Table V). They had to select suitable commercial polymeric material and processing equipment and fully justify their choice. In order to ensure steady and efficient progress on the design projects, work was divided in three four-week stages.

TABLE IV

Introductory Assignments

POLYMERIC MATERIALS

First group	— Low density polyethylene
	— Styrene-butadiene rubber
	— Polyvinyl chloride
	— Polystyrene
	— High density polyethylene
	— Unsaturated polyester
Second group	— Nylon 6-6
	— Polycarbonate
	— Silicone rubber
	— Polyimide
	— Polyurethane
	— Polychloroprene
PROCESSING EQUIPMENT	
First group	— Injection molding of thermoplastics
	— Wire coating
	— Extrusion of tubes
	— Sheet calendering
	— Compression molding of thermosets
	— Film blowing
Second group	— Extrusion-blow molding
	— Glass fiber-resin spraying
	— Thermoforming
	— Fluidized bed coating
	— Rotational casting
	— Styrofoam sheeting

An analysis of the item and its intended use leads to the determination of constraints on the choice of material and process. These constraints correspond to the dimensions and shape of the item, the properties required, the volume of production, the optimum cost, etc. On the basis of knowledge acquired through the comprehensive introduction of the course and the introductory assignments, a preliminary selection of one or several suitable types of polymeric materials and processes was made. A preliminary report was written which contained a description of all steps which led to the preliminary selection and included detailed references. The preliminary report was critically examined by the instructor who made written comments, suggestions and/or criticisms.

Specific technical and commercial literature on suitable material(s) and processing equipment was selected from our commercial literature file or other sources. Contacts were established with materials suppliers and manufacturers of similar or related items in view of technical advice and a subsequent industrial visit. In order to develop their initiative, students were asked to establish these contacts on their own using, for example, the commercial pages (yellow pages) of the telephone directory or names and addresses in our file. The instructor was prepared to back up their requests when necessary. Details of progress accomplished during the second stage were described in a progress report which was discussed at a meeting with the instructor.

By then the students had built up enough background on their design project to expect much benefit from an industrial visit. Each team had to make all arrangements for the industrial visit but the instructor normally participated in the actual visit, providing transportation when necessary. He ensured that the opportunity was used to see all polymer engineering activities in the plant which, although not directly related to the design project, were covered in the course. The very small groups helped make these visits most interesting and the hosts were invariably extremely cooperative and helpful. No re-writing of previously reported information was requested in the final report but emphasis was placed on presenting the details of the final choice for the polymeric material and the processing equipment proposed for the manufacture of the item (companies, specifications, models or numbers, delivery dates, prices, etc.) and a rational justification for the choice.

The work done by each group can benefit all students in the course and oral presentations can be the most effective way of communicating the acquired knowledge if they are carefully organized. It is not wise to schedule more than about six presentations at a time and in view of the total number of items each oral presentation was strictly limited to five minutes with a maximum of

TABLE V

POLYMERIC ITEMS FOR DESIGN PROJECTS

- Handle for cooking utensil
- Elastic band
- Light yogurt container
- Vinegar bottle
- Ski boot outer shell
- Screw and nut
- Garden hose
- Cord electrical switch
- Motorbike seat
- Glass fiber-reinforced plastic canoe
- Garbage bag
- Milk pouch
- Stiff yogurt container
- Hockey stick

five more minutes for questions. The short duration of each presentation called for a careful preparation. Each team had to prepare a 150-250 word abstract of their project supplemented by a few important references; copies of the abstract sheets were available to all students in the course prior to the oral presentations. Drafts for two overhead transparencies had to be prepared also, one being normally for a presentation of the item and the constraints, the second one for the material and the equipment selected. The drafts were examined by the instructor extensive changes being often needed to produce satisfactory final transparencies. An example is given in Figure 3. The reaction of students to the oral presentations of the design projects was sought in individual questionnaires. The response for individual projects provided a valuable rating of their quality which agreed with the instructor's rating. The overall response provided an assessment of the design projects by the students. Fifty-three percent of the students indicated that they knew very little about the topics before the presentations and thirty-one percent indicated that they came to the presentation with a very strong interest; thirty percent found the presentations excellent in all respects and sixty percent rated them good.

CONCLUSION

It is hoped that the somewhat detailed description of a polymer engineering course stressing industrial implications will draw a response from both practicing engineers and educators. A comparison of views should lead to further improvement of the quality and usefulness of polymer engineering education to suit the needs of industrial production as well as research and development. □

The course described here was developed and taught by the author (J.-M. Charrier) in place of the regular polymer engineering course while its instructor, Professor M. R. Kamal, was on sabbatical leave.

APPENDIX I

QUESTION A. A list of ten polymers is given below with a temperature T* in degrees Celsius (°C). This temperature T* corresponds to one of the three following characteristic temperatures: glass transition (Tg), melting of semi-crystalline material (Tm) and onset of serious chemical degradation (Td). Remembering that water freezes at 0°C and boils at 100°C and normal room temperature is about 20°C, associate in a table the given temperature T* to Tg, Tm or Td for each polymer. The polymers are: polypropylene (T* = -20°C), polystyrene (T* = 100°C), polytetrafluoroethylene (T* = 325°C), silicone (T* = -100°C), polypropylene (T* = 175°C), natural rubber (T* = -70°C), polyvinyl chloride (T* = 200°C), nylon (T* = 250°C), styrene-butadiene rubber (T* = 150°C) and polyimide (T* = 500°C).

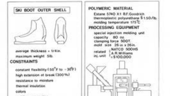

FIGURE 3. Overhead transparencies for oral presentation (ski boot outer shell).

QUESTION B. For each of the four basic polymerization techniques B (Bulk), So (Solution), Su (Suspension) and E (Emulsion), indicate in a table the rating +, 0 or - which best corresponds to each of the following characteristics: 1 = ease of control (generally easy: +, difficult: -), 2 = process technology (generally simple: +, complicated: -), 3 = polymer yield per reactor volume (high: +, low: -) and 4 = purity of product (generally high: +, low: -). Briefly justify your answers for the following combinations: 1/B, 2/Su, 3/So and 4/E.

QUESTION C. Using a logarithmic modulus scale from 1 psi to 10^6 psi, represent the modulus versus temperature curves for the following five materials: Polybutadiene PB which has a glass transition temperature Tg ≃ -85°C, Polystyrene PS which has a glass transition Tg ≃ 100°C, a random copolymer PSB containing 85% of Styrene and 15% of Butadiene, a random copolymer PBS containing 70% of Butadiene and 30% of Styrene and a blend PSB/PBS containing 50% of PSB and 50% of PBS. Briefly justify the use of PSB in paints. Briefly comment of the expected properties and applications of PBS. Briefly comment on the physical structure of PSB/PBS.

QUESTION D. With the help of an illustrated sketch and suitable symbols, define shear stress, shear rate and viscosity for a viscous fluid. A viscous liquid is sheared in the gap between two concentric cylinders. End effects are neglected and the gap thickness t is much smaller than the diameter d. A tangential force F is applied to the inner cylinder while the outer cylinder is held stationary. N is the speed of rotation. Express the relationship between the force F, the system dimensions a, t and d, the viscosity μ and the speed of rotation N.

APPENDIX II

PROBLEM A. The rate of decomposition of an initiator for free radical polymerization can be expressed as the time for decomposition of 50% of the original charge (half-life $t_{1/2}$ for first order reaction). For benzoyl peroxide: $t_{1/2}$ = 43 hours at 60°C. Determine the decomposition rate constant at 60°C in liters/mole/sec. Prepare a simple graph giving the fraction of benzoyl peroxide decomposed as a function of time.

PROBLEM B. Representative values of the rates of propagation (k_p) and termination (k_t) for the free radical polymerization of polymethylmethacrylate, are given in liter/mole/sec. at 30°C (k_p = 251 and k_t = 21 x 10^6) and at 80°C (k_p = 800 and k_t = 30.5 x 10^6). Determine the activation energies E_p and E_t for propagation and termination in kcal/mole. Determine the rate constants k_p and k_t at 60°C (a graphical method may be used).

PROBLEM C. An initial charge for a polymerization in solution contains 10 g of methylmethacrylate monomer and 0.1 g of benzoyl peroxide initiator per 100 milliliters of benzene. Assuming a constant initiator concentration, determine the time needed to polymerize fifty per cent of the charge at 60°C, the corresponding instantaneous number average molecular weight, the corresponding overall number average molecular weight, the times needed for 25% and 75% conversion at 60°C (a graphical method may be used) and represent the conversion curve at 60°C. Taking into account the initiator decomposition, determine the time needed to polymerize fifty per cent of the charge at 60°C and the maximum attainable conversion at 60°C.

PROBLEM D. The heat of polymerization of methylmethacrylate is $-H_{PZN}$ = 13.5 kcal/gmole. The heat capacities of methylmethacrylate, polymethylmethacrylate and benzene are approximately $C_p \simeq 0.5$ cal/g/°C. For a bulk polymerization of methylmethacrylate the initial temperature is around 20°C. Estimate the final temperature if the polymerization takes place in adiabatic conditions. Estimate the total amount of heat to be removed (cal/g and Btu/lb) to keep the temperature below the boiling temperature of methylmethacrylate (T_b = 100°C). For a solution polymerization of methylmethacrylate the initial charge contains 10 g of methylmethacrylate monomer and a small amount of benzoyl peroxide initiator per 100 milliliters of benzene solution. The initial temperature is around 20°C. Estimate the final temperature if the polymerization takes place in adiabatic conditions. Estimate the total amount of heat to be removed (cal and Btu) to keep the system from boiling.

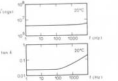

FIGURE 1. Viscoelastic data (storage modulus and loss angle) for problem E (Appendix II).

PROBLEM E. The vibrations of an apparatus are controlled by rubber units. The rubber units are submitted to sinusoidal shear strains of maximum amplitude γ_o = 1%. The frequency of the vibrations is f = 10,000 cycles per minute. The density of the rubber is $\rho \simeq 0.92$ g/cm³, its heat capacity is $C_p \simeq 0.5$ Btu/lb/°R and its glass transition temperature is $T_g \simeq -70$°C. Viscoelasticity data are in Figure 1 at 20°C. Assuming that the energy loss, converted into heat, is not conducted away from the rubber, estimate the rate of temperature rise (°C per second) in the units around 0°C.

PROBLEM F. A special extruder is being designed for the production of plastic film. A schematic cross-section of the extruder is shown on Figure 2. The solid polymer, in pellets or powder form, is fed in a slot (A) and entrained by a cylinder of diameter D and width W rotating at a speed N. Between A and B, the polymer is heated and sheared; when it reaches B, it is molten but not pressurized. The molten polymer is then entrained at a uniform temperature into a thin gap of uniform thickness h extending over half of the cylinder circumference (B-C). In the case where region C is open to the atmosphere, express analytically the volumetric flow rate Q_{vM} of molten polymer emerging as a function of W, h, D and N. In the case where the outlet at point C is blocked off, express analytically the pressure P_M at point C as a function of W, h, D, N and μ (viscosity of the polymer melt assumed to be Newtonian). The extruder is normally fitted with a slit die of width W, gap thickness t and gap length l. Express analytically the volumetric flow rate Q_v of molten polymer in the following form: $Q_v = Q_{vM}$ x (a function of h, D, t and l).

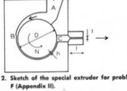

FIGURE 2. Sketch of the special extruder for problem F (Appendix II).

REFERENCES

1. Education Committee, Society of Plastics Engineers.
2. Education Committee, Plastics Institute of America.
3. Education Committee, Polymer Chemistry Division, American Chemical Society.
4. Material Science Division, National Science Foundation.

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REFERENCES

60. Hilko, B., personal communication, University of Waterloo.
61. Hupert, J.J., personal communication, De Paul University.
62. Jones, J.C. (1970), Design Methods, Wiley Interscience.
63. Dixon, J.R. (1960), Design Engineering: Inventiveness Analysis and Decision Making, McGraw-Hill, New York.
64. Krick, E.V. (1965), An Introduction to Engineering and Engineering Design, Wiley, New York.
65. Asimow, M. (1962), Introduction to Engineering Design, Prentice-Hall, Englewood Cliffs, N.J.
66. Buhl, H.R. (1960), Creative Engineering Design, Iowa State University Press, Ames, Iowa.
67. Jenson, V. G. and Jeffries, G. V. (1963), Mathematical Methods in Chemical Engineering, Academic Press, New York.
68. Himmelblau, D.M. (1967), Basic Principles and Calculations in Chemical Engineering, 2nd edition, Prentice-Hall, Englewood Cliffs, New Jersey.
69. Ackoff, R.L. (1962), Scientific Method, Wiley, New York.
70. Servais, W. and Varga, T. (1971), "Teaching School Mathematics," Penguin Books—Unesco.
71. Lewis, J.L. (1972), "Teaching School Physics," Penguin Books—Unesco.
72. Fixx, J.F. (1972), Games for the Superintelligent, Doubleday.
73. Sobol, D.J. (1971), More Two-Minute Mysteries. Scholastic Book Services, New York. (paperback).
74. Bloom, B.S. and Broder, L. (1950), "Problem Solving Processes of College Students," Supplementary Educational Monograph No. 73, University of Chicago Press, Chicago.
75. Bonzan, T., (1974), "Use Your Head," BBC Publication.
76. Experimental Learning Methods. Survival Problems, 39819 Plymouth Rd., Plymouth, Mich. 48170.
77. Royal Bank of Canada monthly letter.
78. Falmagne, "Reasoning: Representation and Process."
79. Woods, D.R., Wright, J.D., Hoffman, T. W., Swartman, R.K. and Doig, I.D. (1975), "Teaching Problem Solving Skills," Annals of Engineering Education, *1*, No. 1, p. 238.
80. Leibold, B.G., et al, (1976), "Problem Solving: A Freshman Experience," ASEE, Fall.
81. Woods, D.R. (1976), "Teaching Problem Solving Skills: Experiences as a Freshman (1974-75) as a Sophomore (1975-76)," McMaster University, Hamilton.
82. Aubel, J.L., personal communication, University of South Florida.
83. Woods, D.R., Chem. Eng. Ed. (Part 1).

POLYMER ENGINEERING: Charrier

Continued from page 129.

5. Lesson Plan for Plastics Courses, Plastics Engineering, July 1974.
6. A. L. Fricke, A Course Sequence in Polymer Processing, *Chem. Eng. Education*, Fall 1973.
7. S. L. Rosen, *Fundamental Principles of Polymeric Materials for Practicing Engineers*, Barnes and Noble, Inc., N.Y., 1971.
8. F. Rodriguez, *Principles of Polymer Systems*, McGraw Hill Co., N.Y., 1970.
9. D. J. Williams, *Polymer Science and Engineering*, Prentice Hall Inc., Englewood Cliffs, N.J., 1971.
10. L. E. Nielsen, *Mechanical Properties of Polymers and Composites*, Vol. 1, Marcel Dekker Inc., N.Y., 1974.
11. E. C. Bernhardt, ed., *Processing of Thermoplastic Materials*, Reinhold Publ. Co., N.Y., 1959.
12. P. J. Flory, *Principles of Polymer Chemistry*, Cornell University Press, Ithaca, N.Y., 1953.
13. J. D. Ferry, *Viscoelastic Properties of Polymers*, 2nd ed., John Wiley and Sons, Inc., N.Y., 1970.
14. J. M. McKelvey, *Polymer Processing*, John Wiley and Sons, Inc., N.Y., 1962.
15. *Canadian Plastics*
16. *Progressive Plastics*
17. *Plastics Technology Magazine*
18. *Modern Plastics*
19. *Plastics World*
20. *Plastics Engineering*
21. *Materials Engineering*
22. *Rubber World*
23. *Rubber Age*
24. *Rubber and Plastics News*
25. *European Plastics News*
26. *Plastiques Modernes et Elastomères*
27. *Revue Générale des Caoutchoucs et Plastiques*

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DISTINGUISHED PROFESSOR TITLE TO LARSON

AMES, IOWA—Maurice A. Larson, professor of chemical engineering at Iowa State University has been awarded the Anson Marston Distinguished Professorship in Engineering.

Larson, born in Mirrouri Valley, was graduated from high school at Ayrshire in 1944. He received his B.S. (1951) and Ph.D. (1958) degrees from Iowa State and was a chemical engineer with Dow Corning in Midland, Michigan, 1951-1954. In 1954 he became a teaching assistant at ISU, was named an instructor a year later and has been on the faculty since then. In 1970 he received the Western Electric Fund Award for excellence in teaching. In 1967 he had received ISU's Webber Teaching Award for inspired teaching in chemical engineering, and in 1972, received the Faculty Citation. In 1971-72 Larson was a visiting professor at University College, London, England. He was an AID-NSF science education consultant in India in 1968.