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THE  
BRITISH SOCIETY  
OF RHEOLOGY

BULLETIN — No. 1, 1965

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Paint Research Station,  
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## Some Mistakes in Rheology

by R. ROSCOE,

*Physics Department, The University, Newcastle-upon-Tyne*

(Presidential Address delivered on September 29th, 1964)

I have been somewhat overawed during the past two years by the prospect of having to give a Presidential Address: the title suggests a dissertation of great weight and authority. Now when I came to look at my own work, I could find very few points of substance which were undeniably correct; but when I looked at other people's, I found a very large number of points which were undeniably incorrect. I am thus better qualified to speak about other people's mistakes than any achievements of my own. That is how it comes about that I shall talk about mistakes in rheology: an enormous subject of which I shall only be able to touch the fringe by the citation of a few interesting examples.

### *The confusion of solids with liquids*

A classical example of this confusion is provided by the work of Trouton and Andrews on "pitch" (1904, 1909) which was carried out to obtain experimental confirmation of the theoretical result that the coefficient of viscous traction for an incompressible liquid is equal to three times its viscosity. The pitch was presumed to be a liquid. Indeed, the strain-time curve obtained at constant stress, shown in the upper graph of fig. 1, is of the type to be expected for an elastic liquid, as the rate of strain appears to fall towards a constant value. This is not a sufficient criterion, however, and the form of the lower graph (in which final rate of strain is plotted against stress) suggests that the pitch was in fact a plastic solid stressed beyond its yield point.

In recent years, attempts have been made to slur over the distinction between solids and liquids by making repeated statements to the effect that "there is no real difference between solids and liquids: the apparent differences are merely a matter of time scale". The falsity of such statements is most easily demonstrated by carrying out an enquiry into the behaviour of actual materials—even to the extent of carrying out a few experiments. In order to make it quite clear that a real distinction does exist, I have chose for illustration a material which appears at first sight to be of doubtful status: perhaps solid, perhaps liquid. This is a bitumen mixture with properties similar to those of the "pitch" used by Trouton and Andrews. A specimen of this material was strained longitudinally by the application of a small load for six minutes, the load was then removed and the material allowed to recover for a long period. The experiment

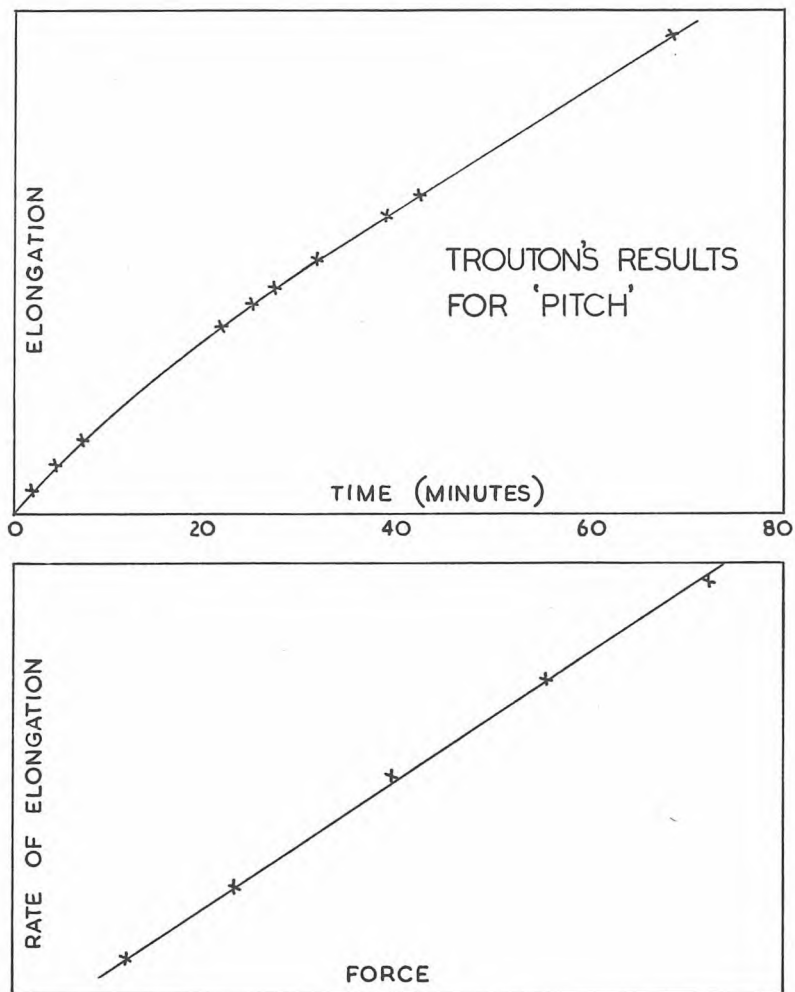


Fig. 1. Trouton and Andrews' observations on a supposed liquid.

was then repeated with other loads and the results are shown in fig. 2. The strains attained after six minutes are in the ratio of the stresses applied (1:3:5), but the residual strains after 54 minutes recovery are in the ratio of 1:15:28. It is clear, of course, that recovery is not complete after 54 minutes and the lower curve seems to be tending towards complete recovery. This is not the case with the other curves: with the highest stress the residual strain was found to drop to half the 54-minutes value after one week and then showed no measurable change over a period of two months.

The inference from this experiment is that the material returns eventually to its original shape after removal of the stress, provided the latter is not too large, and this is the essential characteristic of solid behaviour. The graph of residual strain against applied stress shown in fig. 3 suggests that there is a definite yield stress below which recovery is complete. It is known, however, that yield points are never sharply defined, so the line shown in this graph must curve round at the lower end so as to become tangential to the stress axis. A solid therefore cannot be simply characterised as "a material for which the ultimate residual strain is zero provided a certain yield stress has not been exceeded". On the other hand, if we say that a solid is a material for which the ratio

Residual strain/Applied stress

approaches zero as the stress approaches zero, we have a practical

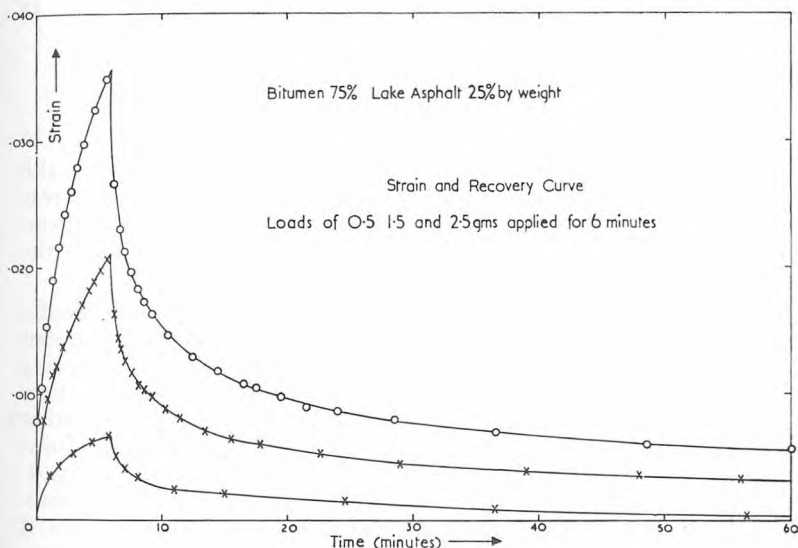


Fig. 2. Strain and recovery test on a doubtful material.

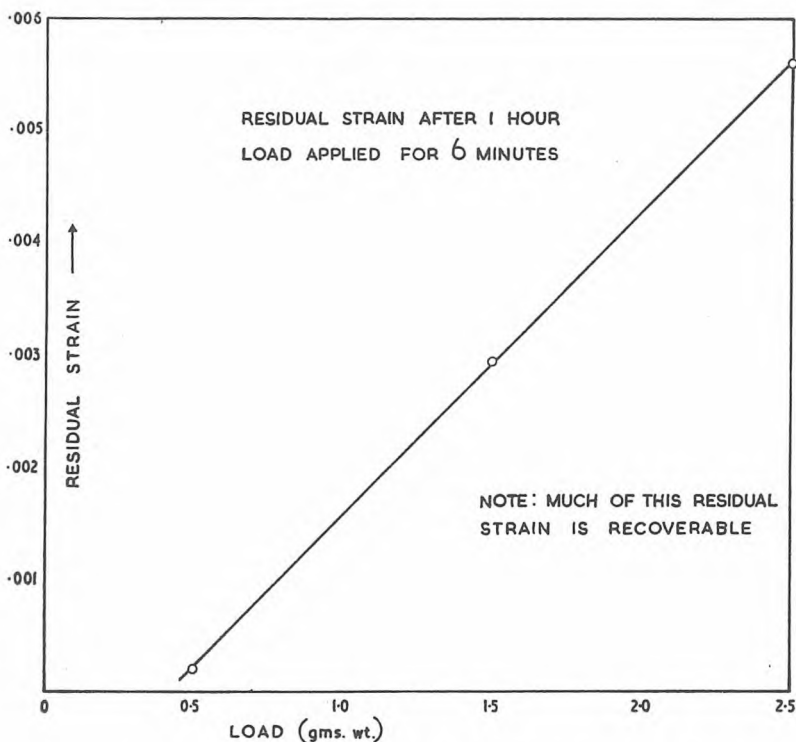


Fig. 3. Residual strain plotted against stress, showing solid behaviour.  
(Results of fig. 2.)

method of distinguishing between solids and liquids. Thus, in the case of liquids, either Newtonian or elastic, the residual strain—stress curve passes through the origin with a finite slope and the ratio given above is equal to the time of application of stress divided by the viscosity.

It is possible to make a simpler though less rigorous experimental test to distinguish between solids and liquids by obtaining a number of strain-time curves at different constant stresses without observing recovery. If the slopes of these curves decrease without limit as time increases, the material may be considered to be a solid. On the other hand, if the slopes become constant these steady rates of strain must be measured and plotted against stress as in the lower graph of fig. 1. Here again, a line passing through the origin at finite slope is an indication that the material is a liquid, but a line which descends as if to cut the stress axis and then bends round so as to meet it tangentially (fig. 4) is an indication that the material is a liquid. It can be

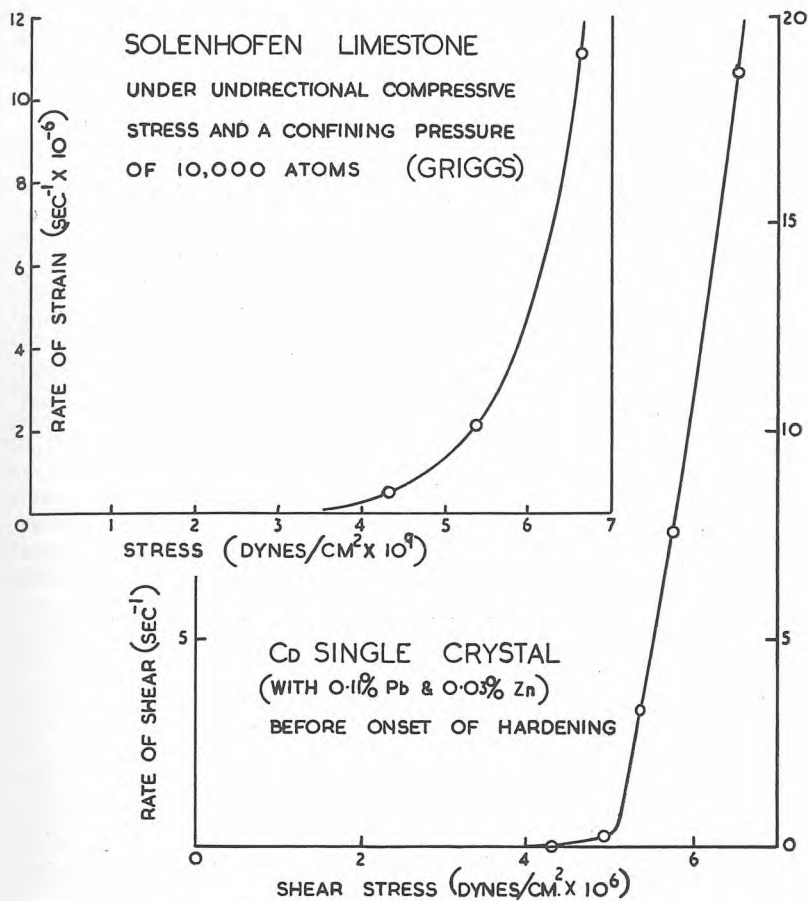


Fig. 4. Steady rate of strain plotted against stress for a rock and a metal single crystal.

shown that, if the material obeys Boltzmann's superposition principle at low stresses, this criterion is equivalent to the more fundamental one which involves residual strain. (A material obeying that principle will eventually recover completely on removal of stress if, and only if, the slope of its strain-time curve approaches zero with increasing time.) Some confusion may be introduced into this test by the advent of hardening, but this phenomenon has not developed during the measurements on a rock by Griggs (1940) and on a metal single crystal by myself (1936) which are shown in fig. 4.

Some would argue that it is of little practical importance whether a given material is really solid or liquid, since a solid stressed well above the "yield value" behaves to all intents and purposes as a liquid. This is true to a certain extent: for instance, the inference drawn by Trouton and Andrews as to the relation between the coefficient of viscous traction and viscosity for a liquid still stands, although the material they used was almost certainly a plastic solid. On the other hand, if one is concerned in explaining the behaviour of a material in terms of its physical and chemical constitution, or in interpreting its behaviour in terms of the recent phenomenological theory of "simple materials with fading memory", the distinction becomes critical. (I suspect that many of the "elastic liquids" currently being tested in rheogoniometers are in fact plastic solids.)

Finally, it must be mentioned that a theory of "vacancy creep" has been developed by Nabarro (1947) and Herring (1950), according to which polycrystalline materials should always show true viscous flow with viscosity coefficients of the order of  $10^{20}$ P or more: an idea which has been applied extensively by metallurgists. It has also been adopted by some geophysicists because it allows the calculation of such effects as convection in the earth's mantle to be made by Newtonian hydrodynamic theory. I feel, nevertheless, that some caution must be used here until there is unambiguous experimental demonstration of the existence of this flow; it is no easy matter to demonstrate such a small effect in the presence of the slow recoverable creep which is observed with most polycrystalline materials. Of course, if the existence of vacancy creep is accepted, the criteria which have been given for distinguishing between solids and liquids must be modified, although they remain adequate for every-day rheology.

### *The misuse of Andrade's viscosity equation*

As soon as a rheologist has made a series of readings of viscosity at different temperatures, he reaches for the log-linear graph paper, plots viscosity on the logarithmic scale and the reciprocal of absolute temperature on the linear scale—and expects to get a straight line. He never does. Nevertheless, the belief that this line should be

straight is very tenaciously held. I recently saw some viscosity data (covering a very wide range of temperature) which had been plotted in this way with a straight line drawn through the low temperature points. The fact that the high temperature points lay somewhat off this line was explained by the observer as being due to the inaccuracy of his measurements in that region. I pointed out that he was unduly modest in this respect as some of the high temperature points lay as much as three decades off the straight line. Nevertheless the graph was published, complete with straight line and explanation.

This curious behaviour arises from a misunderstanding of the viscosity temperature equation

$$\eta = Ae^{\frac{E}{RT}}$$

in which  $R$  is the molar gas constant and  $T$  is absolute temperature. This equation usually bears Andrade's name, although he made no claim to be the first propose it. The point that is generally missed is that Andrade's substantial contribution to the subject (1934) was the recognition that both the quantities  $A$  and  $E$  are functions of the specific volume of the liquid. In fact, when he chose  $A$  to vary inversely as the one-third power and  $E$  to vary inversely as the first power of this quantity, the resulting two-constant formula was found to fit the data for the great majority of liquids with remarkable accuracy. Only in the cases of water and one or two other liquids were the discrepancies greater than the errors of measurement. Although variations in specific volume with temperature are not large, they produce changes (particularly in  $E$ ) which materially affect the viscosity and destroy the linearity of the logarithmic plot.

Once the logarithmic graph has been plotted, it is customary to increase confusion still further by making erroneous determinations of the "activation energy"  $E$  at selected temperatures. This is simply achieved by measuring the slope of the curved line at each temperature and multiplying the result by  $RT$ . But if the logarithmic plot does not give a straight line, either  $A$  or  $E$  (or both) must vary with temperature, and differentiation of the equation shows that in these circumstances the slope is *not* equal to  $E/RT$ . Nearly all published values of this activation energy are vitiated by neglect of this simple fact. (It would seem that a series of measurements made at constant volume rather than constant pressure should give a straight logarithmic plot from which the value of  $E$  at a particular specific volume could be correctly deduced.)

In view of the large consumption of graph paper resulting from attempted determinations of activation energy, it is perhaps of interest to enquire into the precise physical significance of this quantity. In this connection, reference may be made to an excellent review of current theories of liquid viscosity by Bondi (1956), and it is only necessary to mention the main points here. The theory of Born and

H. S. Green starts off by applying kinetic theory to a clearly defined physical model representing a liquid of spherically symmetrical molecules, but mathematical approximations are made as the theory is developed. It leads to a formula of the type given above, with  $A$  and  $E$  depending on temperature through the specific volume. The ratio of  $E$  to Avogadro's number turns out to be approximately equal to half the (negative) potential energy of two molecules separated by a distance equal to the average separation of nearest neighbours in the liquid. On the other hand, Kirkwood, Buff and M. S. Green have developed a similar theory, but using more refined mathematical approximations, and it appears that their calculated results could be fitted roughly to this type of formula with  $E$  having twice the value given by the Born and Green theory.

Reference must also be made to the earlier and more general theory of Eyring. This leads to a similar formula, but the quantity  $A$  now involves the temperature explicitly through a factor  $T^{\frac{1}{2}}$ , although the validity of the derivation of this term has been seriously challenged. It is difficult to give a precise interpretation of the quantity  $E$  on this theory as the latter does not start from a clearly defined physical model. It seems, however, that Eyring regards it as a "free energy of activation" related to the energy of activation required for a local configuration of molecules to change in such a way as to favour the flow process. No doubt, if it were possible to define this quantity more exactly, it might be shown to be of the same order as the corresponding quantities in the other two theories. I think, however, that enough has been said on the theoretical side to make it clear that no precise fundamental information can be obtained at the present time from measurements of activation energies for viscous flow.

### *Some mistakes in nomenclature*

I must first mention the unfortunate practice of referring to the actual viscosity of a non-Newtonian liquid at a given rate of shear as its "apparent viscosity". For practical purposes, viscosity has been defined as the ratio of shear stress to rate of shear in simple shearing motion, and there does not seem to be any sufficient reason to alter this definition when the ratio varies with rate of shear. The alteration appears to have been made by those who, relying upon intuition, maintain that the decrease in viscosity shown by elastic liquids can be explained by purely geometrical considerations and have thence come to regard this decrease as something spurious. It is most undesirable, however, to alter the terminology for physical quantities in order to fit in with hypotheses which may not be generally accepted. This is not the usual practice in Physics. For example, laboratory measurements show that the ratio of the momentum of an electron to its velocity varies with that velocity, but the

ratio is still called the "mass" of the electron and not the "apparent mass".

After having said this, I must admit that such peculiarities in rheological nomenclature, though irritating, are usually harmless. It is well, however, to be clear on the meaning of words; otherwise serious error is possible. As an example, I shall cite the case of "recoverable shear" (a good self-explanatory word). Now it was suggested quite a long while ago, I believe by Professor Weissenberg, that when an elastic liquid is made to undergo simple shearing motion (such that planes normal to the  $x_2$ -direction move parallel to the  $x_1$ -direction) there should be a relation of the type

$$\text{Recoverable shear} = \frac{p_{11} - p_{22}}{p_{12}}$$

where  $p_{12}$  is the shear stress and  $p_{11} - p_{22}$  is one of the normal stress differences. This important result, derived on an intuitive basis, is supported with some modification and qualification by recent theoretical work which I shall mention later. Now the disturbing thing is that a number of papers have recently appeared giving values for the recoverable shear, but when one reads on, one finds the very difficult measurement of this quantity has not been made; the stated values are merely the ratios of the normal stress difference to the shear stress obtained from rheogoniometer measurements. (I have only been able to find three real determinations of recoverable shear in the literature.) It is obviously wrong to use the same name to denote two different things. The equation given above is not an identity, it is an equality deduced from certain hypotheses as to the fundamental nature of the liquids concerned. However well such hypotheses may have been chosen, there can be no guarantee that they are valid for all liquids.

### *The neglect of modern continuum mechanics*

An early lead in the field of elastic liquids was established in this country by the invention and construction of the rheogoniometer by Professor Weissenberg and Mr. Roberts and their collaborators. But, looking at the subject rather as an outsider, I can see that the real future progress is going to be made in the United States unless we alter our theoretical approach.

It is essential to have a basic theory in order to interpret the results of experiment. Ideally, such theories should be derived from a consideration of the physical and chemical constitution of the liquids concerned, and although some progress has been made in this direction (the work of Dr. Lodge and Dr. Giesekus may be cited as examples), development along these lines is slow. Rheologists have therefore to rely on phenomenological theory, and in the early days this was based on intuitive assumptions. A great advance was made

by Professor Oldroyd who showed how it is possible to formulate rheological equations of state (constitutive equations) correctly, and a very large number of these equations have been proposed in attempts to represent the whole rheological behaviour of elastic liquids in concise mathematical form. Unfortunately, with the increase in experimental data it has become necessary to construct more and yet more complicated constitutive equations, and I begin to think that little further progress will be made by following this empirical approach.

On the other hand, a theory of the continuum mechanics of a very general class of isotropic materials, known as "simple materials with fading memory", has been proposed by Coleman and Noll and developed by them and other workers for a number of years. This has been (with only one exception to my knowledge) entirely neglected by experimentalists in this country. This neglect arises, no doubt, from the fact that the work has proceeded on such a high mathematical plane that it has been difficult for the practical rheologist to see what useful applications it may possibly have. With the publication of a paper by Coleman and Markovitz (1964), however, it has become clear that the theory is capable of yielding important general results when applied to incompressible liquids. They have shown that, in slow simple shear, the normal stress difference  $p_{11} - p_{22}$  is connected with the rate of shear  $\kappa$  by the relation

$$p_{11} - p_{22} = G'(\kappa)$$

where  $G'(\omega)$  is the real part of the dynamic elastic modulus of the liquid at a frequency  $\omega/2\pi$ . Unfortunately, this result is only valid in the region of very small  $\kappa$  where the normal stress difference is proportional to the square of that quantity, a region which is difficult to investigate in practice. The result is nevertheless of importance, because it shows that a liquid which exhibits shear elasticity will necessarily show a normal stress difference  $p_{11} - p_{22}$  and conversely. (Notice that there is no necessary connection between shear elasticity and the other stress difference  $p_{33} - p_{22}$ : the non-elastic Reiner-Rivlin liquid is always a theoretical possibility.)

The equation which as just been given leads to the further result that, for low stresses,

$$\text{Recoverable shear} = \frac{1}{2} \frac{p_{11} - p_{22}}{p_{12}}$$

which differs only by the factor of 1/2 from the relation which I quoted earlier. (The result is not stated explicitly by Coleman and Markovitz, but it may readily be obtained with the help of equations given in their paper.)

It will be found that results such as these, deduced from the theory of simple fluids with fading memory, apply to the isotropic liquids obeying the special constitutive equations proposed by Professor

Oldroyd and Dr. Walters, because these liquids are special cases of the class of simple fluids with fading memory. Nevertheless, it must not be supposed that all elastic liquids are necessarily members of this class: it may well be that some liquids, initially isotropic, develop an anisotropy during shear which does not entirely disappear on recovery, and Ericksen's theory of "anisotropic liquids" should be of importance in this connection.

I must admit that very few experimentalists have the time or training necessary to acquire a full grasp of modern continuum theory. In every branch of physical science, however, a stage is eventually reached beyond which real progress can only be made by the application of advanced mathematics. From now on, major rheological research projects should be planned to include the co-operation of experimentalists and mathematicians: only in this way will we prevent the initiative in Rheology passing entirely to the other side of the Atlantic.

### References

- Andrade, E. N. da C., 1934, *Phil. Mag.*, 17, 698.  
Bondi, A., 1956, in *Rheology, Theory and Applications*, ed. F. R. Eirich, Vol. 1, p. 321. (New York: Academic Press Inc.)  
Coleman, B. D., and Markovitz, H., 1964, *J. Appl. Phys.*, 35, 1.  
Griggs, D., 1940, *Bull. Geol. Soc. Amer.*, 51, 1001.  
Herring, C., 1950, *J. Appl. Phys.*, 21, 437.  
Nabarro, F. R. N., 1948, in *Report of a Conference on the Strength of Solids, 1947*, p. 75. (London: Physical Society.)  
Roscoe, R., 1936, *Phil. Mag.*, 21, 399.  
Trouton, F. T., and Andrews, E. S., 1904, *Phil. Mag.*, 7, 347; 1909, *Proc. Phys. Soc.*, 19, 47.

(Reprints of Dr. Roscoe's paper may be obtained from the editor, price 1s. 3d. each, including postage.)

## Annual Conference

The Annual Conference 1965 will be held at Reading University from September 22nd to 24th. In addition to a session on "Rheological Aspects of Aero-space Research" part of the meeting will be devoted to papers dealing with any topic of rheological interest.

If you wish to present a paper at this meeting would you please submit a brief synopsis, before May 1st to:

Dr. D. W. Saunders, Dept. of Materials, College of Aeronautics, Cranfield, Bedford. (Aero-space Research), or

Dr. K. Walters, Dept. of Applied Mathematics, University College of Wales, Aberystwyth. (General Session.)

## Notes and News

Dr. J. H. C. Vernon has prepared a report of the symposium on The Teaching of Rheology, held at Exeter in September 1964.

Reprints of this report, which is to be published in the Institute of Physics Bulletin, will be sent to members of the British Society of Rheology.

Professor Kennedy's address as given in the List of Members, and reprinted in the previous Bulletin, is incorrect. The correct address is:

Professor A. J. Kennedy,  
Dept. of Materials,  
The College of Aeronautics,  
Cranfield,  
Bedford.

## Letters to the Editor

Dear Sir,

I wish to make the following corrections to the reporting of the Exeter Conference which appears in the B.S.R. Bulletin No. 4, 1964.

In the first place the burden of the paper on coaxial cylinder rheometry was that phase-lag measurements appear to discriminate more powerfully between viscoelastic theories in the region of small variable strain rates than amplitude ratio measurements. (Also an unpublished method of phase-lag measurement was outlined.)

Secondly, it is completely incorrect that in the second paper the present author queried whether there was a need for the meeting, or attempted to prove that rheology could not fit as a subject into any educational plan, these two ideas were neither stated nor implied. The paper actually brought out some of the arguments a teacher might be faced with by colleagues in proposing Rheology as a

University course. It is essential that these be considered, and probable that they have not previously been stated.

Finally, the difference between myself and any other person at the meeting (not necessarily delegates) on the definition of rheology is just a matter of choice (not semantics). The definition given: "The study of the relationships between stress and corresponding strain (and time)" rather than: "The science of deformation and flow (except the conduction of heat and electricity, also aerodynamics, hydrodynamics, magnetohydrodynamics and the theory of elasticity for infinitesimal strains, for example)", enables it to fit into materials science and continuum mechanics without encroachment.

Yours faithfully,

J. HARRIS.

Dept. of Civil and Mechanical Engineering,  
Queen's College, Dundee.

Dear Sir,

After reading the last Bulletin (No. 4, 1964) I felt I should write to air my views on the present state of Rheology.

There will be some who will disagree violently, a few maybe who will agree, but my real hope is that it may promote (or provoke) a discussion in the Bulletin which will help to clarify our ideas.

I think that in trying to promote Rheology as a science in its own right we are "flogging a dead horse". The subject "Science of Materials" covers the field adequately and can far more easily be accepted as part of a Physics or Engineering course than can Rheology, which is hampered by its narrow definition.

My old departmental head (in industry) used to say that a subject could not be called a science until it had accumulated sufficient experimental evidence to enable sound theories to be formulated.

Too much rheological work consists of formulating theories and then trying to find a bit of experimental evidence which fits. At the two extremes we have people who only formulate theories or people who only do experiments and these two groups seem to have no common ground.

Perhaps Rheology as I think of it should be described as Technology rather than Science and this distinction could be the reason why there seems to be such a wide gap between industrial and academic Rheologists.

I should be grateful if you could find space to publish this letter and then I think we can sit back and "let t'battle begin".

Yours faithfully,

A. HORSLEY.

John Mackintosh & Sons Ltd.,  
Albion Mills,  
Halifax, Yorks.

Dear Sir,

I read with interest the report on the second part of the Exeter Conference on the teaching of Rheology. Unfortunately I could not attend, partly because I was preparing a course of lectures in Rheology at this college.

From the admittedly short experience of running the first term of a sessional course in Rheology I have come to the following preliminary conclusions:

It is entirely feasible to devise courses in Rheology from which students reading for examinations in specialised techniques (such as are taught at a number of colleges of technology, but not at universities) can profit.

Although the theoretical coverage must be sufficient, this must be limited to the aspects which are of practical significance to the specialised technology with which the particular course as a whole is concerned. It is wrong to teach Rheology in a technological vacuum, in the hope that students will subsequently pupate and emerge as Plastics Rheologists, Biorheologists, Paint Rheologists, Ceramics Rheologists, etc.

The only feasible approach, I submit, is to tell the budding technologist: "You must know about those fundamentals of Rheology with which you will almost certainly be confronted sooner or later in the practice of your chosen technology". If the converse approach is taken: "You are going to be a fully fledged rheologist and it will be up to you subsequently to see what is relevant in your chosen field", this will deter from a study of Rheology the very people who ought to obtain an understanding of Rheology as it applies to their particular sphere of subsequent professional activity. Even if it did not deter, it would certainly make excessive demands on the time of the student who has to study other subjects of his technology besides Rheology. Clearly, an academic approach in this setting is wasteful and inefficient.

If there is now a demand from industry for short courses for graduates it is because people who presently practise a specialised technology have not been taught Rheology in their undergraduate days and have eventually come to realise that the resulting gap in their knowledge hampers them in their research, development, production or technical service activities. This gap cannot be filled by offering them a theoretical course based on continuum mechanics, but it *can* be filled by a course related to the particular technology in question.

Pure Rheology is certainly for the postgraduate university man, but applied Rheology should percolate through all the technologies at undergraduate level and can be profitably taught only if its significance to the particular technology with which the department is concerned is correctly assessed. This means that the course must not

tax the student's effort in a direction which is irrelevant or only marginally relevant to the broader field with which he must become familiar.

Those of our students who are taking the Physics or Engineering route to the Associationship of the Plastics Institute Examination are already catered for. We are now considering offering a similar course to graduates from the plastics industry, a course which is thought to be of the type that such people are looking for. In the meantime perhaps you will be good enough to announce to your readers preliminary details about a Symposium of "Plastics Deformation and Flow" which will be held on Thursday/Friday, May 6th and 7th, 1965, at this college and which enjoys the support of the Plastics Institute, the British Society of Rheology and of the Technical Press.

Those who wish to attend this symposium are invited to write to me for application forms.

Yours faithfully,

R. S. LENK.

*(Lecturer in Plastics Technology.)*

Dept. of Chemistry and Chemical Technology,  
Borough Polytechnic,  
London, S.E.1.

### **British Society of Rheology Research Committee**

As recommended by the Exploratory Committee (Bulletin 1964, No. 4, 4), and approved at the A.G.M., the permanent Research Committee has now been set up, and has held two meetings. The Chairman is Dr. R. Roscoe (Immediate Past President of the Society), with Mr. A. T. J. Hayward as Secretary and Professor A. J. Kennedy, Mr. R. J. Cole, Dr. E. R. Howells, Dr. J. R. A. Pearson and Dr. J. F. Raffle as members. Close liaison with the Joint Working Party on Non-Newtonian Flow (see below) will be maintained.

The Research Committee was pleased to welcome Professor Richardson and Mr. Smith (officers of the Working Party) as guests at its second meeting on January 15th, at which matters of common concern, and arrangements to prevent overlapping of activities were discussed.

### **Working Party on Non-Newtonian Flow**

The Institution of Chemical Engineers and the British Society of Rheology have formed a Joint Working Party on Non-Newtonian Flow. The Chairman is Professor J. F. Richardson, and the Secretary, Mr. J. M. Smith, both of Swansea University. Membership is made up of chemical engineers and rheologists.

Activities of the working party will be reported to the Institution and the Society through the respective Research Committees.

## Rheology of Wood Adhesives

A meeting of the Victorian Branch of the B.S.R. was held on November 18th, 1964.

Mr. K. F. Plomley, of the Division of Forest Products, C.S.I.R.O., South Melbourne, discussed determinations of viscosity of various wood adhesives during the process of gelation. The rate of gelation, and with it the useful pot-life, can be controlled by controlling mixtures. Most adhesives have a flow-curve of the Bingham type with small yield values which may increase near the gel point but are of little significance in practical applications. The effect of filler on the viscosity of phenolic resins was shown and the critical dependence of gelation rate on the concentration of resorcinol was emphasised.

Mr. J. W. Gottstein of the same organisation spoke first about factors encountered in the design and control of glue spreading rollers for veneer and about the rheological properties concerned, including "grip". He demonstrated the results of transfers from spread to new surfaces after various intervals, and the effect of pre-stressing. The important effect of pH on alkaline adhesives and its practical implications were discussed. Mr. Gottstein also described the measurement of stress relaxation in the glue line by introducing shrinkage differences between two laminations and determining the bending deflection of the assembly.

During discussion, the similarities were brought out of the ringing, or tram-lining effect due to roller spreading and a similar effect in the printing industry, and to some extent also in paper sheet formation. The reason for variation in threads on the spreader roller and the importance of the thread form were pointed out in response to a question. Opinions were also exchanged on the relative importance in the gluing process of van der Waals forces and covalent and hydrogen bonds.

(Similar reports of all future meetings of the Victorian Branch of the B.S.R. will be published in the Bulletin.)

## Rheology in France

As mentioned in the previous Bulletin the Society is to maintain closer liaison with the Groupe Français de Rheologie.

Two recent meetings of the Groupe were both held in Paris. On November 19th, 1964, papers were given on "The application of a generalised Bingham model to the rheology of metals" by M. J. Leclerc (O.N.E.R.A.), and on "Elastic energy and work done in models" by Professeur M. J. Mandel (Ecole Polytechnique).

On January 21st A. Kovacs (Strasbourg) presented "A simple theory of flow and volume recovery", and J. C. Robinet (Ecole Supérieure de Physique et Chimie) read a paper on "The rheological behaviour of the volume of amorphous polymers at the glass-rubber transition".

The annual conference of the Groupe will be held this year in Paris, commencing May 20th, the theme being "The Rheology of Two Phase Systems". Further information may be obtained from M. B. Persoz, 68, Bd. St. Michel, Paris 6.

### Future Meetings

A two-day symposium on "Deformation and Flow of Plastics" is to be held at the Borough Polytechnic, Borough Road, London S.E.1, on May 6th and 7th, 1965.

The programme includes:

|                     |                                                                                     |
|---------------------|-------------------------------------------------------------------------------------|
| Dr. D. R. J. Hill.  | Molecular interpretation of visco-elastic behaviour.                                |
| Mr. P. Lamb.        | Laboratory methods of studying melt rheology.                                       |
| Mr. E. B. Atkinson. | Pitfalls in the application of rheological data to problems of plastics processing. |
| Dr. P. L. Clegg.    | Flow in extrusion processes.                                                        |
| Mr. C. A. Brighton. | Flow in injection moulding.                                                         |
| Mr. R. A. Horsley.  | Testing and selection of materials for engineering applications.                    |
| Mr. D. R. Reid.     | Dynamic testing.                                                                    |
| Mr. S. Turner.      | Creep and stress relaxation.                                                        |
| Mr. M. Madan.       | Design for engineering applications.                                                |
| Mr. D. Robak.       | Design for load bearing applications.                                               |

Further details may be obtained from the Secretary, Borough Polytechnic.

A meeting of the Polymer Physics Group is to be held at Shrivenham, September 15th-17th, 1965. Short contributions in the general field of polymer physics are invited. Summaries (150-200 words) should be sent to Dr. I. M. Ward, Research Dept., I.C.I. Fibres Ltd., Harrogate, Yorkshire, as soon as possible.

## Rheology at Battersea College of Technology

The courses of lectures covering all major branches of rheology will conclude for the present session with the following two series:

Five lectures on the Rheology of Polymer Melts given by Dr. H. Zamodits (B.T.R. Industries Ltd.) on Wednesday evenings commencing May 5th at 6.30 p.m.

Six lectures on the Rheology of Dispersions on Friday evenings at 6.30 p.m. commencing May 7th. Mr. R. W. Whorlow and Dr. P. Howard (Battersea College of Technology) will deal with general aspects of the subject while Mr. C. C. Mill (P.A.T.R.A.) and Mr. T. R. Bullett (Paint Research Station) will discuss the rheological properties of printing inks and paints respectively.

Further details of these lectures may be obtained from the Secretary (Rheology Courses), Battersea College of Technology, London S.W.11.

A course in Rheology leading to the M.Sc. Degree of the University of Surrey (by examination and dissertation) will commence in October 1965. The duration of the course would be at least 12 months full-time or two years part-time. Advanced Course Studentships may be available for suitable candidates.

Anyone interested in this course is invited to discuss the matter with Mr. R. W. Whorlow, Physics Department, Battersea College of Technology, London S.W.11.

A conference on "Inhomogeneity in Glass will be held at Sheffield University from April 6th-8th, 1965. A selection of the papers presented will be published in "Glass Technology". Further details are available from the Society of Glass Technology, Thornton, Hallam Gate Road, Sheffield 10.

The Institution of Mechanical Engineers has announced the following meetings which may be of interest to rheologists.

April 7th (evening discussion): How should engineering education take account of development in newer materials? (3) Rubber.

April 27th (evening discussion): Trends in the use of plastics in engineering.

May 27th-29th (Convention): Lubrication and wear.

September 21st-22nd (Symposium—in Leeds): Elasto-hydrodynamic lubrication.

October 13-14th (Symposium—in Birmingham): New engineering materials.

November 2nd-3rd (Symposium): Surges in pipelines.

Meetings are in London unless otherwise stated. Further information can be obtained from the Institution at 1 Birdcage Walk, London S.W.1.

The Society of Glass Technology proposes to hold a three-day symposium in April 1966 on the general subject of Gases in Glass. Papers on either physical and chemical properties, or technological considerations, are invited. Provisional titles should be submitted before May 1965 to the Hon. Secretary, Society of Glass Technology, 20 Hallam Gate Road, Sheffield 10.

The Polymer Physics Group is holding a two-day symposium on "Viscoelastic Behaviour of Polymers and Liquids" in Glasgow on April 12th-13th, 1965.

The programme includes:

|                     |                                                           |
|---------------------|-----------------------------------------------------------|
| Prof. J. Lamb.      | Theoretical survey.                                       |
| Dr. A. J. Matheson. | Viscoelastic properties of polymer solutions.             |
| Dr. G. Harrison.    | Viscoelastic behaviour of polymer liquids.                |
| Dr. A. J. Barlow.   | Viscosity and the elastic behaviour of simple liquids.    |
| Mr. A. Dyson.       | Viscoelastic effects in elasto-hydrodynamic lubrication.  |
| Mr. J. F. Hutton.   | A contribution to the theory of polymer melt fracture.    |
| Dr. J. J. Benbow.   | Elasticity in molten polymer.                             |
| Mr. M. Cross.       | Interpretation of pseudo-plasticity in polymeric systems. |
| Dr. G. Harrison.    |                                                           |
| Mr. P. Lindon.      | Experimental methods.                                     |
| Dr. A. J. Barlow.   |                                                           |
| Mr. J. Richter.     |                                                           |

Further information may be obtained from Dr. G. Harrison, Dept. of Electrical Engineering, The University, Glasgow W.2.

An international conference on Stress Analysis is to be held in Berlin in March 1966. Offers of papers containing new material in subjects associated with experimental stress analysis should be sent to Dr.-Ing. Chr. Rohrback, Bundesanstalt fur Materialprufung, 1 Berlin 45, Unter den Eichen 87, Germany. A copy should also be sent to R. J. Millson, Secretary, Joint British Committee for Stress Analysis, 1 Birdcage Walk, London S.W.1.

The Deutsche Rheologische Gesellschaft and the high polymer group of the Deutschen Physikalischen Gesellschaft are holding a joint conference at Bad Nauheim from April 6th-10th, 1965.

The annual conference of the Deutschen Rheologen-Vereinigung will be held at Berlin-Dahlem from May 11th-13th, 1965. Details may be obtained from Herrn Dr. W. Meskat. 509 Leverkusen 3, Muhlenweg 90a, Germany.

The working party on Fatigue and Creep of Reinforced Plastics, set up by the Reinforced Plastics Group of the British Plastics Federation, is compiling a register of research workers in the appropriate fields. It is hoped to use the register to assist contact between workers on closely related topics, to inform participants of meetings on the subject, and to form the basis of a posting list for material published by the Structural Design Data Sub-committee.

For further information contact W. C. Wake, Esq., The British Plastics Federation, 47-48, Piccadilly, London W.1.

### New Members

| NAME AND ADDRESS                                                                      | INTERESTS                         |
|---------------------------------------------------------------------------------------|-----------------------------------|
| R. R. Bilboul,<br>9 Gloucester Walk,<br>London W.8.                                   | Suspensions.                      |
| J. M. Baxter-Brown,<br>Dept. of Mech. Eng.,<br>Queen's College, Dundee.               | Suspensions, rocks.               |
| C. J. Camilleri,<br>Dept. of App. Maths,<br>University College, Swansea.              | Theory, elastico-viscous liquids. |
| M. M. Cross,<br>Speedwell, Bow Green Road,<br>Bowdon, Cheshire.                       | Polymers.                         |
| H. W. Giesekus,<br>5 Koln-Stammheim,<br>Haterkamp 3, Germany.                         | Theory, polymers, suspensions.    |
| A. E. Hawkins,<br>Unilever Research Labs.,<br>Colworth House,<br>Sharnbrook, Bedford. | Foodstuffs.                       |
| J. E. Johnson,<br>74 Belgrave Road,<br>New Moston, Manchester 10.                     | Viscometry.                       |
| D. T. Jones,<br>Dept. of App. Maths,<br>University College, Aberystwyth.              | Theory.                           |
| A. J. Lovett,<br>10 Westfield Close,<br>Dorridge, Solihull, Warwicks.                 | Polymers, rheo-goniometry.        |

## NAME AND ADDRESS

B. J. Meakin,  
38 Orchard Road,  
Nailsea, Somerset.

J. L. den Otter,  
Veursestratweg 213,  
Leidschendam, Holland.

L. Peters,  
89 Victoria Road,  
Leeds 6.

N. Pilpel,  
20 Nassau Road,  
Barnes, London S.W.13.

Toshimaro Sone,  
Research Lab.,  
Snow Brand Milk Products Co.,  
27-1 Akabanekita 3, Kitaku,  
Tokyo, Japan.

G. H. West,  
11 Knowsley Road,  
Hazel Grove, Stockport, Cheshire.

B. Wright,  
6 Bedford Road,  
Eccles, Manchester.

K. Buckley,  
2 Baldocks Lane,  
Melton Mowbray, Leicestershire.

## INTERESTS

Emulsions, suspensions.

Molten polymers, polymer solutions.

Textiles, theory.

Surface-active agents, surface visco-  
metry, powders.

Biorheology.

Thermoplastics, viscometry.

Polymers.

Viscosity of Gums, foodstuffs.

## Obituary

We note with regret the death on November 12th, 1964, of Mr. H. B. Oakley, of Unilever Research Laboratories. Mr. Oakley had been a member of the Society since 1944.