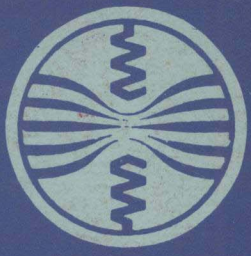

International Conference

Practical rheology in polymer processing

26 and 27 March 1980

Loughborough University of Technology, Leicestershire

THE PLASTICS AND RUBBER INSTITUTE
11 HOBART PLACE · LONDON SW1W 0HL

International Conference
PRACTICAL RHEOLOGY IN
POLYMER PROCESSING

26 and 27 March 1980

Loughborough University
Leicestershire, LE11 3TU

The Plastics and Rubber Institute

11 Hobart Place
London SWIW OHL
Telephone 01- 245 9555

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Conference

PRACTICAL RHEOLOGY IN POLYMER PROCESSING
26 and 27 March 1980

GENERAL INFORMATION

Purpose of the conference

To review the practical application of polymer rheology in relation to processing and product performance.

Sponsors

The conference is jointly sponsored by the Plastics and Rubber Institute (Processing and Engineering Group Committee) and the British Society of Rheology.

The organising committee comprises:

Dr D E Marshall	Institute of Polymer Technology, Loughborough University
J F Monk	Lucas Research Centre
Dr C J S Petrie	Newcastle-upon-Tyne University

Secretary:

Miss P C Durston	The Plastics and Rubber Institute

Venue (please see plan inside front cover)

The conference will be held in the Mechanical Engineering Building (Lecture hall T103) of the University of Loughborough, Loughborough, Leicestershire LE11 3TU (Telephone: Loughborough (0509) 63171) which is located on the outskirts of Loughborough close to junction 23 of the M1 motorway. The nearest railway station is Loughborough approx 4 miles from the University.

Car Parking

The University campus has many car parks and delegates are advised that vehicles must be parked in a designated parking area and not left on the roads.

Accommodation (in Rutherford/Caley Halls of residence)

If accommodation at the University was requested on the registration form, a card acknowledging this will be enclosed with the preprint book.

Preprints

This booklet contains the texts of papers as submitted by the authors in the form of camera-ready copy. Papers have not been edited by Institute staff.

Publication of the proceedings

It is hoped to prepare a general report on the conference to be considered for publication in a future issue of the Institute's members' journal 'Plastics and Rubber International' and/or the BSR Bulletin. The copyright in the papers is claimed initially by the Plastics and Rubber Institute.

Programme and timetable

This is detailed on pages iv to vi.

Contributors' biographical details

These are detailed on pages viii to xiii.

VAT invoice

All those who have requested a VAT invoice (and paid the appropriate fee) will find the invoice enclosed. Please pass it to your accounts department.

Refreshments and meals

Refreshments will be served in the lecture hall foyer, and all other meals will be served in Rutherford/Caley Hall.

Conference Dinner

A place at the dinner had been reserved for all registered delegates. Production of the delegates' name badge will allow entrance. Tickets for delegates' guests are available for purchase, price £10.00 plus £1.50 VAT each.

Discussion

The discussion periods will be an important part of the conference, and the cooperation of all concerned is sought in ensuring that the timetable is adhered to. When the time for discussion becomes short, delegates are asked to keep their contribution concise so as to allow the maximum number to participate.

Reception desk

Institute staff will man an enquiry/reception desk from 1630-1745 on 25 March and throughout the conference on 26 and 27 March, where delegates may leave messages or seek information. It is regretted that it will not be possible to contact any delegate other than by passing a message to him during a convenient break in the conference programme.

Institute publications

A selection of publications will be available for perusal and/or purchase.

Sports and recreational facilities

Delegates will be able to use the University's facilities whilst on campus. Details will be available on arrival.

THE PRI

The Plastics and Rubber Institute - an amalgamation of the Institution of the Rubber Industry, founded in 1921, and the Plastics Institute, founded in 1931 - is the oldest and largest international professional society in the world devoted exclusively to providing a service for personnel employed in the plastics and rubber and allied industries.

Over 11,600 individual members, of whom about 5,800 are resident overseas.

The PRI's membership qualifications are internationally recognized as the leading qualifications in the fields of polymer science and technology. Examinations for the higher grades of membership are conducted at various centres throughout the world and are open to members who have completed approved courses of study.

Publications include the two-monthly 'Plastics and Rubber International' issued free to members, and two research and development quarterlies concerned with 'Materials and Applications' and with 'Processing'. A range of over 80 books, pamphlets and study guides are also available at preferential rates to members.

Over 150 meetings are organized each year. Coming major events: June 4-5 RP '80 conference; June 9-10 Cars; September 3-5 Adhesion and adhesives: science, technology and applications; October Health and safety in the plastics and rubber industries; November 5-6 Moulding of polyolefins.

CONTRIBUTORS BIOGRAPHICAL DETAILS

Dr F S BAKER graduated with an honours degree in Chemistry at Queen Mary College, London University and obtained his PhD in Physical Chemistry at the same college. He joined the Civil Service in January 1965 as a Scientific Officer and is now a Principal Scientific Officer.

Mr P F BRIGHT graduated with an honours degree in Engineering Science from Reading University in 1970 and an MSc degree in Polymer Technology from Loughborough University in 1973. He worked for Hawker Siddeley Aviation Ltd from 1970 to 1972 and for Daniels Hamilton Ltd.from 1973 to 1975. In 1975 he joined Cranfield Institute of Technology as a Research Officer to work on the processing and properties of short fibre reinforced thermoplastics. He moved to Raychem Ltd in August 1979.

Mr J D BYAM graduated with a BCHE degree from the University of Delaware in 1950. He joined the Du Pont Company that year and transferred to the Elastomer Chemicals Department in 1964. Presently he is a senior technical representative in the Process Engineering Group of the Applied Technology Organization.

Mr R E CARTER gained from the Polytechnic of the South Bank, the Higher National Diploma in Applied Chemistry with Chemistry and Technology of Polymers in 1971, and the Graduateship of the Plastics Institute in 1972. In 1973, he was awarded both the MSc in Polymer Technology and the Graduateship of the Institution of the Rubber Industry at the Institute of Polymer Technology at Loughborough University of Technology. He joined the Ministry of Defence (Procurement Executive's) Explosives Research and Development Establishment - now the Propellants, Explosives and Rocket Motor Establisjment in 1973, where he is now a Higher Scientific Officer.

Mr F N COGSWELL joined the Plastics Division of ICI in 1959 and is presently a Division Science Associate studying the rheology of polymers.

Mr G P COLBERT graduated with a masters degree in Chemistry from the University of Wisconsin in 1953 and joined the Elastomer Chemicals Department of the Du Pont Company the same year. Presently he is a senior technical representative in the Process Engineering Group of the Applied Technologies Organization.

Dr R J CRAWFORD graduated from Queen's University in 1970 with a 1st class honours degree in Mechanical Engineering. In 1973 he obtained a PhD for research into the fatigue behaviour of plastics. Since then he has worked in ICI (Plastics) and Denroy Plastics and for the past five years has been a lecturer in the Department of Mechanical and Industrial Engineering at Queen's with research interests in the moulding/properties of plastics.

Dr M W DARLINGTON graduated with an honours degree in Physics from Southampton University where he also obtained his PhD degree. In 1965 he joined Cranfield Institute of Technology as a Research Fellow to study mechanical anisotropy in oriented thermoplastics. He is currently a Senior Lecturer in the Materials Department of the Institute, where his research interests include processing, mechanical properties and design data for fibre reinforced and filled thermoplastics.

Mr B HAWORTH graduated with honours in the science of engineering materials at the University of Newcastle-upon-Tyne in 1978. After conducting research on internal stress and orientation in glassy polymers for an MSc he transferred to Hepworth Industrial Plastics, Burnley late in 1979.

Prof J G INGEN HOUSZ graduated in Mechanical Engineering at the Technical University of Delft, The Netherlands. After three years in the USA (The Babcock & Wilcox Co and E I DuPont de Nemours & Co Inc). He joined the Van Leer Group of Companies in 1954. From 1960 he was Chief Engineer of the Non-metal Division. In 1965 he assumed his present post in the Technical University of Twente, where he teaches Polymer Technology in the Department of Mechanical Engineering.

Mr K ITO graduated in Mechanical Engineering from Tokyo University in 1945. He received his doctorate of engineering from Tokyo in 1960 after work in Japan and the USA. Since 1964 he has been Professor of Mechanical Engineering in Hosei University in Tokyo, as well as holding visiting and affiliate professorships. In 1979 he held a Science Research Council Senior Visiting Fellowship in the Department of Engineering Mathematics of the University of Newcastle-upon-Tyne. He is the author of three books and translator into Japanese of "Polymer Processing" by J M McKelvey.

Mr L P B M JANSSEN received his engineering and doctoral degree from Delft University of Technology. He has worked for a year as visiting assistant professor at the University of Delaware and is now a staff member at Delft. He is Secretary of the EFChE Working Party on Non-Newtonian Fluid Processing and Chairman of the Netherlands Extrusion Society.

Dr J L LEBLANC graduated in chemistry in 1970 obtained his PhD from Liege University (Belgium) in 1976. Up to that date, he was Assistant Professor at the University. He joined Monsanto in December 1976, in the Rubber Chemicals MTS Group at Louvain la Neuve, Belgium, where he is currently responsible for application research programmes in rubber processability.

Mr R J LIPPE obtained a BS in Chemistry from the University of Lowell in 1959. He then joined the FA Putnam Mfg Co, transferring in 1962 to Cabot Corporation as a research chemist. Mr Lippe's primary areas of interest include the rheology of paints, sealants and unpigmented coatings. He is a member of the American Chemical Society.

Mr U MASBERG graduated at his study of mechanical engineering with the title Diploma Ingenieur at the RWTH Aachen, in 1976. First he worked as a scientific at the Institute of Aerodynamics and since 1977 he is working at die design as a scientific at the Institut fur Kunststoffverarbeitung in Aachen.

Mr H E H MEYER studied Mechanical Engineering at the Technical University of Twente, graduating in 1975 in the Polymer Processing Group. He is currently employed at Twente University as a member of the Scientific staff of this group. His research work is directed at the melting process in single screw extruders.

Mr M D MOORE graduated with honours in Applied Physics from Bath University in 1976. Since then he has been employed as Research Scientist with special responsibility for process developments.

Mr A C PATEL graduated with a PhD from the University of London in 1964. He joined the research section of Ashland Chemical's Carbon Black Division in 1969 and is currently working in the Technical Service Laboratory with special responsibilities towards applied research.

Mr H J PEARSON graduated with honours in Part II of the Mathematical Tripos at Cambridge in 1976. He obtained honours in Part III of the Mathematical Tripos in 1977, and is preparing a doctoral dissertation at the Cambridge University Department of Applied Mathematics and Theoretical Physics in geophysical fluid dynamics. He has worked on computational problems for ICI Plastics Division and the Acushnet Company during vacations

Prof J R A PEARSON graduated with honours in Part II of the Mathematical Tripos and Part II of the Engineering Tripos at Cambridge in 1953. He took a Master's degree in Engineering and Applied Science at Harvard University in 1954 and returned to take his PhD in fluid mechanics at Cambridge in 1957. He worked for three years with ICI and one year with the Metal Box Co as a scientist, and from 1960 to 1972 was Assistant Director of Research in Chemical Engineering at Cambridge University. He was appointed to his present position of Professor of Chemical Engineering at Imperial College, London, in 1973 and was awarded the degree of ScD, Cambridge in 1974. He has consulted widely in the plastics and rubber industry.

Dr C J S PETRIE studied Chemical Engineering at Cambridge University, and received his PhD in 1965. In 1966 he took up his present post of Lecturer in Engineering Mathematics in the University of Newcastle-upon-Tyne. He held a Leverhulme Fellowship at the University of Delaware in 1974, studying elongational flow of molten polymers while on leave from Newcastle. He is the author of a book entitled 'Elongational Flows' (Pitman, 1979) and is currently Secretary of the British Society of Rheology.

Mr J M PLAYER joined the Plastics Division of ICI in 1960 and after working both in PVC Research and Technical Service Departments is now responsible for the Development and Technical Service of Acrylic Processing aids for PVC.

Dipl Ing H REICHSTEIN since 1978 he has been a member of the Scientific Staff of the Institute for Plastics Processing (IKV) of the Technische Hochschule, Aachen, Germany.

Dr S M RICHARDSON graduated with honours in Chemical Engineering from Imperial College, London, in 1972. He obtained a PhD from Imperial College in 1976, with a thesis on the numerical solution of the 3-D Navier - Stokes Equations. He then joined the Engineering Department, Cambridge as a research assistant, and subsequently moved to the Chemical Engineering Department, Cambridge, as an 18SI Research Fellow. Since 1978, he has been a lecturer in the Chemical Engineering Department, Imperial College, where he has been involved in all aspects of teaching, as well as pursuing his research interest of modelling polymer processing operations.

Mr G J SANDILANDS graduated with honours in the science of engineering materials at the University of Newcastle-upon-Tyne in 1977. He was awarded an MSc in 1978 for work on the analysis of internal stresses in thermoplastics and continues to do research at Newcastle University where he now studies fatigue in semi-crystalline polymers.

Dr Ing R SCHULZE-KADELBACH since 1978 he has been chief engineer of the Institute for Plastics Processing (IKV) of the Technische Hochschule, Aachen, Germany.

Mr G TARGIEL graduated at his study of mechanical engineering with the title Diploma Ingenieur at the Rheinisch - Westfalisch - Technischen Hochschule in Aachen, 1977. Since 1977 he is working at the rheology of rubbers as a scientific man at the Institut für Kunststoffverarbeitung in Aachen.

Mr D M TURNER graduated with an honours degree in Natural Sciences from Cambridge University in 1952 and since then has been employed by Avon Rubber Company in a variety of technical roles. He is currently Director of Special Projects. He is also Chairman of the PRI Technical Committee.

Mr R C WARREN graduated with an honours degree in Physics from the University of New South Wales, Australia, in 1966, and obtained an MSc degree in Physics in 1969. He joined the Australian Department of Defence in 1970, transferring to the Weapons Systems Development Laboratory in 1972 to work on the mechanical properties of polymeric materials. He is currently on attachment to the Propellants, Explosives and Rocket Motor Establishment.

Dr J R WHITE graduated in physics from Imperial College, London, in 1964 and completed a PhD in the Department of Chemical Engineering of Imperial College in 1968. After spending one year with Morganite Carbon Ltd, Battersea, and two years at Johns Hopkins University, Baltimore, USA, Dr White took an appointment in the Department of Materials, Queen Mary College, London in 1971. Since 1975 he has been a lecturer in the Department of Metallurgy and Engineering Materials, University of Newcastle-Upon-Tyne.

Mr J D WILSON graduated with an honours degree in Polymer and Fibre Science from Manchester University (UMIST) in 1975. After graduation he stayed at UMIST to conduct postgraduate research. He is currently engaged as a research assistant in the Department of Mechanical Engineering at UMIST.

Dr R A WORTH obtained a first class honours degree in Mechanical Engineering at the University of Bradford in 1971, and a PhD in the field of polymer processing in 1975. He then spent two years as lecturer in mechanical engineering at the University of the West Indies, Trinidad. In June 1977 he returned to the United Kingdom to take up a post as lecturer in polymer engineering at UMIST. On 1 April he joins Manchester Polytechnic as principal lecturer in mechanical engineering.

Mr R C YOUNG joined the Plastics Division of ICI in 1967 and after working in PVC Technical Service is now studying the rheology of polymers within the Polymer Science Division of Research Department.

Dr H EL SOBKY obtained a 1st class honours degree in mechanical engineering from Cairo University in 1967. He went on to take on MSc at Imperial College, London in 1971, followed by a PhD at Leeds University. Since 1974 he has been employed as lecturer in polymer engineering at UMIST.

Mr S BILGIN graduated with a BSc in polymer engineering at UMIST in 1979. He is now engaged in research for the degree of MSc in the UMIST Mechanical Engineering Department.

Dr W G HARLAND obtained the degree BSc Hons in Chem and PhD, both at University of London. He worked for 13 years at the Shirley Institute on molecular weight distribution in rayons and on various aspects of textile finishing. Since 1960 he has been a lecturer, then Senior Lecturer, in polymer and fibre science at UMIST and has been responsible for teaching courses in polymer technical engineering.

PROGRAMME

26 March 1980

0900		Registration
0925		Chairman's welcome and introduction
0930	1	An integrated approach to efficient polymer processing G P COLBERT/J D BYAM (E I Du Pont de Nemours, USA)
1000	2	Simulation of injection moulding J R A PEARSON/S M RICHARDSON (Imperial College of Science & Technology)
1030		Discussion
1045		Coffee
1115	3	Three dimensional calculation of velocity fields in complex flow channels U MASBERG (Institut fur Kunststoffverarbeitung, Aachen)
1135	4	Control of wall thickness uniformity in non-circular blow mouldings using profiled dies R A WORTH (UMIST)
1155	5	Prediction of wall thickness of blow moulded containers C J S PETRIE/K ITO (University of Newcastle-upon-Tyne)
1215		Discussion
1230		LUNCH
1400	6	The effect of pressure and metal surface on the flow behaviour of rubber D M TURNER/M D MOORE (Avon Rubber Company Ltd)
1420	7	Determination of the rheological properties of rubber compounds-flow properties and wall slip G TARGIEL (Institut fur Kunststoffverarbeitung, Aachen)
1440	8	Rheological measurements - a versatile tool for the formulation and preparation of elastomeric sealants R J LIPPE' (Cabot Corporation, USA)
1500	9	Capillary rheometer: a practical tool to characterize carbon blacks A C PATEL (Ashland Chemical Company, USA)
1520		Discussion
1540		Tea
1610	10	Rheology and the growth of strong polymer fibres L P B M JANSSEN (University of Delft, Netherlands)

1430	20	Flow of polymer melts in cooled flow channels - described by means of the dimensional analysis method H REICHSTEIN/R SCHULZE - KADELBACH (Institut für Kunststoffverarbeitung, Aachen)
1450	21	Extrusion of pipes using a rotating die system W G HARLAND/R A WORTH/H EL SOBKY (UMIST)
1520	22	Instrumentational aspects of rheological measurement with respect to capillary and rotary rheometry P COOMBER (Instron Ltd)
1550		Discussion
1610		Conclusion followed by tea.

AN INTEGRATED APPROACH TO EFFICIENT POLYMER PROCESSING

J.D.Byam and G.P.Colbert*

A computer is used to simulate polymer processing by integrating the interrelationships between rheological, chemical, physical and thermal properties of polymers, equipment design and operating parameters. Much trial-and-error in factory operations can be eliminated by simulating the operation with a computer thereby saving time, money and speeding optimization of the process.

INTRODUCTION

Profitable polymer processing operations require optimization to achieve minimum cost, maximum productivity, high yield and quality parts. Usually this is achieved by trial and error after equipment has been installed and put in operation. It may require extensive searching for the best operating conditions, equipment modifications or reformulation of polymeric materials. Any of these steps can result in costly time delays.

Several approaches have been used for treating polymer processing in a more scientific manner. One of these is the "black box" approach. Correlations are derived between input and output variables but neglect detailed consideration of what happens in the operation. This method can be useful, can define some of the controlling variables but the results are limited to the operation studied.

A second might be described as a unit operations approach. Each step of the operation is investigated in terms of known physical laws and attempts are made to express the operations mathematically. This approach has received considerable attention in recent years and has contributed substantially to a better understanding of polymer processing. Rheology of melt flow is an essential factor for understanding these operations.

*Elastomer Chemicals Department, E. I. du Pont de Nemours & Co., Inc., Wilmington, Delaware 19898

An integrated, scientific approach to studying polymer processing is described in this paper. It is an expansion of the unit operations approach to include consideration of chemical and physical properties of polymers in addition to rheological properties. It can be used at any stage; e.g., design, start-up or factory operation. Some of its greatest benefits can be realized, however, by using this technique to help estimate viability and profitability of an operation during the design stage and to speed factory start-ups.

DESCRIPTION OF APPROACH

One of the basic concepts of all polymeric fabricating processes is that performance characteristics such as rate, quality and economy are functions three basic parameter sets - polymer or compound characteristics, equipment design parameters and operating variables. A conceptual expression of this is:

$$\begin{bmatrix}\text{Rate, Quality}\\ \text{and Economy}\end{bmatrix} = f\left(\begin{bmatrix}\text{Polymer}\\ \text{Properties}\end{bmatrix}, \begin{bmatrix}\text{Equipment}\\ \text{Design}\end{bmatrix}, \begin{bmatrix}\text{Operating}\\ \text{Variables}\end{bmatrix}\right) \quad \ldots . (1)$$

This expression suggests an interrelationship between these parameters and, indeed, there is, but frequently it is forgotten or ignored when planning a factory operation. For example, mold designers ignore polymer characteristics when applying their craft because they seldom have access to good flow and thermal data. Similarly, materials suppliers often overlook the wide variety of processing equipment in use when promoting their products. It is important, however, to keep these interrelationships in proper perspective when planning or analyzing a processing operation.

Three key elements are required for understanding these processes and the interrelationships involved in them. One is a practical mathematical model constructed to describe the processing operation. The model should be simple enough to solve the important factors while omitting irrelevant calculations. The second is a computer for performing the complex, time-consuming calculations. The third is an engineer who recognizes the capabilities and limitations of the model, can assemble the requisite data to supply the computer and, in turn, interpret the results.

Repeated simulations of a modeled operation can move the trial-and-error procedures from a factory floor to the computer where it can be analyzed quickly and inexpensively. An outline of a procedure for analyzing an injection molding operation is presented schematically in Figure 1. Similar schematics can be prepared for other processes. An engineer assembles information on the material to be molded, the molding press, suggested operating conditions and the design or proposed design for the mold. Laboratory tests are performed to obtain the necessary flow, thermal and chemical properties needed for the analysis. The sequential flow paths in the delivery system from plasticator