

-7 FEB 1989

THE BRITISH SOCIETY OF RHEOLOGY

BULLETIN



1988, Vol. 31 No. 4

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ISSN-0045-3145

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THE BRITISH SOCIETY OF RHEOLOGY
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1988/89

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Council for 1988-89

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Seated: Dr A.Evans, Dr J.Ferguson, Mrs C.Moules, Mr R.Carter.

EDITORIAL

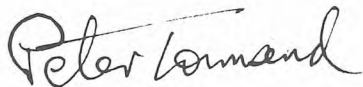
The time for photographs is here again. Those members of the new council who could be persuaded to make an appearance are to be found overleaf.

This issue contains a second tribute to G.V.Vinogradov - this time from David Tabor. David obviously has very fond memories of this great Russian scientist.

We are pleased also to publish in this issue a record of two important lectures. The first is the Scott Blair memorial lecture which charts the life of our founder member. The second is Anthony Pearson's Gold Medal address.

Ralph Oliver and Chris Petrie report back from Sydney - not just on academic matters but also a few words on, amongst other things, the marine life of the Great Barrier Reef!

It is some time now since I mentioned those ties but yes they are still available in blue and mid-grey, complete with BSR motif. The price is still only five pounds fifty pence and you should contact the secretary if you are interested. If you can't make up your mind as to which colour to choose, why not buy one of each?



Peter Townsend

G.V. VINOGRADOV

I was very saddened to learn from John Hutton's affectionate tribute that Georgi Vladimirovich Vinogradov has passed away. I knew him only from his occasional visits to London and Cambridge and from one marvellous Gordon Conference encounter, but I was completely won over by his charm and intelligence.

Vinogradov was born into a distinguished Russian family in 1910. He was educated at the Moscow Technological University and after the War embarked on research into the physical chemistry and rheology of lubricants and greases. In the sixties he moved into the field of polymer rheology at the Institute of Petrochemical Synthesis and it was here that he earned his outstanding reputation as an original and creative worker in the field of rheology. But apart from his professional achievements there were many aspects of his life that one could only learn from his own lips. I remember at dinner in Hall at Caius he once revealed to us that his father was Stalin's personal physician. During the last phase of Stalin's paranoia his father was sent to prison and accused of attempting to poison the Soviet leader. If Stalin had not died, so Vinogradov told us, his father would have been shot, his family sent into exile and the children dispersed into various orphanages. "But" added Vinogradov, with a perfectly straight face, "Stalin died". These three words exposed a private background which must have coloured much of Vinogradov's view of Soviet society. He was critical of the invasion of Czechoslovakia by Soviet troops in the days of the Dubcek "spring", and sometimes expressed rather quizzical views about other aspects of Soviet activities. On a few occasions I would broach some political issue on which he knew I had strong feelings: he would then stop speaking in English and speak in Russian in carefully chosen words, ending with the phrase "More I will not say".

Vinogradov served in the Soviet Tank Corps throughout World War II in some of the bitterest and coldest phases of the War. He told us that the amount of fuel his tank consumed was only equalled by the amount of alcohol he imbibed to keep up his temperature and his spirits. After the War he became almost a total tee-totaller. We could never persuade him to drink at meals or functions.

I used to write to him, with some labour, in Russian and he would reply in either language. I treasure in particular the Russian letter he sent me after I had congratulated him on the award of the Tribology Gold Medal: it expressed great warmth and friendliness. I am also very glad that I was able to communicate one of his last papers to the Proceedings of the Royal Society on jetting and the generation of static electricity during the flow of viscoelastic fluids. There was an extremely long delay in his response to the referees' reports and I was able to persuade him that these were not negative criticisms and that only a trifling amount of textual

change was required. It appeared soon after in P.R.S. A409, 249-270 (1987) entitled "The Static Electrification of linear flexible-chain polymers extruded through ducts above the glass transition temperature".

Vinogradov was devoted to his motherland: he was a true Russian in the sense portrayed by Yevtushenko in his poem "Babi Yaar". He was marvellous company. We are all the poorer for his passing.

David Tabor

THE SCOTT BLAIR MEMORIAL LECTURE

My President, ladies and gentlemen -

I am honoured, and deeply grateful, for the British Society of Rheology's invitation to deliver the memorial lecture to my good friend the late Dr. George William Scott Blair.

I first made his acquaintance in the mid 1950's when I accompanied Armand de Waele who was then Director of Research to Gestetner Ltd., where I was employed, to meetings of the society. Our acquaintance continued in a casual way until around 1960 when I established a closer contact with his department at the National Institute for Research in Dairying, at Shinfield, following my move to the Unilever organisation. Curiously, the reason for this contact was not of a rheological nature but to examine the possibility of adapting a spectroturbidimetric technique developed by one of his scientific staff, Dr. J.D.S. Goulden, to determination of the fat content of homogenised ice cream mixes. This led to closer acquaintance and, subsequently, to frequent meetings to discuss food rheology and psychorheology. Eventually, this resulted in his being appointed a consultant in rheology to my laboratory at Unilever Research, Welwyn. Following his retirement in 1967 my wife and I enjoyed the pleasure of visits to the Scott Blair's charming cottage by the river in the village of Iffley, Oxford. During such visits discussions on matters rheological often developed. George William Scott Blair was born in Weybridge in 1902. His early education was received at Charterhouse School, and then he proceeded to Trinity College, Oxford University, to read Chemistry.

During the latter period his tutor was the later internationally renowned chemist Sir Cyril Hinshelwood. His first paper, published from Trinity College, was "Periodic Precipitation in Dilute Gelation Gels".

In 1924 he joined the Research Department of Henry Simon Ltd., Manchester, from where he published his first papers in rheology. This was a series of four papers on the rheological properties of flour-water suspensions.

1927 saw a move to the Rothamstead Experiment Station, where he remained for 10 years. It was from here that he wrote, in conjunction with R.K. Schofield, a series of four classic papers on dough rheology which were published in the Proceedings of the Royal Society of London between 1932 and 1937. The title of this series of papers was "The Relationship Between Viscosity, Elastic and Plastic Strength of Soft Materials as Illustrated by Some Mechanical Properties of Flour Doughs". It represents one of the earliest attempts to study the fundamental rheological properties of baker's dough, and these publications are still quoted frequently to this day. During this period Scott Blair published extensively on the rheological properties of soil and clay pastes.

During 1929-30 he spent a year in the USA working with Professor W.D. Bancroft at Cornell University on the rheology of ceramic clays.

He was also able, during this time, to make the acquaintance of Professor E.C. Bingham and attend the meeting in Washington D.C. in December 1929 at which the American Society of Rheology was established.

1937 brought a move from Rothamstead to the National Institute for Research in Dairying (NIRD), Shinfield, Reading, which is now the AFRC Food Research Institute, Reading, to take charge of the Chemistry Department. The activities and interests of this department then grew to such an extent that eventually it was split into two departments, Chemistry and Physics, and Scott Blair became head of Physics.

The 30 years that were spent at NIRD were the most productive in terms of research activity and publications. His department quickly established an international reputation and attracted scientists from, and developed contacts with, many different countries. Although the main interest was study of the rheological properties of dairy products such as milk, cream and natural cheeses, he was also responsible for pioneering the application of psychophysics to the subjective evaluation of food texture. This is now known as psycho-rheology. In addition, he extended studies of rheological changes in bovine cervical mucus, which led to a reliable test for detecting pregnancy in cows, to other materials of biological interest, especially blood, and thus actively pioneered the science of haemorheology. The interest in psychophysics arose from contacts in the late 1930's with David Katz, a distinguished psychologist who had to leave Germany following Hitler's ascent to power, and an awareness of Professor J.C. Steven's psychophysical studies at Harvard University. This led to Scott Blair considering the feasibility of developing an "imitative" rheological test, which would simulate the force conditions to which a solid food is subjected when its firmness is assessed by squeezing between the fingers, for example, and so be capable of predicting this subjective evaluation without having to resort to the latter type of test. Interest in this application of rheology has increased substantially over the past 25 years and there are now many laboratories, especially here and in the USA, which are actively working in this field. Scott Blair's initial studies in biorheology have provided a comparable stimulus to present studies in haemorheology.

During Scott Blair's last years at NIRD his research on blood rheology was partially funded by the U.S. National Institute of Health and also by the British Heart Foundation.

Although he was a departmental head, and therefore responsible for all administrative problems relating to his department, Scott Blair still found time to work at the bench and he undoubtedly enjoyed doing this. For much of his time at NIRD there was not much rheological equipment available commercially, and certainly not the sophisticated, computer controlled, rheometers which so many of us are accustomed to use nowadays. Consequently, he had to design relatively simple equipment, by present day standards, which was built in the NIRD workshop. The level of research output achieved with such equipment was truly remarkable. Many scientists from other countries were introduced to rheology by working with Scott Blair at the bench during this period. One of these scientists,

Dr. W. Tusynski from Warsaw, Poland, gratefully acknowledged the benefits of time spent in Scott Blair's laboratory in the "Festschrift" to Scott Blair on his 70th birthday (J. Texture Studies 4, 13, 1973) by the following tribute "Dr. Scott Blair has always regarded newcomers interested in rheology as part of his family. His enthusiasm, dedication and noblesse d'esprit are boundless".

During this time Scott Blair did not lose sight of the requirements of the dairy industry for routine simple quality control instruments and he was able to design instruments to assist cheese graders in their duties.

Following his retirement in 1967 Scott Blair continued to work on blood rheology at the Oxford Haemophilia Centre until failing sight compelled him to withdraw from this research, which he did most reluctantly. His last published paper, which was from this centre, was "Blood Viscosity and Multiple Sclerosis".

Until his demise in 1987 scientists from many countries visited the Scott Blairs at their retirement home and it was through these contacts, and friends who voluntarily read articles in journals to him, that he was able to maintain an awareness of developments in rheology.

Scott Blair's research activities over a period of nearly a half century resulted in the publication of a total of 284 original and review papers. The original papers can be classified under 6 different headings, as shown on Table 1. Three of these viz. dough rheology, dairy products rheology and psychorheology, are aspects of the general theme of food rheology and have provided the foundations on which later generations of food rheologists have built and expanded our knowledge. Other rheologists also have much to be grateful for because of his pioneering work on the general theory of flow and in blood rheology. The breadth and diversity of Scott Blair's contributions to rheology are best summarised by another tribute paid to him by Professor A.L. Copley on his 70th birthday in the "Festschrift" issue of the Journal of Texture Studies (4, 10, 1974) - ".... since Scott Blair has worked in more fields of rheology than anyone else, George Scott Blair can be considered as the only rheologist who has done pioneering work in so many fields".

Not to be satisfied with his extraordinary large output of published papers Scott Blair also wrote 4 books, and co-authored a fifth with the late Professor Markus Reiner, (Table 2) in which he reviewed his ideas and views on various branches of rheology. His first book, "A Survey of General and Applied Rheology", was first published in 1943 and reprinted as a second edition in 1949. It was an important standard text on rheology for a very long time and especially during the period when not many books on rheology were available.

Scott Blair was a scientist of the "old school" category with a traditional education along classical lines, in contrast to modern practice in school education. This was reflected in the quality and fluency of his writing, his delivery when lecturing, and also in his proficiency in several languages. When he received an invitation to contribute a paper to a journal published in another country he would willingly accept and write it in the appropriate language when he was able to do so.

Because of the international recognition which he received for his work he was invited to lecture in many countries, including France, Germany, Holland, Israel, Switzerland, Portugal, Sweden and the USA. Many awards and honours were bestowed on him, as shown in Table 3. It will be of particular interest to this assembly that Scott Blair was a founder member of this society and its President from 1949 to 1951. He was also a member of the French and German societies of rheology. I enjoyed the pleasure of attending two meetings of the French Society in his company, although my understanding of the presentations at those meetings was grossly inferior to his.

Scott Blair was associated with the First and Second Congresses on Rheology. He was a founder co-editor of Biochemistry with Professor A.L. Copley and continued in this capacity until failing eyesight compelled him to resign. In 1968 he was approached by Reidels, Dordrecht, Holland, with the view to his becoming the editor of a proposed new journal devoted to food rheology. He felt compelled to decline the invitation owing to the amount of time he was devoting already to Biorheology. Nevertheless, he intimated that he would be willing to join the editorial board provided that Dr. Alina S. Szczesnick of the General Foods Research Centre, N.Y., U.S.A., and I agreed to assume the responsibility of co-editors-in-chief. This we did, and Scott Blair remained a member of the editorial board of the Journal of Texture Studies until his untimely death in 1987.

Scott Blair was a person with great faith in the goodness of the individual. Never did I hear him speak ill of anyone or lapse into a bad temper. His last years were dogged by ill health, due initially to his failing eyesight and ultimately to physical infirmity, but he retained his outward composure. Throughout these years, as indeed throughout all his professional life, he received strong support and encouragement from his wife, Rita, who honours us with her presence here today.

In a tribute to George William Scott Blair in the "Festschrift" issue of the Journal of Texture Studies (4, 3, 1973) Dr. Alina S. Szczesniak and I quoted a phrase from Robert Browning's poem "Rabbi Ben Ezra". I would like to close with another few lines from that poem which I think helps indicate the debt of gratitude which rheologists owe him for his life's work.

" Therefore I summon age
To grant youth's heritage
Life's struggle having so far reached its terms
Thence shall I pass, approved"

TABLE 1

**G.W. Scott Blair: Branches of Rheology, and
Main Themes, Relating to Published Original Work**

1. GENERAL RHEOLOGY

Flow of suspensions through narrow tubes. Influence of proximity of solid wall on rheological properties of viscous and plastic materials. Theory of quasi-properties and its applications. Firmness of soft materials based on Nutting's equation.

2. SOIL RHEOLOGY

Flow of clay pastes and soils. Sigma effect.

3. DOUGH RHEOLOGY

Rheology of flour doughs; relationship between elasticity, viscosity and plastic strength; influence on bread making properties.

4. DAIRY PRODUCT RHEOLOGY

Rheology of milk, milk gels, cream, natural cheese. Design of quality control instrumentation for evaluating the consistency of natural cheese.

5. PSYCHORHEOLOGY

Subjective assessment of elastic and plastic properties of soft bodies. Firmness evaluation in soft materials. Psychophysics in the dairy and bread-making industries.

6. BIORHEOLOGY

Milk; bovine cervical mucus; blood. Rheology of blood in living and artificial capillaries. Coagulation of milk and blood. Blood viscosity in multiple sclerosis.

TABLE 2

G.W. Scott Blair: Books Authored and Co-authored**1. 'SURVEY OF GENERAL AND APPLIED RHEOLOGY' (1943)**

Pitman. Reprinted 1945; 2nd Edition 1949

2. 'MEASUREMENTS OF MIND AND MATTER (1950)

Dobson

3. 'AGRICULTURAL RHEOLOGY' (1957)

Jointly with Markus Reiner, Routledge and Kegan Paul

4. 'ELEMENTARY RHEOLOGY' (1969)

Academic Press

5. 'AN INTRODUCTION TO BIORHEOLOGY (1974)

Elsevier

TABLE 3

G.W. Scott Blair

Academic Qualifications	M.A. (Oxford), Ph.D., D.Sc (London)
Professional Qualifications	Fellow of the Royal Society of Chemistry Fellow of the Institute of Physics Member of the British Society of Rheology Member, Groupe Francais de Rheologie Member, Deutsche Rheologische Gesellschaft
Activities and Honours	Rockefeller Fellowship 1929-30 Founder member, and President, British Society of Rheology 1949-51 Secretary, 2nd International Congress on Rheology, Oxford 1953 Herbert Freundlich medal of the Deutsche Rheologische Gesellschaft Poiseuille gold medal of the International Society of Haemorheology 1969 Gold medal of the British Society of Rheology 1970 Co-editor, Biorheology Member of editorial board, Journal of Texture Studies 1969-87



**Professor Sherman presents flowers to Mrs Potten
at the Scott Blair Memorial Lecture.**

RHEOLOGY AND TRANSPORT PHENOMENA

by J.R.A.Pearson

INTRODUCTION

As is customary, I shall use this opportunity to look back on my own involvement in rheology, as well as to make some general comments on the subject of applied rheology. I think of myself as an engineering scientist, rather than as a mathematician or practicing engineer. My stimulus has come from seeking answers to engineering problems, and it is probably an accident of my upbringing that I almost always attempt to create a mathematical model to do so. Inevitably therefore, I formalise and generalise most problems in the process - the characteristic mark of an academic I suppose.

An undergraduate study of Pure Mathematics and Natural Philosophy (with a foray into Electrical Engineering) led me to Fluid Mechanics. At that time the fluids studied were conventionally ideal; viscous effects were the speciality of the initiated; the majority of academics regarded non-Newtonian and elasto-viscous fluids with the same degree of suspicion as chemists regarded polymers, i.e. as not suitable for scientific investigation and best left to empirical technologists. Employment in the chemical industry, then waxing fat on the great commercial success of the new thermoplastics, persuaded me otherwise: there were a host of important problems that could not be solved by the existing methods of fluid mechanics, and which cried out to be treated in a more profound fashion. Fortunately, I came across, by accident, J G Oldroyd's classic 1950 paper: this together with his earlier papers set out all the required formalism, and so sealed my commitment to studying the flow of complex fluids.

However, I realised that there was much more to solving engineering problems in the process industries than understanding the rheological characteristics of the materials involved. As a result, I found myself working happily in Departments of Chemical Engineering for over twenty years. More recently, I have been concerned with process problems in the oil industry, and have found the environment equally interesting and stimulating. This is a good moment to pay tribute to the stimulus and encouragement I have had from many students and colleagues all around the world, most notably those with whom I have published joint papers: I am very conscious of the profound influence they have had on my career.

Definitions are important to a mathematician, and were there time I might attempt to distinguish between Rheology, Continuum Mechanics, Micromechanics and constitutive equations; between formal theories and applications; between the approaches of mathematicians, physicists, chemists and engineers; between different classes of materials. But this suggests fragmentation and specialisation, which is the reverse of what I wish to discuss here. My concern has been to combine the best of all these activities and approaches with the chemical engineer's notion of Unit Operations: this means breaking down complex processes into a set of simpler ones, with relatively clear interactions between them. Individual sub-processes may have to be examined in great detail; yet the results of these detailed studies have to be

expressed in simpler (averaged or integrated) terms in order that the interactions between the sub-processes can be effectively subsumed in an overall process model. Study of the latter model then shows which are the key unit operations, and hence directs attention to the critical parts of the process.

Curiously, I have noticed that the same approach has actually been useful, indeed necessary, in tackling many apparently purely rheological problems. Even in the simplest case, that of measuring simple shear viscosity, the flow in almost all forms of apparatus requires careful analysis for a direct absolute interpretation to be possible. In a cone-and-plate viscometer, the classic device for providing a truly affine deformation, edge effects have to be considered, particularly since secondary flows can occur, introducing particle migration in suspensions, and hence fluid inhomogeneities; in a capillary viscometer, entry and exit effects arise, particularly for an elastico-viscous fluid. In both of these geometries, it is convenient to analyse various regions of the flow field separately and to derive order-of-magnitude corrections to account for flow disturbances in the non-uniform regions. In the microrheological field, the Doi-Edwards theory for predicting the constitutive behaviour of polymer melts relies on the separate treatment of processes having very different time scales, thus arriving at the notion of reptation.

Process operations usually involve and are determined by the controlled flow of mass, momentum and energy, i.e. by transport phenomena. Chemical reaction or phase changes (including separation or mixing) often take place simultaneously with the flow processes. The chemical engineer's task is to achieve the desired changes with the required degree of control. Experience has shown that rheological properties often play a critical role in process dynamics.

My own work has concentrated on modelling the mechanics of polymer melt processing, i.e. on forming operations for thermoplastics and rubbers. It has proved necessary to seek approximations for

- * flow geometry - simplified general channel or sheet description
- * melt rheology - relevant constitutive approximation for given flow field
- * equations of heat, momentum and mass transfer
- * solutions of sets of algebraic, differential and integro-differential equations

A powerful means of obtaining such approximations is to use non-dimensional formulations of the problem, and to note the values taken in typical cases by the dimensionless groups that arise naturally. This often allows perturbation and asymptotic techniques to be used: for engineering purposes only the leading terms are needed. A veritable cornucopia of these dimensionless numbers arises: Reynolds, Froude, Weber, Weissenberg, Deborah, Brinkman, Peclet, Gatz, Nahme-Griffith, Biot, Nusselt, Fourier and others besides.

A common practical difficulty in such processes - extrusion, film blowing, fibre spinning, calendering or injection moulding - is that the desired symmetry of the expected flow is lost under certain conditions. Unsteadinesses and/or non-uniformities arise; in a processor's terms, control of the process is lost. Analysis shows that they are the result of non-linear dynamical behaviour. Fairly simple explanations can be given in some cases, e.g. fingering in planar die flow with cold walls, or ribbing in coating flows, but others, such as extrudate flow instability remain relatively obscure in origin (almost certainly because there is no unique cause). Detailed predictions (of bifurcation points) still rely on linearised perturbation analysis, though extension of the solutions into the fully non-linear regime is rarely easy. As in the case of breakdown to inertial turbulence, some phenomena like extrudate flow instability may be the result of repeated bifurcations (and best described as chaotic).

ROLE OF LENGTH AND TIME SCALES

Experience of tackling problems involving slurries, emulsions, polymer solutions and gels (for drag reduction), granular media, soft rocks and multi-phase flow has shown that helpful classification of behaviour can come from a careful analysis of relevant length and time scales. All of continuum mechanics depends on suitably chosen averages (time, space or ensemble). This allows the details of complex mechanical behaviour at one scale to be subsumed in terms of an approximate constitutive law or an interfacial boundary condition at a larger scale. Natural phenomena (part of geoscience) represent the largest scales of interest, large constructional projects (dams, tunnels, harbours) the next. Engineering process scales overlap laboratory ones, though it is usually assumed that laboratory experiments represent simpler, more readily controlled processes than industrial ones. In the table below I have attempted a simple classification covering the rheologist's main interests.

Molecular effects	0.1 - 100 nm	Microscale	$\ll 1$
Particulate effects	100 nm - 100 μ m	Mesoscale	$O(1)$
Macroscopic effects	100 μ m - 100mm	Macroscale	$\gg 1$

The interesting point to note is that the three scales do not overlap, yet each covers 3 orders of magnitude. Furthermore, there is room for larger-scale effects: anything over 100mm can be regarded as a supra-rheological (or engineering) length scale. For simple molecular fluids, particulate effects are not present, and so precise constitutive laws (rheological equations of state) can be expected to hold for all scales above at most 1 μ m. For slurries, gels and emulsions, constitutive relations can safely be applied for scales over about 1 mm. For bubbly gas/water flows, large scale movements of granular media (e.g. in hoppers or as bed loads in rivers) or

deformations of rock masses, the minimum length scales over which constitutive behaviour may be approximated can be up to 100mm.

Examples of now familiar techniques in each of these ranges can be given. At the rheologist's microscale, molecular dynamical calculations are used to provide direct predictions of three-dimensional transport coefficients (viscosity, thermal conductivity and mass diffusivity) of homogeneous simple molecular fluids. Similar but less accurate calculations are done for polymeric fluids; here the full complexity of visco-elastic behaviour is involved, while mass and heat transport coefficients can be strongly influenced by realistic deformation rates. This can be explained most simply in terms of the time scales characterising the molecular motions and the flows respectively. Non-linear behaviour arises when these overlap. Brownian motions with short time scales are however an important characteristic of all molecular theories.

It is also noteworthy of these theories and calculations that the deformation rates are taken to be as uniform (affine) and steady as possible; although a continuum length scale far greater than that of molecular motions is implicit, constitutive laws are derived from consideration of affine deformations only, even for the individual long-chain polymers in most of the quasi-analytic theories. Despite the power of large-scale computers, it will probably be a long time before direct calculation shows whether large and significant departures from affine behaviour occur on a sub-constitutive scale for polymeric systems. For inertia-free systems, overlap of material time scales with those characterising the rate of change of deformation rates is possible, as is essential if creep and relaxation phenomena are to be modelled.

Special arguments and techniques have to be developed to describe and predict material behaviour at "interfaces" between pure phases for which three-dimensional continuum relations are appropriate (cf. Gibbs' theory for surface tension). These two-dimensional continuum approximations are usually called boundary conditions in continuum mechanics: it is important to realise that in many cases they describe molecular effects having length and time scales similar to those of the pure phase. The confusion surrounding the familiar no-slip condition is an example which has interested me over the years. A free-slip (no wall shear stress) condition at the microscale can become, because of the presence of asperities at the interface on the mesoscale, an effective no-slip condition at the macroscale. Similar but more elaborate arguments apply when considering wall boundary conditions for polymer melts or the movement of contact lines. Another example can be taken from two-phase flow in porous media: the Buckley-Leverett approximation, involving a sharp discontinuity in the individual phase saturations during co-current flow, is a way of embedding most of the diffusive effects of capillarity within an interface.

At the particulate level (the rheologist's mesoscale), the constitutive relations governing the behaviour of the basic components of the mixture (by definition multi-phase) will be those already defined from molecular considerations for the pure phases together with the relevant boundary and line conditions. Provided that the macroscopic effects are on a much larger scale, particle dynamical calculations

entirely analogous to molecular dynamical calculations can then be carried out to provide supra-particulate constitutive relations and boundary conditions. This is an area of growing interest and is doing for suspensions (of spheres, plates and rods) and emulsions (of deformable drops) what has already been done for polymer fluids.

A wider range of possible physically distinct inter-particle forces leads to more obvious dynamical complexity, particularly in concentrated systems. Yield stress (to the extent that the latter can ever exist above absolute zero temperature - it implies an upper limit to time scales of interest), thixotropic effects on a time scale very large compared with those of the deformation rate, and shear dilatation (involving local mass transport between phases) can all be investigated and characterised. Brownian motion is often neglected at this level, because its direct effect on the particulate system now has a time scale large (as opposed to small in the molecular dynamical case) compared to the deformation-rate time scale. Mixing (or demixing) effects are driven by the flow. There is already evidence from large computer simulations of local structure development (strings or sheets of particles) on a range of length and time scales not directly predictable from the relations governing individual particle dynamics. It therefore remains an open question whether the total separation of constitutive laws from the overall length and time scales of the global motion is ever more than a convenient approximation for specific calculations of entire flows.

In the table above, we see that molecular constitutive laws apply at the mesoscale, while particulate constitutive laws apply only at the macroscale. For the applied rheologist, the relevant classification is better described by a second table.

Particulate effects	Microscale	$\ll 1$
Constitutive law	Mesoscale	$O(1)$
Process dynamics	Macroscale	$\gg 1$

Absolute scales are not given because they depend on the process and material involved. They need not differ by more than one or two orders of magnitude.

Most of the comments given above refer to modelling of flowing (or deforming) materials. Much the same comments can be made when discussing experimental observations. Clearly observations are very difficult to make on a molecular scale, and most molecular motions are inferred rather than observed in experiments. However detailed information on microscopic (optical) scales is often available, and so theories based on particle dynamics can then be checked directly and in detail against experiment. Gross continuum measurements can also be checked against either theoretical constitutive relations in cases of uniform flow or against solutions of the relevant equations of motion, using the same constitutive relations, in more complex flows.

ENGINEERING APPLICATIONS

For engineering calculations, it is often of little importance whether the constitutive relations used come from modelling at a smaller length scale or from experiment (therefore empirical in the usual sense of the term) at the mesoscale in the above table. The important proviso is that the experiments used be sufficiently general to uncover all the material behaviour needed to describe the full flow behaviour. Indeed, most theories contain within them constants that are not evaluated theoretically, but are derived from experiment. There are many cases where the engineer is not interested in deformations and deformation rates as such, but in the consequences they have for temperature and concentration within the flow field.

This raises the interesting question of how (and by whom) theories and experiments obtained at the micro- and mesoscales are carried over to provide useful answers (to engineering problems) at the macroscale. Within well-developed areas of industrial activity, such as traditional polymer melt processing, there is now a continuous spectrum of interest at academic establishments, so that elaborate models and simulations of industrial processes have been carefully compared with a range of experimental observations on real processing equipment. The validity and utility of simpler approximations has been investigated at each level, so that design and control techniques can in principle be devised starting from fundamental properties. This state has taken fifty years to achieve. It is consistent with the view that we can teach engineers what they need to know only for mature industries. There is then a danger that work on polymer melt systems will be overdone, particularly in terms of rheological modelling.

The more difficult challenge is to provide means of making rapid use of fundamental scientific knowledge when faced with new opportunities and new problems at an engineering level, and of ensuring the necessary extension of our empirical knowledge to deal these unusual situations. My own view is that it requires a cultural change at many of our universities, where too much teaching at the undergraduate level looks backwards; to the proper and necessary instruction in fundamental science and some exemplary engineering analysis should be added a more open approach to problem solving. This should contain a heuristic experimental element, that of the practical inventor. It should also introduce mathematical ideas and techniques in a more practical context. Some ideas on the this last issue are discussed below.

ROLE OF MATHEMATICS

Every worker has his or her definition of what constitutes mathematics as opposed to theoretical physics, chemistry or engineering; those working in mechanics find it more difficult to see a clear distinction, perhaps because studies in mechanics have driven many seminal developments in pure mathematics. Formal mechanics (or classical physics) is based on abstraction just as is mathematics, and avoids any of the taxonomic departures of chemistry (e.g. the periodic table) or physics (e.g. particle physics or stellar astronomy). This does not mean that it is so idealised that it has

little to do with real materials or processes. On the contrary, the rigorous requirements of modern continuum mechanics are essential if progress is to be made in modelling and hence predicting the outcome of real engineering processes.

Its first role is in specifying unambiguously the averages that are implied by any of the thermodynamic or kinematic variables used by engineers. These issues are of great importance in some problems, such as multi-phase flow through porous media, particularly when irreversible (entropic) changes are occurring - who in this audience has not met the difficulty of defining pressure and stress in a flowing "incompressible" polymer melt!

A second is to ensure that constitutive relations are properly invariant and thermodynamically acceptable. This is intimately connected with the three-dimensionality of space and the "arrow" of time. The inevitable introduction of vector and tensor analysis at this stage sadly banished such issues to the outer limits of physics and engineering, and even of applied mathematics, in many institutions. (I am glad to report encouraging developments since I was a student.) Combination of these constitutive relations with similarly invariant laws of mechanics (the conservation laws of classical physics) provides formal mathematical models (governing equations) for continuum processes. My own view is that however satisfactory any one person's understanding is of a given flow process, transmission of that understanding in a reliable, convincing and logical manner to the whole community of scientists and engineers is not possible without using the relevant formal model as a starting point.

The next stage is to translate engineering judgement into an initially heuristic (but finally formally-justified) approximation of the governing equations. This rarely involves the calculus or more advanced functional analysis. As explained earlier, it is achieved primarily by making the governing equations non-dimensional, using mass, length and time scales appropriate to the problem under consideration. The aim is to ensure that all the dimensionless variables (unknowns) are of order one in at least part of the flow field, and are nowhere large compared with one. To do this more than one length, velocity or time scale may be required. (These can arise from different operating parameters or geometrical lengths in the process equipment, or from various constants in the constitutive relations.) This introduces quite naturally a series of dimensionless groups usually as linear factors premultiplying certain terms in the now non-dimensionalised governing equations. Some of these may be simple ratios of length or time scales. At this stage, values for the parameters describing the problem will give numerical values for the various dimensionless groups. If some of these are either very small or very large, a simple deduction is that the terms they multiply are either negligible or dominant in the equation concerned, and a correspondingly simplified form of the governing equations is obtained.

Only at this stage does mathematics begin to fulfil its conventional role: that of obtaining detailed quantified (analytical or numerical) solutions to the governing equations. Even at this stage experience of solving related flow problems may be necessary, because of the often singular nature of the asymptotic solutions that are

characteristic of the full non-dimensional governing equations. This means that further intrinsic length or time scales arise from within the flow itself (typically from boundary layers) demanding separate treatment for the relevant regions of the flow field, with implied matching or patching procedures. Even for steady Newtonian fluid flow, multiple scalings are encountered. For flows involving coupled transport processes with reaction, a lifetime's study may be required to cover all situations of interest.

It is almost axiomatic that initial solutions are sought with the maximum of symmetry and steadiness; these however may not be stable to small disturbances, and it is therefore part of the full problem to carry out such analyses mathematically, particularly when the symmetrical/steady solutions are not unique. In certain cases - disappointingly frequent when tackling real flows causing engineering problems - the flows exhibit 'chaotic' behaviour, and so the whole process of obtaining engineering approximations from a careful and apparently rational separation of constitutive and process scales fails. One is forced into seeking empirical correlations based on gross engineering variables, such as total flow rates and mean pressures or temperatures at inlet and exit. The exact gives way to the pragmatic.

CONCLUSIONS

The audience will have noted that I have interspersed my talk with remarks that relate to the management of R&D, and to the skills that are needed to make timely and economical use of trained manpower. I summarise and sharpen these remarks in the following three paragraphs.

The applied rheologist must keep pragmatic engineering considerations in mind, and must seek to form a bridge between the practicing engineer, weary of inadequate though still elaborate theoretical solutions, and the dedicated specialist, ever willing to master still more precise and profound models of rheological behaviour.

The ability to act in such a bridging role depends on an understanding of the needs of the former and the limitations of the latter. It is a rare ability in my limited experience, not least because of the frequent belief among engineers and scientists that the bridge cannot usefully be made.

A lack of awareness of the importance of and difficulties surrounding this bridging role (equally necessary in many other technical contexts) is at the heart of the current world-wide inability to translate notable scientific achievements into valuable technological improvements and advances. Persuading an ever greater number of people to opt for science and technology - which remains the aim of most national governments - will be of no avail if the polarisation I have mentioned above is thereby deepened. There is a real danger of that happening: we have our own two-cultures problem, which in a way is far more serious today than that of which C.P.Snow wrote.



THE TENTH INTERNATIONAL CONGRESS ON RHEOLOGY

Sydney - August 14-19 1988

The visitor to Sydney soon understands the meaning of the airline phrase "long haul". However, the welcome we received and the most friendly attitude of the locals in the shops, on buses and on the campus made the trip worthwhile. Most people stayed in the St. John's and the Sancta Sophia Colleges, or in the Camperdown Travelodge across the road. The colleges were quite cold in the evenings - buildings of this type do not usually have central heating - but modern fan heaters were standard issue to the residents. As the sun came up the day warmed rapidly and sweaters were peeled off before mid-day.

A fifteen minute walk across a lovely campus, to the accompaniment of sub-tropical birdsong, took us to the Great Hall for Professor Bird's opening lecture, the rest of the meeting took place in the Chemistry building. The organisation was tidy and efficient, with five simultaneous sessions, but a minor criticism was that the "fifth" lecture theatre (even more spartan than the rest) was in a separate building and tended to attract correspondingly reduced audiences.

Most days started with an invited lecture, sessions of other papers before and after coffee, a little over an hour for lunch, an invited lecture at 2.00 p.m. and two more sessions separated by a tea-break. This kept delegates busy until close to 6.00 p.m., although by the fifth day both audiences and speakers were a little hard to find. It was disappointing, to say the least, that a significant number of authors did not attend the Congress to present papers which were in the programme.

The invited lectures began with a masterly display by Professor R.B. Bird in the plenary lecture which he constructed as a tribute to "The Two JGs". Since Bob Bird's rheological achievements have straddled both the continuum and molecular approaches to our subject, who could better have traced the important fundamental contributions of a founding father of continuum mechanics, J.G. Oldroyd, and a founding father of statistical mechanics, J.G. Kirkwood. There was meat in this lecture for the seasoned conference-goer and digestible information for the novice. The presentation was colourful and appropriate - drawing on the stars of the Australian flag for the inspiration of the layout of his slides. Did anyone answer the question as to why one of the stars has only five points?

The subjects discussed in the contributed papers showed strong support for "theory" (including Fluid Mechanics and Numerical Methods) with 63 papers, followed by "polymers" with 34 papers. Rheometry (26), industrial rheology (25), suspensions (22) and polymer solutions (22) are clearly topics of sustained interest. Composites and solids accounted for 18 presentations, with a further 18 on blood rheology and biorheology. What has happened to "food" and "pharmaceutical" rheology? Finally, 7 papers were devoted to a relatively new topic, liquid crystals.

Excellent tours were organised which were perhaps the highlight of the meeting; wives and friends were busily occupied each day of the week. The evening cruise of Sydney Harbour was attended by all and was the perfect way to see Double Bay, Rushcutters Bay, the Bridge and the Opera House, with night falling and lights flickering on all around. A quick drink on the upper deck was followed by dinner below with waitress service. Likewise, the afternoon visit to Koala Park on another lovely day was enjoyed by all, the little bears being sleepy most of the time, the kangaroos eating the bags as well as the popcorn and emus snatching food in the manner of a certain television bird: the style is real, not affected! This was followed by tea in a yachting harbour and a tour of the northern beaches. Another tour was to the south coast, with brunch in the Royal National Park, but the most spectacular day tour was to the Blue Mountains. This range, about fifty miles west of Sydney, represented a major problem for early explorers in their search for farmland in the interior. Surprisingly, the valleys are still impenetrable but the wide, flat ridges which now carry the road represented a slowly climbing route for the explorers to follow, the bush being less dense. Thus the (seemingly) ordinary town of Katoomba is at the height of Snowdon and is surrounded by magnificent cliffs - a "lost world" in the midst of civilisation. The original explorers finally reached the western edge of the plateau at Mount York and were able to find a difficult track down into the fertile valley beyond.

The afternoon tour of the Opera House was best followed by a live evening visit; the rather bland Richard Strauss contrasting with the powerful cacophony of Stravinsky's "Rites of Spring". The auditorium is a masterpiece of wood finishes, with good acoustics but the bars and coffee areas are impressive rather than comfortable. Broad, ascending, curving stairs surround the main auditorium and we finally discovered a carpeted area during the second interval!

Returning to the scientific programme. Miss Cathey, Mikkelson and Macosko presented three papers dealing with a new extensional rheometer, based on opposed jets placed a short distance apart. This seems capable of measuring extensional viscosity for Newtonian liquids of shear viscosity down to 2 poise, with a range of extensional strain rates (for different liquids) between 1 and 10^4 reciprocal seconds. Discussion was lively on these papers and the technique looks promising.

Cogswell's talk on the flow of structural composite materials pinpointed an area which is certain to grow in importance as "tailored" composite structures move from aerospace applications to cars and commoner items. Other papers in this field dealt with aging (Simha), anelastic and plastic response (Legrand) and with adhesion (Klein).

Professor Pipkin relaxed us by announcing that the problem he wanted to discuss, viscoelastic pulse propagation, had been settled 30 years ago. He then explained that those who had settled the problem were wrong for the excellent reason that their results did not agree with experimental observation. The resolution of this led through some nice mathematics to clearly understandable ideas about waves in dispersive media.

Professor Fuller gave a most illuminating description of optical rheometry, explaining clearly the different information about (polymer) molecular configuration which is yielded by measurement of birefringence and dichroism. Application to liquid crystals and colloidal systems went further than simple rheometry and illustrated the relevance of these tools to furthering our understanding at a microscopic and molecular level. Professor Pearson's discussion of oil wells dealt with a number of interesting practical problems and their solution. It left the listener with a few puzzles to resolve afterwards; not, one feels, because of a reluctance to reveal trade secrets but rather because there are some problems requiring very careful thought based on a sound grasp of basic mechanics.

Professor Crochet's presentation must be mentioned. The sessions on numerical simulation of fluid dynamical problems were always lively and this review perhaps allowed the Belgian view an unfair advantage. However, the presentation was thorough and the results convincing, the more so because their shortcomings were discussed and failures as well as successes were related. Perhaps most important is the inference from this polished performance that the organization of the XIth International Congress in Brussels will be carried out by an extremely competent team, Professors Mewis and Crochet each having given invited lectures in Sydney and each having a great deal of experience of our congresses.

Several participants were fortunate enough to go on the post-Congress tour of the Barrier Reef - or, to be more exact, Heron Island. For some, this provided a first flight in a helicopter, with views of whales on the way over and a brief descent on the way back to inspect two ships which were about to dock at Gladstone Harbour. The trip was a marine biologists delight, with octopus, squid, turtle, small sharks and sea cucumber frequently seen. The latter can exude a long stream of sticky and highly elastic liquid in order to deter predators!

In the "semi-submersible" boat, visitors sit in the keel, with angled observation windows on each side. The crew take left-overs from the restaurant and feed the fish some distance out along the edge of the reef - long before this they all swarm around the boat and at times one could hardly see out for multi-coloured fish pressing close to the windows. The coral is at its best when viewed from this vessel, but on "reef walks" at low tide the variety of corals and wierd sea-creatures is amazing. We lived in well-equipped chalets along the shore, the food in the restaurant was excellent but one still caught the relaxed atmosphere of a coral cay, with humans intruding briefly into an ancient life-system.

Finally, all the organisers must be thanked, notably Roger Tanner and David Boger, for their dedicated work in putting together such an excellent meeting. Compliments must be paid to the presenters of many fine papers, notably by the young Australian postgraduates. Australia is on the map rheologically and, unless all these young people emigrate, it will remain there!

D.R. Oliver

C.J.S. Petrie

CONFERENCE DIARY

Date	Place	Details
20-23/3/89	Combloux, France.	'Extensional flow' contact: Prof. K. Walters, Dept. Mathematics, U.C.W., Penglais, Aberystwyth SY23 3BZ, Dyfed, U.K.
6/4/89	Birmingham, U.K.	'Rheology in the Lab' contact: Dr S. Guy, Chemical Engineering, Birmingham Univ., Birmingham B15 2TT
19-21/4/89	Darmstadt, Germany, (B.R.D.)	'Annual Meeting' Deutsche Rheologische Gesellschaft: contact Professor Dr. K. Kirschke, Deutsche Rheologische Gesellschaft, Unter den Eichen 87, D-1000 Berlin 45, German Federal Republic.
18-23/6/89	Nancy, France	'7th International Congress of Biorheology' contact: Lorraine Congres, Symposium INSERM, Palais des Congres, 1, rue de Grand Rabbin Haguenauer, 54000 Nancy, France.
29/8/89 - 1/9/89	Glasgow U.K.	'Bifurcation phenomena in solids' Euromech 252: contact Professor R.W. Ogden Dept. of Mathematics, University of Glasgow, Glasgow G12 8QW, Scotland, U.K. .
4-8/9/89	Clermont- Ferrand, France	'Powders and Grains' International conference on micromechanics of granular media: contact R. Gourves, C.U.S.T., Laboratoire de Genie Civil, Universite Blaise Pascal de Clermont-Ferrand II, Rue des Meuniers, 63170 Aubiere, France.
12-15/9/89	Warwick U.K.	'Rheology of food, pharmaceutical and biological materials' British Society of Rheology: contact R. Carter, Carter Baker Enterprises, P.O.Box 2, Stansted, Essex CM24 8JG, U.K.
Sept. 1989	Krakow, Poland	'Applications of continuum damage mechanics' Euromech 251: contact Professor M. Chranowski, Politechnika Krakowska, ul. Warszawska 24, 31-155 Krakow, Poland.

- | | | |
|-----------------------|---------------------------------------|---|
| Oct. 1989 | Hamburg,
Germany.
(B.R.D.) | 'The time-dependent behaviour of ice'
Euromech 258: contact
Professor O. Mahrenholz, Technische
Universitat Hamburg-Harburg, Eissendorfer
Strasse 38, 2100 Hamburg 90, German
Federal Republic. |
| 21-26/10/89 | Montreal,
Canada. | 'First Inter-American Conference on
Rheology' and '61st Annual Meeting, Society
of Rheology' and 'First Annual Meeting of the
Canadian Rheology Group': contact
Dr. L.A. Utracki, NRCC/IMRI, 75 boul. de
Mortagne, Boucherville, Quebec, Canada,
J4B 6Y4. |
| 31/10/89 -
2/11/89 | Paderborn,
Germany.
(B.R.D.) | 'Thermal effects in fracture of multiphase
materials' Euromech 255: contact
Professor Dr. K.P. Hermann, Laboratorium
fur Technische Mechanik, Paderborn
University, Pohlweg 47-49, 4790 Paderborn,
German Federal Republic. |
| 3/90 | Liverpool,
U.K. | 'Rheology of fresh cement and concrete'
contact: Dr P.F.G.Banfill, School of
Architecture and Building Engineering,
University of Liverpool, P.O.Box 147,
Liverpool L69 3BX, U.K. |
| 24-26/7/90 | Cambridge
U.K. | 'Polymer Blends'
contact: Dr D.J.Hourston, Dept. of Chemistry,
University of Lancaster, Bailrigg, Lancaster,
Lancashire LA1 4YA, U.K. |
| 3-7/9/90 | Edinburgh,
Scotland, U.K. | 'Third Conference of European Rheologists'
and 'Golden Jubilee Meeting' British Society
of Rheology' contact Dr. C.J.S. Petrie,
Dept. of Engineering Mathematics, University
of Newcastle upon Tyne, Newcastle upon
Tyne, NE1 7 RU, U.K. |
| Oct. 1990 | Albuquerque,
New Mexico,
U.S.A. | '62nd Annual Meeting'
Society of Rheology: contact secretary
(Professor D.G. Baird, Polymer Materials and
Interfaces Laboratory, Virginia Polytechnic
Institute and State University, Blacksburg,
Virginia 24061-6496, U.S.A. |

INTERNATIONAL CONFERENCE ON EXTENSIONAL FLOW

Following the successful Chamonix meeting in January 1988, a follow up conference will be held in Combloux, near Megève, France from March 20th to 23rd, 1989. The main purpose of the meeting is to assess the utility of extensional rheometers by appeal to data on one dilute polymer solution supplied by Dr. T. Sridhar, Monash University, Clayton, Victoria, Australia. Other experiments are also being performed and the meeting should provide an important set of data for both simple and complex flows on this one sample.

Attendance is limited to approximately 40 participants and early registration is essential. The approximate cost of accommodation and registration fee will be £200. Further details may be obtained from: Professor K. Walters, Department of Mathematics, University College of Wales, Penglais, Aberystwyth, SY23 3BZ, Dyfed, UK.

RHEOLOGY IN THE LABORATORY

One Day Meeting

A one day meeting 'Rheology in the Laboratory' will be held in Birmingham University, Chemical Engineering department on Thursday, 6th April 1989. This is intended to explain the basic principles of rheological measurement to all rheologists including those who are in the formative stages of their careers. Application forms are included with this edition of the Bulletin.

For further details please contact:

Dr. S. Guy
Chemical Engineering Department
Birmingham University
BIRMINGHAM
B15 2TT

Tel: 021-414-5282

LAST CALL FOR PAPERS

"Rheology of Food, Pharmaceutical and Biological Materials"

University of Warwick, 12-15th September, 1989

The Society's Annual Meeting for 1989 will be on the topic above. Additionally, papers will be considered for a session on "General Rheology". The aim of the conference will be especially to encourage workers in different fields to compare notes to their mutual benefit.

Titles and abstracts of about 200 words should be sent by December 31st, 1988 to:

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The registration fee, including accommodation, meals, conference dinner (a mediaeval banquet at Warwick Castle) and hopefully, a copy of the proceedings, will be round £150. Registration forms will be available early in the New Year.

FIRST CALL FOR PAPERS

AN INTERNATIONAL CONFERENCE ON THE RHEOLOGY OF FRESH CEMENT AND CONCRETE

To be held in Liverpool, March 1990

The conference will be concerned with the rheology and related matters of all materials based on inorganic cement: e.g. fresh concretes, mortars, cement pastes, grouts, oils, well slurries and special products.

Papers are invited in the following subject areas:

- (a) Fundamental studies, Theoretical or Experimental
- (b) Relationships between rheological properties and composition, hydration reactions, microstructure, processing techniques etc.
- (c) Instruments and methods for testing rheology whether for research or industrial control
- (d) Technological applications such as site trials and quality control through rheology.

Applications by 28th February 1989 to:

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FIRST CALL FOR PAPERS

GOLDEN JUBILEE MEETING AND THIRD EUROPEAN CONFERENCE

Edinburgh 3-7th September 1990

Offers of papers are requested for the above meeting as soon as possible. Please send a title and 250 word summary to

**Dr. C.J.S. Petrie
Department of Engineering Mathematics
University of Newcastle-upon-Tyne
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NE1 7RU**

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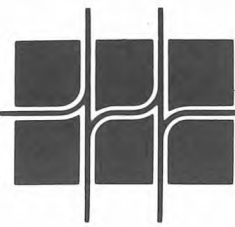
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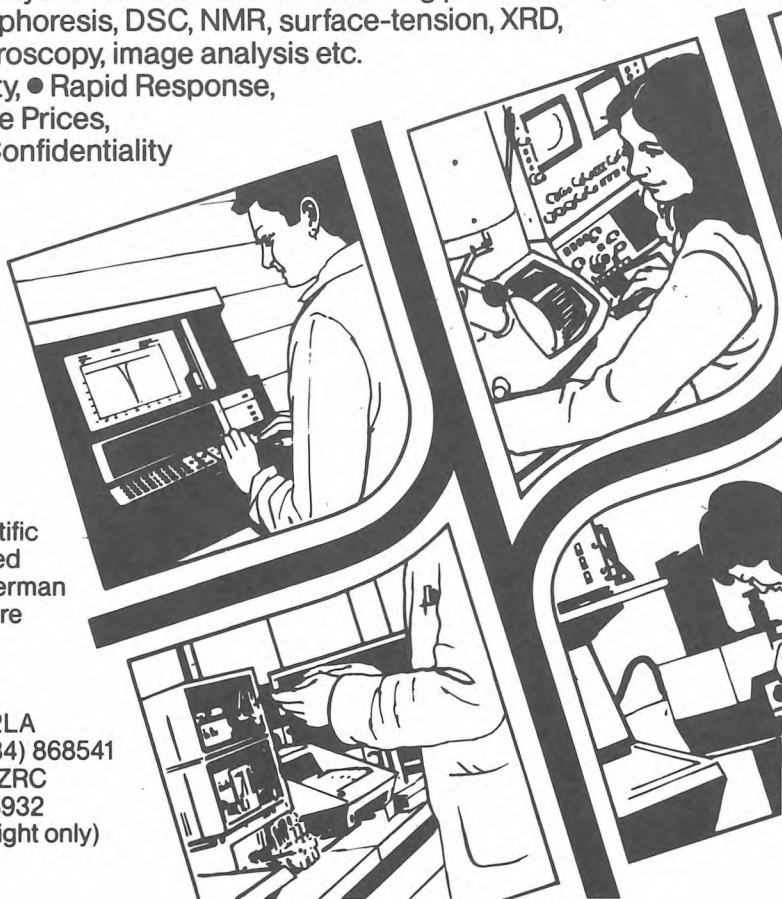
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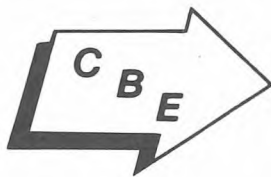
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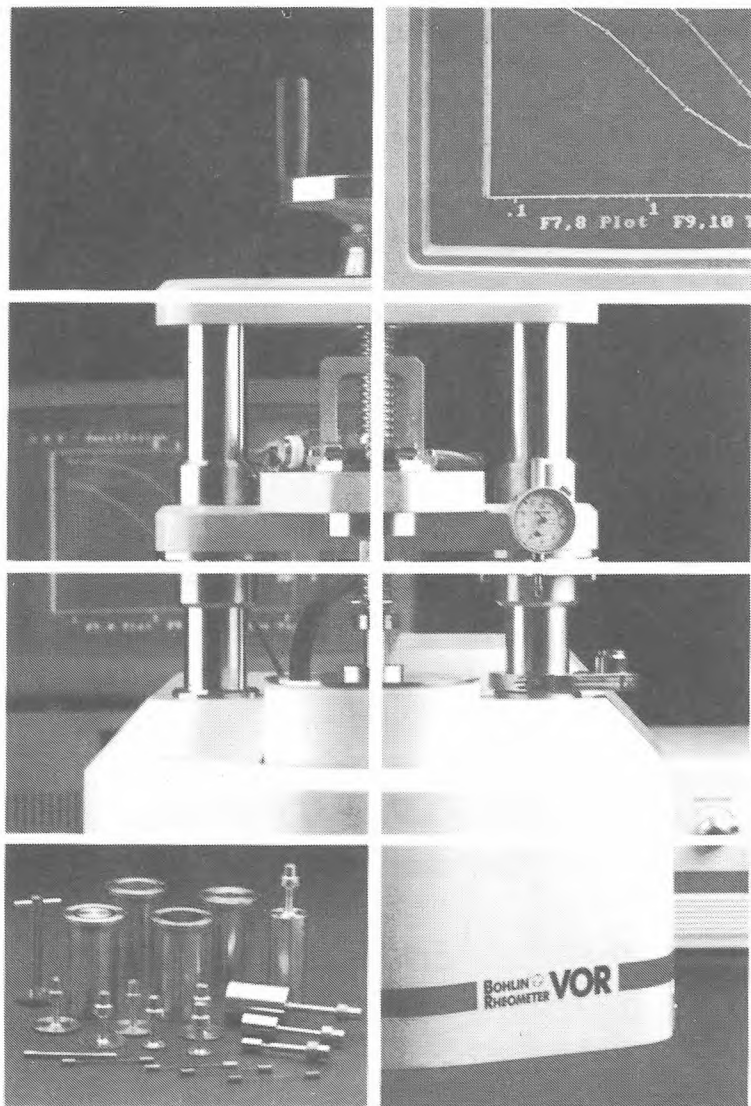
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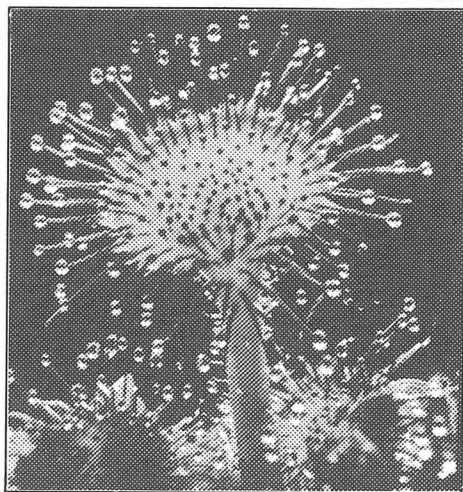
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control the behaviour of the materials during manufacture, storage and use.

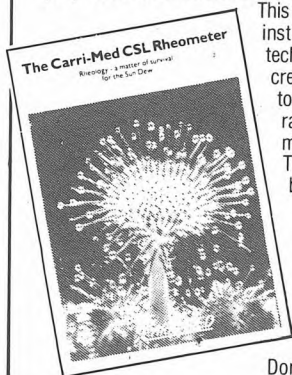
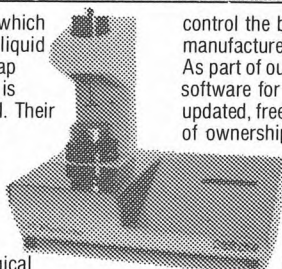
As part of our philosophy of total customer support, software for the CSL Rheometer is continually updated, free of charge, during the first two years of ownership.

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