

# Rubbercon '81

THE INTERNATIONAL RUBBER  
CONFERENCE

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Volume I



The Plastics and Rubber Institute  
11 Hobart Place London SW1W 0HL

## RUBBERCON '81

### Theme and objectives

The science of technology and its profitable and practical application to the rubber industry will be the theme of RUBBERCON 1981. Changing applications of polymers, and the innovations that will result from processing the wide range of natural and synthetic polymers, urethanes and thermoplastic elastomers available will be reviewed. As rubber is a multi-discipline industry, the conference will aim to bring together chemists, physicists, engineers, designers and technologists. It will try to build bridges between these experts, to cross-fertilize their ideas and to break down inter-disciplinary and international barriers.

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## RUBBERCON '81

THE PLASTICS AND RUBBER INSTITUTE celebrates in 1981 its Diamond Jubilee. The Institute - an amalgamation of The Institution of the Rubber Industry, founded in 1921 and The Plastics Institute, founded 1931 is a registered educational charity and the oldest and largest international professional society in the world which is devoted to providing a service for personnel employed in the plastics and rubber, and allied industries.

The principal aims and objectives are:

the development for the public benefit of a professional body comprising members concerned with the art, science and technology of plastics, rubbers and other high polymers in academic, research, commercial and administrative capacities.

and

the advancement of the standards and methods of education and training at all levels in these fields, and in related technical and non-technical subjects including management, economics and finance.

### EXAMINATIONS AND QUALIFICATIONS

The Institute's membership qualifications are internationally recognized as the leading qualifications in the fields of polymer science and technology.

Most of them are obtainable either by success in the Institute's own examinations or by exemption from them on the basis of appropriate qualifications. Examinations are conducted at various centres throughout the world and are open to members who have completed approved courses of study. The three higher grades - the corporate (professional) grades - are available to suitably experienced persons working at graduate and post-graduate levels. The Associate Member grade - equivalent to Associateship - is for all suitably experienced graduates who having one year's Institute service are working in the plastics or rubber industries, but who are not graduates of the Institute and do not therefore qualify for Associateship.

### PUBLICATIONS

In 1981 the Institute offers members a choice of two publications: Plastics and Rubber International, to be issued two-monthly free to members; and Plastics and Rubber Processing Applications. The latter is available on subscription at a preferential PRI members rate of £33.60 per annum from Applied Science, Ripple Road, Barking Essex.

A range of over 80 books, pamphlets and study guides are also available at preferential rates to members: new titles are always in the course of preparation.

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Dr P W Allen graduated in Chemistry at Oxford. After three years' research on fibres at British Nylon Spinners Ltd (now ICI Fibres Division) he joined the Malaysian Rubber Producers' Research Association in 1952. His present position is Assistant to the Director. For the past 20 years he has been concerned with the economics of natural rubber, on which subject he has written many articles and published a book.

Mr H M Scopes. After studying chemistry at Nottingham University, Herman Scopes joined ICI in 1960. A succession of jobs in the Sales and Marketing areas of the company's Petrochemicals Division, including a 3-year secondment to ICI Germany, was followed by a switch to the Purchasing function in 1977. He was promoted to the Division Board in April 1980 and is responsible for the procurement of feedstock and fuels and the commercial management of ICI's crude oil processing operations.

Mr L H Krol. After graduation as a chemical engineer at Delft Technological University in 1951 L H Krol joined the Royal Dutch/Shell Group. He was first engaged in the process development and the manufacture of epoxy and vinyl resins in the Shell laboratories in Amsterdam and in the plants at Pernis. After his transfer to the newly established Koninklijke/Shell Plastics Laboratorium at Delft he worked on the fundamentals of extrusion and the end-use properties of pipes based on various thermoplastics. In 1963 switching to elastomers, he concerned himself with the potentialities of the stereospecific isoprene and butadiene rubber in truck and car tyres and their introduction in the industry. Further, he worked on the fundamentals and machine aspects of the injection moulding of rubbers, in particular isoprene rubber.

During 1969-1971 he was in Marketing with Shell International Chemical Co. in London where he took part in the preparation of the manufacture of thermoplastic rubbers in Europe. After his return to the Netherlands he became head of the Elastomers Department in the Shell laboratories in Amsterdam, leading the integrated process and product research.

Dr M Morton was educated in Montreal, Canada, receiving his BSc in chemistry from McGill University in 1934. After spending 8 years in industry, mainly as chief chemist for the Canadian Johns Manville Co, he returned to McGill for postgraduate study in chemistry, receiving his PhD in 1945. He was Professor and Head of the Chemistry Department at Sir George Williams College (now Concordia University) in Montreal until 1948, when he accepted the post of Assistant Director of Rubber Research at the University of Akron. He became Director and Professor of Polymer Chemistry in 1953, and in 1956 became the first director of the Institute of Rubber Research (now the Institute of Polymer Science) at Akron. In 1967 he was also appointed Head of the newly-formed Department of Polymer Science, and in 1969 was named by the State of Ohio as the Regents Professor at the University of Akron. In 1978 Dr Morton retired as Director of the Institute and was appointed Regents Professor Emeritus of Polymer Chemistry.

Dr T J Dudek graduated from the University of Akron with a PhD in Polymer Science in 1961. He served as a 1st Lt with the US Air Force Materials Lab from 1959-62, transferring to NASA, Moffett Field, California, as an Aerospace Technologist from 1962-64. He was Manager, Materials Research Department at Lord Kinematics, Erie, Pennsylvania, from 1964-69, transferring to the Polymer Physics Section of the Research Division of General Tire & Rubber Company in 1969. He was named to his present position, Manager, Engineering Mathematics and Physics Department, in 1975.

Dr G S Fielding-Russell graduated from Loughborough University of Technology, with an honours degree in Industrial Chemistry in 1963. He obtained an MSc from Leicester University in 1965 and a PhD from Loughborough University of Technology in 1967. In 1968 he joined the Research Division of The Goodyear Tire and Rubber Co as a Senior Research Chemist. In 1976 he became Group Leader in the Tire Physics Section and in 1979 he became Section Head of Materials Physics Research.

Dr D I Livingston received BS in Chemistry from the now City University of New York in 1941 and PhD in Physical Chemistry from the Polytechnic Institute of Brooklyn in 1950, specializing in Polymer Chemistry. After several industrial positions, he joined The Goodyear Tire and Rubber Co in 1959 as Section Head of Polymer Physics Research. At the present time, he is Section Head of Tire Physics Research.

Mr K C Gong graduated in chemical technology from South China Institute of Technology in 1953. In 1959 he was awarded a candidate of technical science at Moscow Institute of Fine Chemical Technology. He is associate professor of polymer material science and is head of research laboratory of structural changes and ageing of polymers at South China Institute of Technology.

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Mr P S Oubridge MSc, FPRI obtained an honours degree in physics from Birmingham University in 1954. After National Service, he joined the Physics Department of the Dunlop Research Centre and in 1965 was awarded his MSc for a thesis on the energy losses in pneumatic tyres. He is now Development Manager, Design and Performance Engineering in Dunlop Technology Division and serves on the Technical Committee of the PRI and the Research and Technology Committee of the CBI.

Mr B J Hinton MSc graduated in physics and mathematics as an external student of the University of London in 1955 and obtained his MSc in Automobile Engineering at Cranfield Institute of Technology in 1961. Apart from 4 years in the glass industry he has worked in the Tyre Division and Polymer Engineering Division of Dunlop Limited, before joining Dunlop Technology



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Mr C M Handley, LIMA studied mathematics, statistics and computing at Birmingham Polytechnic and obtained his LIMA in 1974. He joined Dunlop Research Centre in 1967 and worked on materials development before undertaking the development and implementation of graphically aided computer programs for use in the field of finite element analysis. He is now a member of Design and Performance Engineering, Dunlop Technology Division.

Dr K V Nelson graduated from Leningrad University, the faculty of physics, in 1944. In the same year he started his work as a junior research worker at Leningrad Physico-Technical Institute, transferring to Leningrad Synthetic Rubber Institute in 1951. Since 1955 he has the master's degree in physico-mathematical sciences and since 1975 the doctor's degree in chemical sciences. He works at Leningrad Synthetic Rubber Institute specializing in polymer physics and mechanics.

Dr W J E Parr received his PhD from York University in 1974. After two years as a post-doctoral fellow at the University of Manitoba, Canada, and a further year at Warwick University, he joined MRPRA in 1977 as Project Leader in oxidation chemistry. In 1980 he transferred to Akzo Chemie UK as Head of the Diversification Laboratory.

Mr G Rayner graduated in chemistry at the University of Manchester. He joined the Rubber Service Laboratories of ICI in 1958 where he was employed in a number of areas ranging from Research and Development on new Products, to Technical Service to the Rubber Industry in both the UK and overseas markets. His current areas of interest in the Technical Service Department of Vulnax International Limited concern matters relating to the tyre industry.

Mr P Hill BSc, London MRIC, APRI, joined ICI Limited UK, in the then Dyestuffs Division in 1956. He transferred to the Rubber Services Laboratories in 1957. Since then he has been involved on technical service to the rubber industry with initial emphasis on general rubber goods and speciality synthetic rubbers. He is now Manager responsible for the UK-based applied research and Technical Service facilities of Vulnax International Limited, the company in which ICI and Rhone-Poulenc recently merged their rubber chemicals interests.

Dr Th Kempermann graduated at Heidelberg University in 1955 in Organic Chemistry. He joined BAYER AG the same year. His first task was Development of Rubber Antioxidants. He is now Manager Rubber Chemicals Development and Technical Service of Bayer AG-Rubber Division.



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Dr G Wouters obtained a PhD degree in Chemistry from the University of Leuven (Belgium) in 1977. After being Postdoctoral Research Chemist at the University of California in San Diego from 1978 to 1980; joined Essochem Europe Inc in 1980 in the Elastomers Technology Department.

Dr A A Dontsov graduated from Lomonosov Institute of Fine Chemical Technology (Moscow) in 1958. He received his candidate degree of chemical science (PhD) in 1963 and in 1974 a degree of doctor of chemical science. Since 1977 Mr Dontsov has been a professor of chemistry in high molecular compounds. In 1976 he left Lomonosov Institute and joined Scientific Research Institute of the Rubber Industry as a chief of the department for physical-chemical investigations. Since 1977 Mr Dontsov has been appointed a deputy director of the Rubber Institute responsible for perspective scientific-engineering decisions, development and application of raw materials.

Mr J A Sidwell graduated with an Honours degree in Applied Chemistry from Lanchester Polytechnic, Coventry in 1972. From there he joined the Laboratory of the Government Chemist (Department of Industry) working on the development of High Performance Liquid Chromatography primarily for the analysis of pesticide formulations and residues. In 1977 he joined RAPRA and is now currently assisting in the running of their Analytical Testing Laboratory providing a consultative analytical service to the Rubber and Plastics Industries.

Mr G F Morton graduated with an Honours degree in Physics from the University of Durham and joined Dunlop in their Central Research Division. He has held the following appointments: Research Manager, Dunlop Textiles Ltd, Rochdale; Manager, Tyre Laboratories, Fort Dunlop; Technical Director, UK Tyre Group; Development Director - Tyres and is now Tyre Research & Laboratories Director. He is a member of the Institute of Physics, a Fellow of the Plastics & Rubber Institute and delivered the 1970 Foundation Lecture.

Mr L A Walker received a BS degree in Chemistry from Carson-Newman College in 1947 and an MS in Chemistry from The University of Tennessee in 1954. After two additional years of graduate studies in Organic Chemistry, he joined Monsanto Company as a Research Chemist in 1956. He has been a Senior Research Specialist in the Tire Marketing Technical Service Group since 1972.

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Dr A C West graduated from Texas A&M University in 1971 with a PhD degree in Polymer Chemistry. After a post doctoral assistantship at SUNY College of Forestry in Syracuse, he joined 3M Commercial Chemicals Division and is presently Manager of FLUOREL Product and Process Research.

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Mr W F Helt graduated with a degree in Chemistry from The University of Dayton in 1969. He joined the Firestone Tire & Rubber Co in 1969, and transferred to Monsanto Company, Rubber Chemicals Division in 1980 as US Tire Marketing Technical Service Manager.

Dr K M Kiepert born in 1922 in Eichwalde near Berlin, studied Pharmacy after graduating from high school in 1940 (Abitur). After being conscripted to serve in a Pharmacy, he studied chemistry in Berlin and Wurzburg and graduated in organic chemistry in 1955. During the same year he joined Chemische Werke Huls AG and worked in the research department. In 1965, he was appointed section head of the rubber research department. In autumn of 1965, he was transferred to the technical applications department and in 1967 was granted limited and in 1970 full power procurement.

Sir Campbell Fraser, Kt was born in Dunblane, Scotland, on 2 May 1923. A B Com., he was educated at Glasgow University and the Dundee School of Economics.

He served in the RAF during the war and then completed his studies in economics. In 1952 he joined the staff of the Economist Intelligence Unit taking charge of industrial research. In 1957 he joined the Dunlop Rubber Company (as it was then known) and was appointed public relations officer of the Group in 1958.

In 1962 Sir Campbell became Dunlop's group marketing controller, and early in 1967 was appointed managing director of Dunlop New Zealand Limited. At the beginning of 1969 he returned to the UK as director of resources and planning at Dunlop's head office, and in May was elected an executive director. In January 1971 he became joint managing director and, at the end of 1972, sole managing director. In January 1977 he became chairman of Dunlop Limited, the main operating company and in May 1978 he succeeded Sir Reay Geddes as chairman of Dunlop Holdings Limited.

Sir Campbell is a fellow of the Royal Society of Edinburgh, a fellow of the British Institute of Management, and a fellow of the Plastics & Rubber Institute. He is president of the Society of Business Economists.

Sir Campbell is a member of the board of the Industrial Development Advisory Board, the Board of British Petroleum Company Limited, and the Boards of Finance for Industry and Finance Corporation for Industry Limited. Sir Campbell is also chairman of Scottish TV Limited, chairman of the Steering Board of the University of Strathclyde Business School, and a Council member of the Scottish Business School.

Sir Campbell is a Trustee of The Economist, a member of the CBI Council, Chairman of the Industrial Policy Committee of the CBI, a member of the President's Committee of the CBI, a member of the Council of the Society of Motor Manufacturers & Traders, and a member of the Executive Committee of the Society of Motor Manufacturers & Traders.

## NATURAL RUBBER : OUTLOOK FOR THE 1980s

P.W.Allen \*

The natural rubber (NR) market is becoming increasingly differentiated into tyres and specialized (eg engineering) applications, plus fast-growing use in developing countries including those that produce NR. Growth of technically-specified NR will continue. Powdered NR, already commercially available, will take off only if there is a general move towards powdered elastomers. Thermoplastic and epoxidized NR are at the take-off stage. High performance vulcanization (EV and urethane) is well established.

### INTRODUCTION

Assessment of likely future technological developments affecting natural rubber (NR) must be undertaken with recognition of certain highly significant trends relating to NR's position in the market-place. The trends which are especially relevant are: market share, production prospects, pattern of end usage, geography.

### Market share

NR's current share of the world elastomer market is determined by NR production relative to world elastomer consumption and in no way reflects NR's long-term technical and economic potential. Following a steady drop, from 100 per cent prior to 1939 to around 30 per cent in the early 1970s, NR's market share has levelled off since 1972, the result of a drastic cutback in world elastomer consumption growth offsetting sluggish growth in NR production. For the remainder of the decade the prognostication is that the market share will remain at, or a little below, the current level, and there is now little likelihood that during this decade the NR producers will be able to boost production to the extent that the market share can move towards the 40-plus per cent indicated by NR's techno-economic potential (1). Figure 1 summarizes the likely position to 1990.

It has become fashionable to talk of a growing shortage of NR, but whether or not this will develop is dependent both on the behaviour of the world economy and NR production growth in the next few years. On present form the probability is that supply and demand will remain more or less in balance for the time being.

\*The Malaysian Rubber Producers' Research Association

Production prospects

In the longer term, the ability of NR to maintain and if possible increase its market share is of course dependent on the ability and desire of NR producers to expand production at faster rates than hitherto. In fact, a variety of factors (eg countervailing attractions of other crops) have conspired to reduce the rate of growth from the peak levels of the 1960s (Figure 2) and the question is: what is the chance of permanently raising this rate to higher levels?

There is no doubt concerning the technical ability of NR producers to obtain much greater quantities of NR than at present from a given land/labour mix, by "genetic, physiological, agronomic, horticultural and other forms of plant manipulation"(2). Significantly, 1981 is the year in which an expedition is being mounted to widen the genetic base of Hevea by collecting new varieties from the Amazonian rain forests.

There is also mounting evidence that the producing countries are taking renewed interest in the socio-economic merits of NR production, and it is significant to note that plans for new planting of Hevea in Asia, Africa and South America total 1.5 million hectares (3) which is 20 per cent of the present total area. (There is also growing interest in the potential of NR from the Guayule shrub, though this will not make a significant contribution during the 1980s). The confidence of producers, especially smallholders (who own about 75 per cent of the total world planted area), will be greatly reinforced by realization that price stabilization, now in being with the establishment last year of the International Natural Rubber Agreement, offers some assurance against unacceptably low levels of price.

Pattern of end usage

A very significant trend which has become apparent in recent years is the substantial increase in the percentage of NR consumption going into tyres, from under 60 per cent ten years ago to over 70 per cent today (Figure 3). This arises from combination of the following factors: (i) the production of car and truck tyres has grown by 12 per cent/year and 16 per cent/year, respectively, over this period against less than 7 per cent/year for NR production/consumption, (ii) the proportion of NR in car tyres has been greatly increased by conversion to radial-ply tyres, an effect which is only partially offset by the increased tyre life, and (iii) truck tyres, which contain a much greater weight of NR per tyre, have as noted shown faster production growth than have car tyres.

Thus, the proportion of the NR market available for non-tyre uses (disregarding latex which remains a steady 7-8 per cent) is getting appreciably smaller. Moreover, in those less demanding applications where the special merits of NR (eg high strength) are not really required, NR has been largely replaced by synthetics (plastics and rubbers).

The fact is that NR is becoming, in a sense, a special-purpose elastomer. This is superficially not a surprising situation for a material which accounts for only 30 per cent of the total market; the important point is that NR does possess special attributes which have enabled it to establish new markets in those types of end use (eg engineering applications) for which NR is uniquely suited. If NR had been unable, for technical reasons, to move in this direction, then its 30-per cent market share could be interpreted as signifying decline. As it is, NR's unchallengeable position in the radial-ply tyre, combined with its new role in specialized markets, offers exciting prospects for the future and provides a spur for new scientific and

technological endeavours.

### Geography

Another significant trend is the steady and substantial shift of rubber products manufacturing from North to South; the rubber industry is following the pattern of other industries eg textiles. In the case of NR several developing countries have become major consumers. Korea now ranks as the ninth largest NR consuming country, almost equal to the UK. Collectively the developing countries have almost doubled their share of the NR market in the last decade and the process is accelerating (Figure 4).

One group of developing countries that has a vested interest in NR - the NR producing countries - is showing great determination to expand rubber products manufacturing, not merely for domestic use but also for exports. Malaysian NR consumption, for example, is already about one-half that of the UK and is growing at 10 per cent/year. Such expansion offers great opportunities for the rubber industry, and suppliers, in the developed countries, eg via joint ventures.

Combining this with the comments of the previous section leads to the proposition that future NR consumption will be sharply split three ways: radial-ply tyres, specialized uses mainly but by no means exclusively in developed countries, general use in developing countries.

### THE RAW MATERIAL

The most important single NR development during the past 20 years has been initiation and growth of technically-specified NR, an operation undertaken in the teeth of bitter opposition from all manner of interests. Starting with Standard Malaysian Rubber (SMR) in 1965, growth has been very fast and the 1979 output, 1.3 million tonnes, represents almost 40 per cent of all NR (Figure 5).

Examination of the growth pattern using standard S-shaped curve fitting procedures leads superficially to the impression that on present form this market will level off at around 50 per cent of all NR production (including latex concentrate). The reason for this apparent slowing down is that conversion from old to new methods of presentation has been most attractive, and therefore has proceeded faster, at the lower quality end (ie the 'field grades' made from naturally coagulated latex) where there are distinct financial advantages to producers. These advantages are less clear-cut for the latex grades (eg RSS) and conversion of these has so far been less extensive though still substantial.

Recognizing the importance of accelerating this change, not merely to maintain momentum but also because there are definite long-term advantages to producers and consumers in achieving virtually total conversion to technically-specified forms, the Malaysian producers have recently developed a 'general-purpose' material (SMR GP) comprising a three-part blend (deliberately coagulated latex; sheet material; field coagulum) which is also viscosity-stabilized (4). This is now in production and is proving technically satisfactory to those consumers who have sampled it.

### Powdered NR

If all the claims that have been made in recent years concerning the merits of powdered elastomers were valid, the industry would now be using

substantial tonnages. In fact, it is doubtful whether more than about 2 per cent of world elastomer usage is in the form of powders or granules (the distinction is unimportant here). To quote J.P. Berry, Director of RAPRA, "powdered rubber has not lived up to its earlier expectations" (5).

It is now reasonably clear that the comparative advantage that powdered elastomers have over materials in bale form is insufficient to induce a substantial change-over under present circumstances. Earlier talk of simple, low-cost processing has now met the reality that the present generation of powder processing equipment is as expensive and complex as are orthodox mixers, and although there are some savings in energy and labour costs these are often insufficient to offset the intrinsically higher cost of powdered forms. It is probably true that powdered elastomer processing may be economically advantageous in completely new installations specifically designed for the purpose, but there is no clear evidence to validate this claim.

Despite considerable doubts concerning the prospects for large-scale use of powdered elastomers in the next decade or so (accepting that they are of value in special situations), there has been some activity on a commercial scale with NR. There are two routes to powdered NR: by mechanical granulation of bale NR, or directly from latex in a producing country. The former route is operated on a modest scale (eg "custom granulators") and there are signs that interest in such materials is growing; current work has described technological details such as the influence of choice and level of partition agent on particle size (6). There is one commercial producer of material made directly from latex, in Malaysia using spray drying (7), and the fine powder produced by this means finds use in adhesives manufacture (fast dissolution) and in the production of very soft compounds (20 IRHD or lower). Recent work in Malaysia indicates that it may be possible to produce powdered NR direct from crumb NR (as produced during the "block rubber" process) without use of partition agents, by hardening the surfaces of the crumbs by bromination (8).

Substantial growth in use of powdered NR will occur only if the rubber industry as a whole moves towards general use of powdered elastomers, and as noted there are no real signs that this is about to occur. Assuming it does, is growth - in the case of NR - more likely to be via export from producing countries, or via granulation in consuming countries? And where will be the main centre of growth? Exporting powdered NR involves a substantial cost penalty (ca £50/tonne) consequent on the lower density compared with bales, and given the fact that there is likely to be greater investment in new factories in the NR producing countries than in the industrialized North, it may be speculated that if there is to be a major take-off in the use of powdered NR this is more likely to happen in the NR producing (or adjacent) countries than elsewhere.

#### Thermoplastic NR

Thermoplastic forms of NR (TPNR) can at present be produced experimentally in two ways: by blending NR with a polyolefin, by formation of graft copolymers. The two routes yield materials having different properties.

NR can readily be blended with a polyolefin in standard internal mixers, and the blends have properties very similar to those of all-synthetic thermoplastic blends (9). They are not revolutionary new types of material, but they do offer NR the opportunity of getting into certain specialized markets (eg automotive body components) which are inaccessible to normal vulcanized NR. Some commercial-scale production has been undertaken and full-scale development appears imminent.



The TPNR graft copolymers are scientifically much more interesting, though their commercial exploitation is not immediately in sight. They are akin to the SBS-type block copolymers, and can be produced on a laboratory scale by "capping" the chosen polymer (typically polystyrene) with a chemical group capable of reacting with NR during normal mixing (10). The route for polystyrene grafts (Figure 6) starts with (i) anionic polymerization of styrene followed by conversion to hydroxy-polystyrene, and (ii) formation of the capping reagent, typically an azodicarboxylate. Reaction of these produces capped polystyrene, and it is this material which can be smoothly grafted to NR under normal mixing conditions. This is a potentially versatile method, offering the chance that it may be possible to market a "graftable polymer" which would enable a rubber manufacturer to convert NR into TPNR as part of his normal processing operations. This, though, is for the future.

### Epoxidized NR

This is the latest of a long line of chemically-modified forms of NR, of particular interest for several reasons. The modification reaction (11) is a simple one-step process which can take place in latex; it uses relatively cheap chemicals (a fatty acid; hydrogen peroxide); the properties of epoxidized NR are distinctly attractive. These are dependent on the level of epoxidation which is easily controllable: they include increase in oil resistance and reduction in air permeability as the epoxidation level is raised (Figure 7) with the added advantage that, since the modified material remains strain-crystallizable, the tensile strength is unaffected by level of epoxidation. Pilot plant trials are now under way in Malaysia, and it may be surmised that epoxidized NR will fit well into NR's evolving role as a special-purpose material.

### VULCANIZATION AND COMPOUNDING

The main thrust of NR vulcanization research and development over the past two decades has been aimed at high performance, both during processing and in service. The need has been recognized to adapt NR to high-temperature curing processes (injection moulding, liquid salt bath curing, etc). Concerning service performance, although conventionally compounded NR is adequate for many requirements there is need for something better in the newer engineering and similar applications, and indeed in all those applications where service requirements have become more severe (more demanding service conditions and/or more stringent specifications).

"Efficient vulcanization" systems, dating back to the 1960s and now widely used, represent a valuable step in this direction: they provide improved thermal stability during processing plus substantial retention of many properties during high-temperature ageing (12).

Conceivably, though not certainly, these systems represent the performance limit for sulphur vulcanization. There is thus considerable interest in the technological merits of "urethane vulcanization". This is based on the use of the Novor range of vulcanizing chemicals (essentially condensation products of a nitroso-phenol with a di-isocyanate), used either on their own or in synergistic combination with sulphur (13). Urethane vulcanizates of NR (the precise nature of the crosslink is not known) have two important attributes: they have better reversion resistance than wholly sulphur-based vulcanizates and thus perform very well in high-temperature curing methods; their fatigue resistance actually increases during ageing, almost to the level of unaged sulphur vulcanizates (Figure 8).

Although urethane vulcanization is intrinsically costlier than sulphur vulcanization (typically 15 per cent more on compound cost) it has already attracted considerable attention and has started to establish some commercial use. Examples include engine mounts (heat resistance), couplings, bushes and suspensions (improved fatigue life after ageing), rollers (improved reversion resistance), linings for valves and tanks (resistance to hostile environments).

## APPLICATIONS

The point has been made that the NR market in developed countries is becoming sharply differentiated into tyres and specialized uses, particularly engineering applications.

The technical status of NR in tyres is unlikely to change during the decade. It will only be seriously affected if there were to come about major changes in the design and fabrication of tyres. This could occur if, for example, future environmental and energy constraints were to generate demand for new types of vehicle such as low-speed cars for urban use, possibly electrically-driven (5). Such vehicles might be better suited with tyres of performance lower than is the case today, and a trend in this direction could well favour use of injection-moulded or cast cordless tyres made from polyurethanes or thermoplastic elastomers. It is safe to assert that such a trend cannot become significant on any scale during this decade, during which period the tyre industry's share of the NR market may well increase to about three-quarters (see Figure 3).

Concerning non-tyre applications, the innately conservative image of the rubber industry generally may tend to convey the impression that the inventory of applications has changed little since the days of Thomas Hancock. It is true that few large-tonnage new uses for NR have emerged during this century (latex foam is one example), but it is equally true that, outside tyres and a few mainstream traditional uses (footwear, hose, belting), most other applications consume only about 5000 tonnes/year of NR (14). At this level there has been a substantial flow of new uses for NR.

An example of a developing sequence of new NR applications is the use of laminated steel/NR bearings in civil engineering, both to permit thermal movements in the decks of medium-span bridges (15) and to isolate buildings from adjacent vibrations eg from trains (16). Satisfactory experience with such applications has encouraged investigation of the use of NR bearings to isolate buildings from earthquake shock; preliminary indications are hopeful and development is under way (17). This might become an important market for NR in the late 1980s but it is too soon to say.

By definition, it is not possible to predict what kinds of new applications along these lines will come forward in the future. One thing is certain, they will arise primarily in response to "consumer pull": recognition by an industry, or an individual, of a problem - or an unfulfilled need - which may perhaps be helped with the use of NR. A nice and very recent example of this process (albeit modest in terms of NR tonnage) is the use of an NR bearing to provide a controlled extent of movement in a "standing frame" for handicapped people (18).

There are two main ways in which the NR industry seeks to assist this innovative flow: by providing potential users (often from outside the rubber industry and therefore with a different technical background) with appropriate information, and by extending the applicability of NR. The former need is met