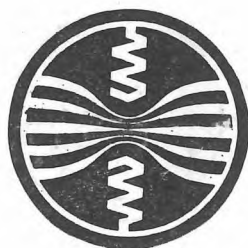


BULLETIN



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FOREWORD

If the full impact of the Rothschild report is felt throughout the field of scientific and technological research it may well be that many rheologists, given the current level of application of rheology in industry, will find funds for research more difficult to come by in the future than in the past. The reason for this is that in what might be termed technological research, the research activity has relied heavily on government funds for support and very little on private industry. There has in fact been evidence of some contraction of industrial interest in rheological research.

One of the fundamental tenets of the Rothschild report is that a sharp distinction may be drawn between scientific and technological research and that therefore financial support for the two areas may quite reasonably be placed on separate and different foundations. The former being, by nature, unplannable and subject to minimum control and the latter financed on a customer-contract basis and therefore capable of direction towards limited goals in definite financial and time scales.

Much of the area of development engineering can, and has been, treated along the above lines. But the exclusive use of such controls may prove a hindrance to some. That the recommendations of the report are to be implemented there seems little doubt, but what matters in the end is not the letter of the law but how it is used by human beings. There may be some comfort in the pattern of Government agency sponsored research in the United States, for there the sponsorship is wide ranging and not, apparently, too inhibiting.

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VISCOMETERS WITH CURVILINEAR FLOW PATTERNS

PART II: CONE AND PLATE VISCOMETER

J. Harris

(University of Bradford)

1. Introduction

In Part I of this work, radial migration of particles in a concentric cylinder geometry viscometer was treated. Formulae for several other physical quantities such as the wall shear rate, normal stress at the wall and effective slip velocity at a solid boundary were also given. The latter item may arise from particle geometry effects, particle migration or the production of a failure plane in paste-like materials. Even in polymer melts the possibility of wall slip effects cannot always be completely ruled out.

Other phenomena may occur of course, such as Taylor vortices, but consideration of this phenomenon was not included in the work. Brownian motion of the very fine particles was also not considered.

It may be worthwhile mentioning here that the evaluation of wall shear rate and wall normal stress according to the methods described in all sections of the present work rests upon the validity of expressing these qualities as functions of shear stress alone.

2. Radial Migration of Particles

Somewhat similar conditions will be assumed in this treatment to those applied in Part I: Relatively small migration velocities in directions perpendicular to the axis of rotation and uniformly distributed disperse phase of concentration c_0 on time $t=0$.

Actually, as the continuous phase is displaced inwards when the disperse phase migrates outwards, then adjacent to the conical surface there will also be some axial displacement of the particles. But for small cone angles, this will naturally be of smaller order of magnitude than the gross particle flow velocity out towards the perimeter.

Equations (1) to (6) inclusive of Part I may be used directly. But (7) needs to be in the appropriate spherical coordinate system (r, φ, α) where α is measured from the equatorial plane. See figure 4.

(Note that in Part I in equations (7) and (8) $(wr)^2$ is misprinted as (w^2r) .)

The continuity equation for the present case is given by (24) where small values of time t are considered. The velocities in (24) are connected to the observed migration velocity (u) by (25). The appropriate alternative to the relative velocity given by (3) of Part I is (26) in this case. Now combining (24), (25), (26) and (4) of Part I yields (28).

Integrating (28) and assuming a uniform volume concentration c_0 everywhere on time $t=0$, then the distribution (29) results. To com-

plete the initial specification of the problem the angular velocity in (26) needs to be specified as a function of the coordinates.

3. Cone and Plate—Rotating Cone

In the initial stages when the suspension is not too far from homogeneity then the approximate form of angular velocity given by (30) will be reasonably applicable. An interesting feature arises in this particular case; c in (29) is only a function of time and the angle from the equatorial plane, it is independent of radius.

Combining (3), (4) of Part I and (30) produces the migration velocity (31). At higher Reynolds numbers, both disperse and continuous material will rotate in a radial plane in the same direction.

4. Effective Slip at the Boundary

The fact that variations in concentration do not initially depend upon the radial coordinate in the cone and plate geometry is useful in the remainder of the work. It means that variations in apparent material properties using cones of the same angle but differing radius may be traced to edge effects and these may be eliminated, if present, by using cones of different radii just as cylinders and tubes of differing length may be used to eliminate end effects in the Couette and Poiseuille viscometers.

Effective slip may be detected as shown in figure 5. Distinctly different curves, one for each cone angle will be found if there is effective slip at the solid boundary. The experimental data in figure 5 is intersected by a line A - B to find the slip viscosity as in (32).

5. The Shear Rate at the Wall

If concentration gradients exist within the sample then the velocity distribution will depart to some extent from the ideal obtainable with a uniform concentration.

Using (34) and (35) in (33) produces (36). Now (36) may be differentiated with respect to the upper or lower limit. For example differentiating with respect to the upper limit produces the shear rate on the cone (37) with a similar expression for the shear rate on the plate.

Practically this differentiation process is executed on experimental data as shown in figure 6.

6. Normal Stress Measurement at the Wall

The normal stresses at the wall measured in the cone and plate geometry are not invariably independent of cone angle³ and therefore it is reasonable to provide data for measurements at the wall to attempt to eliminate this phenomenon.

Starting from the equilibrium equation (38) and using (35) to change the independent variable: equation (38) can be combined with (39) to produce (40). Again differentiating with respect to the upper

limit produces (41) which represents the first normal stress difference at the surface of the cone. A similar differentiation with respect to the lower limit produces the normal stress difference on the plate.

Note that in this case measurement of wall pressure on both the cone and plate are needed for (41).

Figure 7 shows how the principle of differentiation is applied in this case by obtaining experimental data for different gap angles.

7. Rotating Plate

In the Haake Rotoviscometer and similar instruments it is invariably the cone which is rotated against a stationary flat plate. In the Weissenberg rheogoniometer, for example, either the cone or the plate may be the rotating member. In the case of a rotating plate, there would be no tendency for a heavier disperse phase to move away from the conical surface, but a concentration gradient might, in general, be expected to develop along the plate radius.

8. Conclusion

In the case of a rotating cone a heavier disperse phase could be expected to migrate away from the solid surface. This would not be so serious an effect as in the concentric cylinder arrangement because of the normally shallow cone angle.

Unexpectedly, the concentration as a function of time does not have the radius as a parameter.

9. Finite Cone Tip Clearance

The measurement of normal stress differences using a cone/plate arrangement with a finite cone tip clearance from the plate, has been suggested by Jackson and Kaye¹, and Marsh and Pearson². Such a method is not treated here because of the doubt about the validity of the treatment.

Assuming that the desired ideal flow pattern is achieved in such an arrangement in which the fluid elements move as concentric circles about the axis of rotation. Then the geometry comprises an amalgamation of the cone and plate with the parallel plate arrangement. The join being at an interface defined by the dotted line in figure 8.

The stress distributed in the two component geometries are not compatible however. Hence no such motion as that visualised will, in general, be possible. An exceptional case is that in which no normal stresses are generated, when the motion envisaged is, in the limit of small angular rates of rotation and no boundary disturbances, possible.

10. References

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3. Pritchard, W. G., Phil. Trans. Roy. Soc., Lond. 1971, 270, 507.

11. Appendix Further Approximations

Further approximations to the formula for concentration as a function of time may be obtained by writing the first approximation (29) as $c=c_1(t)$. The second term in (28) becomes $c_1(1-c_1)A$ and (28) may be integrated with respect to time. The same procedure may be used of course in respect of (7) and (8) of Part I.

Naturally, if one knows the viscosity as a function of concentration then the viscosity distribution at a given time t may be evaluated.

We assume throughout this work that the ratio of the local radial acceleration to the gravitational field is large enough for gravity effects to be ignored.

VISCOMETERS WITH CURVILINEAR FLOW PATTERNS

Part II: Cone and Plate Viscometer

Formulae and Figures

Formulae (1) to (6) of Part I (inclusive).

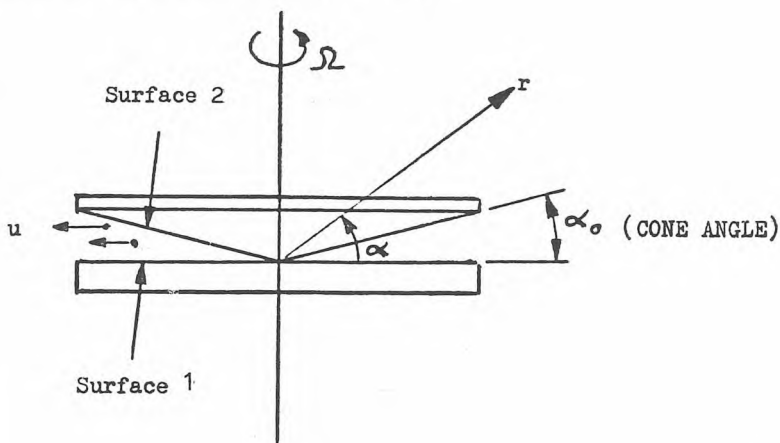


FIG. 4 THE CONE AND PLATE GEOMETRY

$$\frac{\partial c}{\partial t} + \frac{c}{r^2} \frac{\partial}{\partial r} (r^2 u_r) + \frac{c}{r \cos \alpha} \frac{\partial}{\partial \alpha} (u_\alpha \cos \alpha) = 0 \quad (24)$$

$$\left. \begin{aligned} u_r &= u \cos \alpha \\ u_\alpha &= u \sin \alpha \end{aligned} \right\} \quad (25)$$

$$v = K w^2 r \cos \alpha \quad (26)$$

and
$$\left. \begin{aligned} K &= \frac{(p_s - p) d^2}{18 \mu} \\ w &= w(r, \alpha) \end{aligned} \right\} \quad (27)$$

$$\frac{\partial c}{\partial t} + c(1 - c)A = 0 \quad (28)$$

where $A = A(r, \alpha) =$

$$K \left[\frac{1}{r^2} \frac{\partial}{\partial r} (r^3 w^2 \cos^2 \alpha) + \frac{1}{2 \cos \alpha} \frac{\partial}{\partial \alpha} (w^2 \cos \alpha \sin 2\alpha) \right]$$

$$c = \left[\frac{\left(\frac{c_o}{1-c_o} \right) \exp - At}{1 + \left(\frac{c_o}{1-c_o} \right) \exp - At} \right] \quad (29)$$

$$w = \frac{\Omega \alpha}{a_o} \quad (\text{Approximately}) \quad (30)$$

$$u = K(1-c) \left(\frac{\Omega \alpha}{a_o} \right)^2 r \cos \alpha \quad (31)$$

$$\Omega_s = \frac{\partial}{\partial \alpha_o} (\Omega \cos \alpha_o) \quad (\text{At constant wall shear stress}) \quad (32)$$

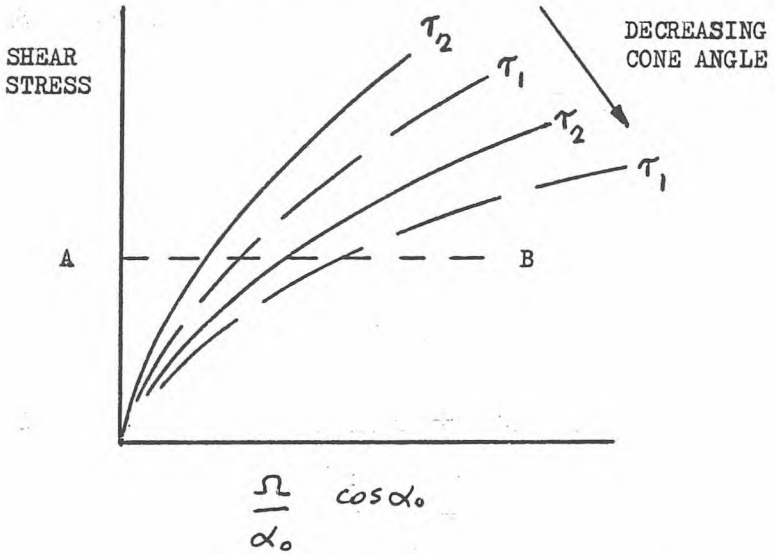


FIG. 5 CONE AND PLATE DATA WITH WALLSLIP

$$\Omega = \int_0^{\alpha_o} \dot{\gamma} d\alpha \quad (33)$$

$$\dot{\gamma} = f(\tau) \quad (34)$$

But, $\tau \cos^2 \alpha = \tau_1 \quad (35)$

$$\Omega = \int_{\tau_1}^{\tau_2} \frac{1}{2\tau} \left(\frac{\tau}{\tau - \tau_1} \right)^{\frac{1}{2}} f(\tau) d\tau \quad (36)$$

$$f(\tau_2) = 2\Omega \sin \alpha_o \frac{d \ln \Omega}{d \ln \tau_2} \quad (37)$$

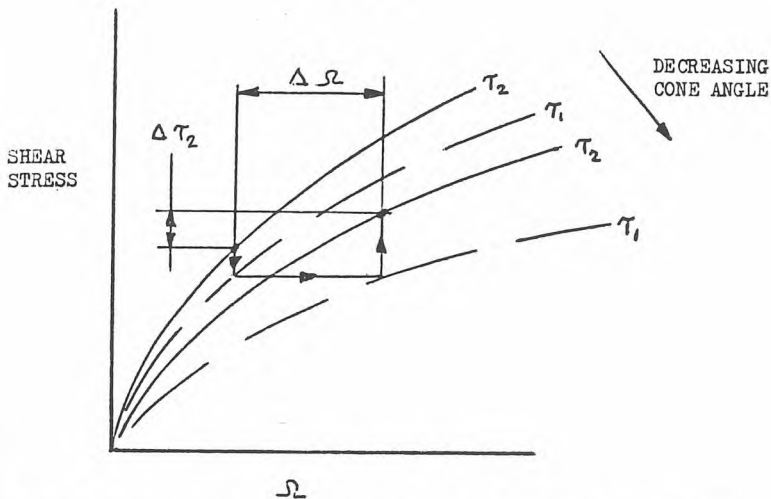


FIG. 6 DIFFERENTIATION OF EXPERIMENTAL DATA FOR EQUATION (37)

$$\frac{\partial \tau_{\alpha\alpha}}{\partial \alpha} + (\tau_{\alpha\alpha} - \tau_{\phi\phi}) \tan \alpha = 0 \quad (38)$$

$$\tau_{\alpha\alpha} - \tau_{\phi\phi} = g(\tau) \quad (39)$$

$$\tau_{\alpha\alpha 2} - \tau_{\alpha\alpha 1} = \frac{1}{2} \int_{\tau_1}^{\tau_2} \frac{1}{\tau} g(\tau) d\tau \quad (40)$$

$$g(\tau_2) = \frac{2\tau_2 d(\tau_{\alpha\alpha 2} - \tau_{\alpha\alpha 1})}{d\tau_2} \quad (41)$$

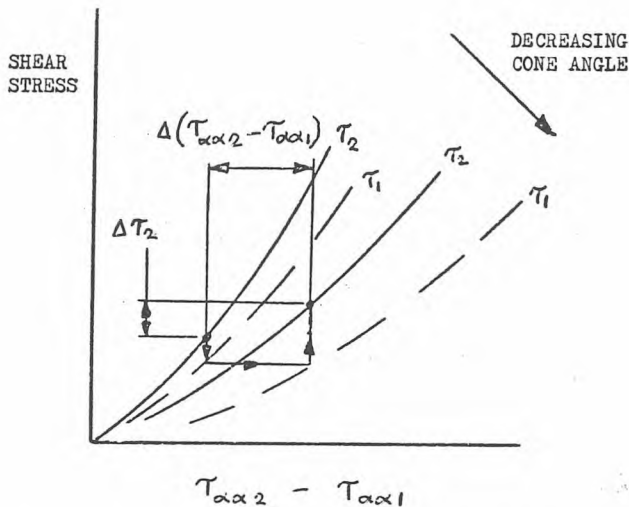


FIG. 7 DIFFERENTIATION OF EXPERIMENTAL DATA FOR EQUATION (41)

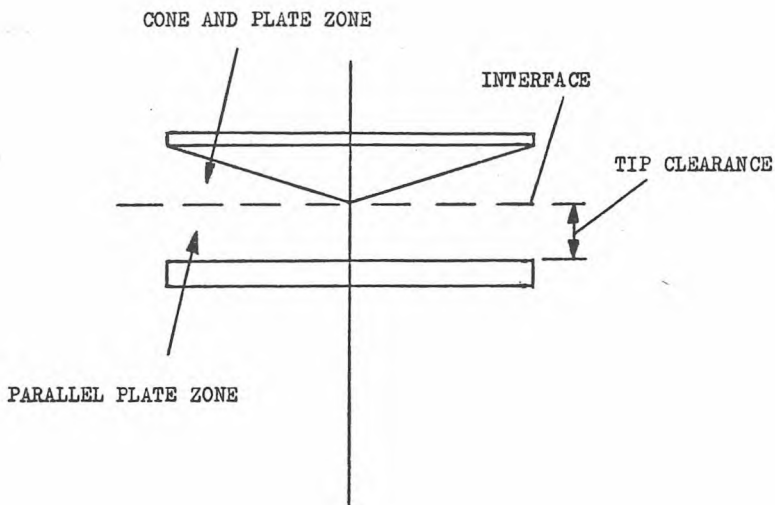


FIG. 8 THE CONE AND PLATE GEOMETRY WITH TIP CLEARANCE

Note on Viscometers with Curvilinear Flow Patterns:

Part 1: Concentric Cylinder Viscometer

(BSR Bulletin 1971, No. 4, Vol. 14, p. 70)

It has been pointed out¹ that if the density of the continuous phase is not negligibly small compared with the density of the disperse phase then to allow for a "radial buoyancy" effect the density term p_s in equations (3), (7) and (12) and also in the expression for K may be written as $(p_s - p)$ where p_s is the particle material density and p is the liquid density.

The liquid density in (2) should be deleted.

Taking into consideration the liquid density of 10^3 kg/m^3 then the particle radial migration velocity on page 71 is $3.9 \times 10^{-4} \text{ m/s}$ and the time for a radial displacement of ten particle diameters is 0.256 seconds. This latter value is still well below the response time of the instrument.

J. HARRIS.

Reference

- ¹ L. Svarovsky Private Communication.

EXPLICIT FORMULAE FOR THE ROTATING OR TRANSLATING CYLINDER WHEN USED IN NON-NEWTONIAN VISCOMETRY

by C. P. Barton, D. C.-H. Cheng and R. W. Higman
(Warren Spring Laboratory, Stevenage, Herts.)

ABSTRACT

Formulae are derived that will enable shear stress and shear rate to be calculated explicitly (without assuming any particular form of functional relationship between them) from experimental data obtained using a single circular cylinder, either in rotation about or in translation along its axis.

In the case of the rotating cylinder the validity of the formulae is demonstrated experimentally using a lubricating oil and a range of solid-in-liquid dispersions.

Notation

a	radius of cylinder
D	shear rate
F	shear stress
h	height or length of cylinder
r	radial co-ordinate
S	thrust
T	torque
v	translational velocity
V	velocity of cylinder
ω	rotational speed
Ω	speed of cylinder

subscripts

$_a$	pertaining to the cylinder wall
$_y$	pertaining to the yield stress

Then it can be shown ⁽³⁾ that the shear stress is given by Equation (1)

Introduction

It is well known that in non-Newtonian viscometry certain relationships known as the explicit formulae exist. These allow the shear stress and shear rate to be evaluated directly from experimental quantities without the need to assume any particular form of functional relationship between them. For example, in tube viscometry the shear rate may be calculated from the Rabinowitsch-Mooney equation¹ and in coaxial cylinder viscometry many such formulae, summarized by Moore and Davis² and later added to by Cheng³ and Krieger⁴, have been derived.

In a previous paper³, the derivation of the explicit formulae was considered for 15 different viscometric flows including Couette and/or Poiseuille flow between parallel planes and coaxial cylinders, and rotational flow between coaxial cones with common apex and concentric spherical surfaces. However it was noted that the formulae obtained "cannot be applied to the case where the outer boundary is absent, for example, in the translation or rotation of a plate or cylinder, or the rotation of a sphere in an infinite fluid, all of which have obvious experimental advantages." It may be added that with materials that possess a large yield stress and low plastic viscosity, the viscometric sample near the outer boundary may well be under insufficiently high shear stress for it to be sheared, in which case, although the gap between the outer and inner boundary may be small compared with the dimensions of the boundaries, the inner boundary would behave as if it was in an infinite fluid.

In this paper the derivation of explicit formulae for viscometry using single bodies is considered. It is at once obvious that only couette flows caused by rotation or translation, are relevant. However, for the translating plane, the usual assumption of laminar flow throughout the infinite fluid leads to results of little importance. Also for the rotating plane, cone or spherical surface, it can be seen that, where a yield stress exists, the surface on which the shear stress equals the yield stress is not planar, conical or spherical, and the usual laminar flow assumption cannot be made. Thus it can be seen that only the motions of a single cylinder give rise to useful results.

Rotating Cylinder

For the rotating cylinder, the assumption of the flow field is such that laminae of the fluid at constant radius from the cylinder axis rotate as rigid bodies. The existence of a yield stress is also assumed with no loss of generality, so that at a radius r_y , the shear stress equals the yield stress and the fluid beyond this position is at rest.

$$F = \frac{T}{2\pi r^2 h} \quad (1)$$

and the shear rate is given by Equation (2)

$$D = -r \frac{d\omega}{dr} \quad (2)$$

On integrating Eq (2) using the boundary conditions: $r = a$, $\omega = \Omega$, and $r = r_y$, $\omega = 0$.

$$\Omega = \int_a^{r_y} D \frac{dr}{r} \quad (3)$$

This equation can be transformed using Eq (1)

$$\Omega = \frac{1}{2} \int_{F_y}^{F_a} D(F) \frac{dF}{F} \quad (4)$$

$$\text{where } F_a = T/2\pi a^2 h \quad (5)$$

Then on differentiating Eq (4) and rearranging,

$$D_a = 2\Omega \frac{d \ln \Omega}{d \ln F_a} \quad (6)$$

Eq (5) and (6) are the explicit formulae for shear stress and shear rate for the rotating cylinder.

The validity of Eq (6) can be readily checked for various model shear-stress shear-rate relations by direct substitution into Eq (3) and carrying out the differentiation that leads to Eq (6). For the power-law model the slope in (6) = $1/n$ is constant, and the corresponding expression for shear rate has been derived by Calderbank and Moo-Young⁵ by a separate route.

Translating Cylinder

For the translating cylinder, such as that obtained in the rod penetrometer, the flow field is such that the coaxial laminae translate as rigid bodies. With the yield stress, the fluid beyond r_y is at rest. It can be shown³ that the shear stress is given by (7)

$$F = \frac{S}{2\pi r h} \quad (7)$$

and the shear rate is given by (8)

$$D = - \frac{dv}{dr} \quad (8)$$

On integrating Eq (8) using the boundary conditions: $r = a$, $v = V$ and $r = r_y$, $v = 0$ Equation (9) results

$$V = \int_a^{r_y} D dr \quad (9)$$

This equation can be transformed using Eq (7)

$$\frac{V}{a} = F_a \int_{F_y}^{F_a} D(F) \frac{dF}{F^2} \quad (10)$$

$$\text{where } F_a = \frac{S}{2\pi a h} \quad (11)$$

Then on differentiating Eq (10) and rearranging,

$$D_a = \frac{V}{a} \left[\frac{d \ln (V/a)}{d \ln F_a} - 1 \right] \quad (12)$$

It is noted that Eq (12) is invalid unless $d \ln (V/a)/d \ln F_a$ is greater than unity. In particular, it is not valid for Newtonian fluids and dilatant-power-law fluids. This fact can also be readily shown by substituting the appropriate equation into Eq (10) when it can be proved that V becomes indeterminate. As a large number of non-Newtonian fluids possess a yield stress or are pseudoplastic, Eq (12) will be useful in viscometry.

Eq (11) and (12) are the explicit formulae for shear stress and shear rate for the translating cylinder.

Application

Some experiments were carried out with the rotating cylinder to demonstrate the validity of the explicit formulae derived above and to illustrate their application. The Brookfield Synchro-leetric viscometer⁶, both a RVT and HBT model instrument, were used, with, in addition to the standard No. 7 spindle ($a=1.588$ mm), cylinders of approximately 1/3, 2/3 and 4/3 ratios of No. 7 spindle radius. Four fluids of different shear-stress/shear-rate relationships were studied: they were a lubricating oil, a 9% aqueous bentonite suspension, a 30% china clay in paraffin paste and a liquid polysulphide polymer sealant.

Before Eq (5) and (6) can be applied to experimental measurements, it is advisable to ascertain whether various boundary factors are significant in influencing the data. These include end effects, wall slippage and the departure of the fluid flow from the assumed laminar flow. The methods of detecting them and correcting for their effects are discussed elsewhere³. In the present work the effect of end effect was assessed by determining the torque for various depths of immersion of the cylinder. From plots of torque versus height, reasonable straight lines, passing through the origin, were obtained, indicating that end effects were negligible. No systematic behaviour could be made of the scatter when all the data, obtained with different experimental conditions, were assessed as a whole and it was considered that it was caused mainly by non-uniformity of the suspensions used and by the low values of scale deflection at low rotational speeds. These explanations would apply to scatter to be noted in later figures.

The mean values of T/h were used in Eq (5) to calculate the shear stress. In view of the experimental scatter it was considered that there is agreement between the results for the cylinders of different radii. This indicates, firstly, that wall slippage was absent during the measurement. Secondly, it illustrates the fact, which can be derived from Eq (4), that there is a one-to-one relationship between speed and shear stress on the cylinder. Because the shear rate is also related one-to-one to shear stress, this proves the fact that at any given shear stress the shear rate is uniquely related to the rotational speed and is independent of the radius of the cylinder.

Eq (6) was then applied to calculate the shear rate and hence the plot of shear stress versus shear rate, Fig. 2. In this, the smoothed curves drawn through the plots of Fig. 1 were used to determine the slope, $d \ln \Omega / d \ln F_a$; and the mean shear stress taken over the different cylinder diameters was shown. Because users of the Brookfield viscometer will normally only have access to the No. 7 spindle the data for this diameter are given in addition. As mentioned before, the difference between the No. 7 spindle data and the mean data is within the experimental error involved in the present work.

It can be seen from Fig. 2 that the shear rate obtained at any rotational speed depends very much on the property of the fluid. For the lubricating oil and the polysulphide polymer the shear rate attained at 100 rev/min was about $30s^{-1}$, but for the two clay suspensions, because of the flat torque-speed curve at high speeds, the shear rate attained was more than $100s^{-1}$ at 100 rev/min.

Also included in Fig. 2 are the results of measurements carried out on Weissenberg Rheogoniometers⁶ using the cone and plate geometry. An R15 model, cone angle 3.9° and cone diameter 75 mm, was used for the china clay in paraffin and the bentonite suspensions, whilst an R18 model, cone angle 2.1° and cone diameter 75 mm, was used for the lubricating oil and polysulphide polymer. It can be seen that there is good agreement between the rotating cylinder data and the cone-and-plate results. The largest discrepancy is about 10 to 20% and can be readily accounted for by uncertainties in the torsion bar/spring constant and the cone angle. Such uncertainties are considered unimportant in the industrial context⁷.

Conclusions

Explicit formulae for shear stress and shear rate have been derived for the motion of a single cylinder, either in steady rotation or in steady translation in a non-Newtonian fluid. The validity of the equations and their implications were tested using a number of materials in the case of the rotating cylinder. The shear-stress shear-rate relationships of these materials cover a wide range of non-Newtonian behaviour. The lubricating oil was nearly Newtonian with a power-law index of approximately 0.84. The china clay in paraffin paste showed some indication of the Ostwald curve⁸, the section shown in Fig. 2 being below the inflection point of the transition from the Newtonian viscosity at rest to a lower Newtonian viscosity at infinite shear rate. The polysulphide polymer possessed a significant yield stress and followed the Herschel and Bulkey⁹ or power-law modified Bingham equation. The bentonite suspension was almost perfectly plastic with a very high yield stress and small plastic viscosity. (The slight increase in shear stress at low shear rates has often been observed in our laboratory in cone-and-plate as well as coaxial cylinder viscometers. The explanation is unknown.) All of the materials were successfully evaluated by means of the explicit formulae.

The experimental results confirmed the theoretical prediction that for the rotating cylinder the shear stress is given by Eq (5). Thus the torque per unit length of cylinder is proportional to the square of the radius and by choosing the appropriate radius the torque can be adjusted to suit a particular viscometer in which the torsion spring constant is fixed. The fact that at any given shear stress the shear rate is uniquely related to the rotational speed and independent of radius was also confirmed. This means that variation in shear rate can only be achieved by changing the rotational speed and not by using cylinders of different radii. However, the exact shear rate obtained does depend on the rheological property of the fluid involved.

Although with the materials used in the present work, end effect and wall slippage were negligible this, in general, will not always be true. It is thought that the end effect was negligible because the radii used were small compared with the depth of immersion, and wall slippage could be expected with suspensions in which the solid and liquid are more readily separable. Also the assumption regarding laminar flow is valid over the range of parameters involved in the present work. The upper limit for the speed which avoids more complex flow situations is not known. This will depend on the size of the cylinder involved.

Acknowledgement

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- ⁹ *Herschell, W. H. and Bulkey, R.*, Koll. Z., 39, 291 (1926).

Fig. 1. The shear stress of test fluids plotted against rotational speed using different radii cylinders. (3281)

Fig. 2. The flow curves obtained using the explicit formulae. (3282)

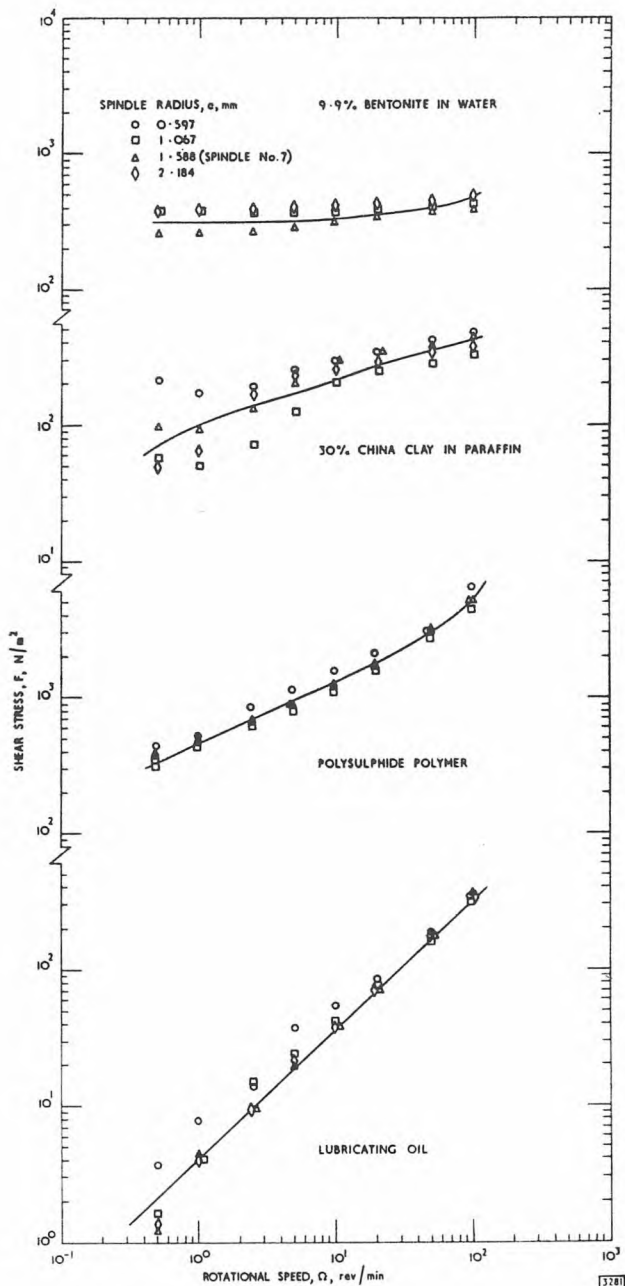


FIG.1 THE SHEAR STRESS OF TEST FLUIDS PLOTTED AGAINST ROTATIONAL SPEED, USING DIFFERENT RADI CYLINDERS.

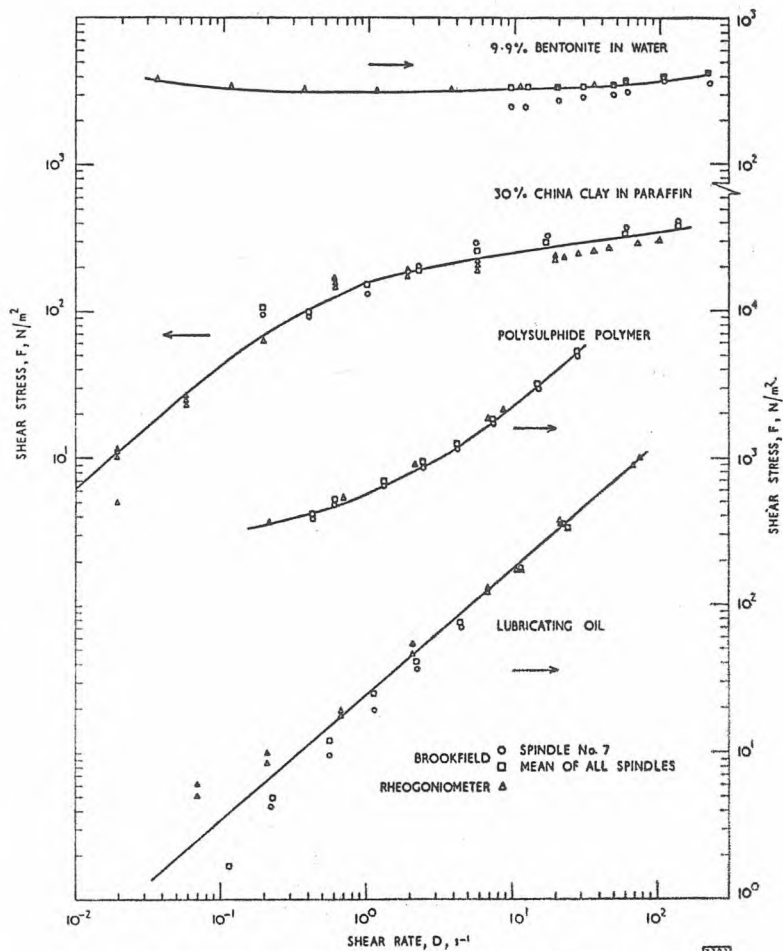


FIG. 2 THE FLOW CURVES OBTAINED USING THE EXPLICIT FORMULAE

European Federation of Chemical Engineering
EXTRUDER MODELLING AND PERFORMANCE

Open Meeting of the Working Party on Non-Newtonian Liquid Processing

16 March, 1972

Dechema-Haus, Frankfurt (M), Theodor-Heuss-Allee 25

Scientific Programme

Responsible: Prof. J. M. Smith, Technische Hogeschool Delft, Netherlands

W. J. Beek, Unilever, Vlaardingen (Netherlands):

“Cooperation in the analysis of polymer processing systems.”

J. R. A. Pearson, University of Cambridge (U.K.):

“Numerical analysis of the metering zone of a screw extruder.”

N.N.:

“Experimental data from German laboratories that have been presented to the Working Party.”

A. K. van der Vegt, Shell Plastics Laboratory, Rijswijk (Netherlands):

“Data from medium scale extruders.”

J. van Leeuwen, TNO Central Laboratory, Delft (Netherlands):

“Measurements of melt temperature and pressure.”

H. Janeschitz-Kriegl, TH Delft (Netherlands):

“Experimental evidence of some fundamental processes in plastics extrusion.”

H. Vermeulen, AKZO, Sassenheim (Netherlands):

“The melting process in a polymer extruder.”

J. M. Smith, TH Delft (Netherlands):

General conclusions

SIXTH SYMPOSIUM ON POLYMER PROCESSING OF THE
IKV—AACHEN

March 22nd and 23rd, 1972

Organizer

“Institut für Kunststoffverarbeitung (IKV) in Industrie und Handwerk” at the Rhein. Westf. Technische Hochschule Aachen. Director: G. Menges.

Place and Time

The Sixth IKV Symposium was held on the 22nd and 23rd of March, 1972, in the Auditorium Maximum (AM) and the Red Room of the University-lecture building, Wüllnerstrasse/Turmstrasse, Aachen.

Reports and Prints

All papers will be published later.

Wednesday, 22nd March, 1972

Injection Moulding

Analysis of the injection moulding process aimed at computer control. S. Stitz, IKV Aachen.

Systematic description of the process—evaluation of response variables—influence of stock pressure and temperature in the mould on the moulded part's quality—open-loop and closed-loop control, supervision of forming the part—computer control.

Open-loop and closed-loop control of relevant injection moulding variables. J. Vargel, IKV Aachen.

Concept of stock temperature control equipment—set up and function of pressure control equipment—controlling stock pressure in the mould.

Improving the efficiency of screw-type plastifying units of injection moulding machines. W. Elbe, IKV Aachen.

Comparison: conventional and novel plastifying units based on improved conveying-plastification, stock temperature, melt quality, and mechanical energy consumption at variation of geometrical and operating variables.

Large Tubes

New techniques to manufacture large tubes. H. Brintrup (reader), D. Auffenberg, H. Berg, A. v. Harnier, P. Mohren, IKV Aachen.

Extrusion of foamed thermoplastic tubes of sandwich structure—continuous feeding of foam glass-pellets between two coating layers with the GRP-winding process—comparison with conventional sewage pipes concerning strength—calculation of the economical side.

Reinforcing

Wet winding of carbon fibres. A. v. Harnier, IKV Aachen.

Development of a system for guiding and wetting the carbon fibre with wet winding—influence of various system material-parameters on wetting and laminate properties.

Education

Modern teaching methods in the field of Polymer Processing. G. Porath, IKV Aachen.

Programmed teaching and audiovisual (teaching) media—inter-dependence between methods, audience, and programme level—expenses and profit.

Influence of flow—and cooling behaviour on the properties of injection moulded parts. G. Wübken, IKV Aachen.

Calculation of the cooling time—interaction between flow and temperature in the melt—interpretation of dimensional stability, distribution of orientation, and internal stresses as functions of flow patterns and variation of thermodynamic state—rules for laying out mould cooling in the light of quality and economy of moulding.

Mould insets of special materials. P. Mohren (reader), B. Horn, IKV Aachen. Comparison steel—graphite; properties—applicability—manufacture—economy.

Progress in processing reactive polymers. D. Rheinfeld, IKV Aachen.

Chemical cross-linking of pure and filled thermoplastics—cross-linking of low molecular resins—high pressure injection moulding— injection mixing—comparison with conventional injection moulding concerning cycle time and final product quality.

Testing/Dimensioning

Dimensioning plastic parts under multi-dimensional load. E. Alf, IKV Aachen.

Creep behaviour of PMMA and PP under one- and multi-dimensional pulsating tensile load, and under alternating compressive, tensile load—influence of notches—self heating of the specimens—forming of crazes—time invariable flow or deformation limit as permissive limit for dimensioning.

Deformation behaviour of thermoplastics in fluid media. R. Rieß, IKV Aachen.

Classification of media according to their influence on polymers—knowing the uncritical linear elastic behaviour dimensioning can be based on tensile data.

Mechanical testing of phenolic resins. R. Kosfeld, K. O. Günther, Department of Physico-Chemistry of Polymers in the Physico-Chemical Institute at the University of Aachen.

Fatigue behaviour of filled phenolic resins at varying temperature—correlation with dynamic mechanical damping measurements.

Economical Themes

Improving the profit-cost situation of injection moulding plants. D. Auffenberg, IKV Aachen.

Cost structure—demand for personal-productive and non-productive machine time—analysis of the present state—how to cut material costs and personal expenses and increase efficiency.

Is computer control of injection moulding production economically justified? Th. Custodis jr., IKV Aachen.

Studies of various injection moulding plants concerning structure—analysis of production costs and (production) time—improvement achievable thanks to use of computers—cost and minimum plant size for computer control.

New and simple rules for dimensioning GRP. H. J. Roskothen, IKV Aachen.

Failure behaviour of mat-laminates—micro-cracks as criteria for dimensioning under mono- and multi-dimensional as well as cyclic load—applicability in practice.

A non-destructive test technique for determining critical pressure values at cylindrical containers. G. Nonhoff, Institut für Leichbau TH Aachen.

By means of eigenfrequency shapes of cylindrical containers under load the critical buckling pressure is determined without destroying the shell.

This technique will be demonstrated with cylindrical shells under external pressure.

Extrusion

Optimizing a novel single-screw concept. U. Kosel, IKV Aachen.

Separation of the functions: conveying, plastifying, homogenizing—empirical investigation of the distinct zones—mathematical/statistical optimization of conveying area and shear zone-melting in channel and slit disk zones.

Temperature and energy measurement in the entrance zone of single-screw extruders. R. Hegele, IKV Aachen.

Screw- and barrel-temperatures in conventional case and with positive conveying entrance zones—subdivision of the total energy consumed in the entrance zone—influence of barrel temperature on energy consumption—calculation of screw drive power dissipated in the entrance zone.

Internal friction of powders conveyed in single-screw extruders. E. Goldacker, "Institut für Verfahrenstechnik," TH Aachen.

Analysis of the entrance zone—theoretical determination of the influence axial grooves have on conveying—approximation solution for determining conveying rate, drive power, as well as pressure profile along the screw.

Designing

Design methods for plastics. H. Schulze, IKV Aachen.

Relationship cost/design—forming basic elements for design—design, material- and process-selection as a working sequence—decision finding by evaluation—effect and profit of a systematic design method—state of art of a method for injection mouldings.

Dimensioning rib-fortified plates of thermoplastics. F. Knipschild (reader), H. Schulze, IKV Aachen.

Theoretical fundamentals—experimental equipment—specimen geometry—measurement of strain distribution—critical deformation in plate and ribs—studies of similitude—testing structures.

Long term behaviour of K-elements. H. Langer, "Institut für Maschinenelemente und Maschinengestaltung."

Application and calculation—different load conditions with separable and fixed joints—application of second order bending theory—optimization and testing under polarized light—terms of reference for dimensioning based on long term static and dynamic behaviour.

New measuring techniques for characterising mixing quality at the extrudate.

V. Giegerich, IKV Aachen.

Dispersing colour beads in translucent melts is measured optically in a tool adjacent to the screw area—light absorption is a measure of homogeneity.

High Pressure Plastifying

Ultra-high pressure plastifying of polymers. E. Döring (reader), W. Dalhoff, D. Rheinfeld, H. Potente, IKV Aachen.

Necessary pressure—mechanism of energy conversion—experimental results won on a ultra-high pressure plastifying unit (prototype at the IKV)—discussion in the light of the theory.

Foaming

Moulding from Polyurethane-sandwich foam. K. Schwanitz, IKV Aachen.

Forming the outerskin—determination of density—controlling the sandwich structure—novel processing techniques—process data.

Corrosion Protection

Predicting the working life of corrosion protective polymer coatings on metal. W. Schneider, IKV Aachen.

Behaviour of thermoset/metal composites under aggression of media measured by means of electrical techniques—failure by bubble forming—penetration of inorganic acids through thermosetting films and re-diffusion of gaseous components.

Welding of Polymers

Prediction of the weldability based on material data. D. Pieschel (reader), H. Potente, IKV Aachen.

Ultra sonic welding: analysis of the welding process and formulation of material characteristics for estimating the weldability of various thermoplastics—heating element welding: studies of the heating mechanism as a function of operating conditions and material properties.

Heat transfer at blown films and shrinkage behaviour. W. Predöhl, IKV Aachen.

Elastic deformations during film production—variables governing the elastic deformation—temperature and time dependence of shrinking—analysis of heat transfer—formulation of a heat transfer law based on temperature and velocity field measurements.

Improved control of the extrusion process. M. Meißner, IKV Aachen.

Terms of reference for dimensioning water cooling and laying out control equipment—comparison to airfanning—optimizing the start-up period with extruders—aspects towards application of computers for controlling extrusion equipment: steps of realization, economy.

Controlling melt viscosity with extrusion. M. Petrik, Laboratorium für Ultraschall TH Aachen.

Fundamentals of measuring melt viscosity by means of ultra sonic waves—sound velocity and absorption measurements with melts—cascade control of extruders using viscosity as controlled variable—comparison with temperature control.

FORTHCOMING MEETINGS

Materials Science Club

STRUCTURE AND TEXTURE OF FOOD

6 and 7 July, 1972

University of Surrey, Guildford, Surrey

Introduction

This meeting is being organised jointly by the Materials Science Club and the University of Surrey Food Research Group, which comprises members of the University in the Departments of Hotel and Catering Management and Biochemistry and Biological Sciences. Mr. John O'Connor of the Department of Hotel and Catering Management is acting as organiser of the meeting, and Mr. M. G. Bader will act as coordinator on behalf of the Materials Science Club.

The meeting will follow the normal format of the Materials Science Club meetings, starting with lunch on day 1, and finishing at tea-time on day 2, 7 July. There will be an informal dinner on the evening of the first day. Accommodation will be available at the University and the total charge for registration, accommodation and meals is envisaged to be of the order of £9.

Programme

FIRST SESSION 14.00 hrs. 6 July—"Food Structure"

Dr. A. W. Holmes, Director of B.F.M.I.R.A. (British Food Manufacturing Industries Research Association) will give an introductory talk and we then have contributions on "The Structure of Biological Products, Meat and Plant Tissues, The Structure of Manufactured Products, Cereal Foods, and Fats and Related Foods."

The evening will be devoted to the dinner.

SECOND SESSION—"Food Texture, Rheological Techniques"

Dr. P. Sherman of Queen Elizabeth College, London (previously of Unilever) has agreed to act as Chairman, and we also have a contribution from Dr. Scott Blair. The topics to be covered in this second session are the "Rheology of Liquid Foods, Rheology of Semi-solid Foods, Rheology of Solid Foods, Powders and Non-particulate Solids."

Conference

YIELD, DEFORMATION AND FRACTURE OF POLYMERS

26-29 March, 1973

Churchill College, Cambridge

- L. J. Broutman, Illinois Institute of Technology, Chicago, Ill. 60616, U.S.A.
"Toughness enhancement of polymers by cold rolling and thermal tempering."
- S. Arad, L. Culver and J. Radon, Imperial College, London S.W.7.
"Strain rate sensitivity of polycarbonate and nylon."
- B. L. Earl, Yarsley Research Laboratories Ltd., Chessington, Surrey.
"Effects of fibrous filler upon crazing in polystyrene."
- M. M. Hall, RAPRA, Shawbury, Shrewsbury SY44NR.
"The effect of thermal ageing upon the physical properties of polymethylmethacrylate."
- J. W. S. Hearle, Dept. Textile Technology, UMIST, Sackville Street, Manchester.
"Mechanism of fracture and fatigue in polymeric fibres."
- D. Hull, Dept of Metallurgy and Materials Science, University of Liverpool, P.O. Box 147, Liverpool L69 3BX.
"Some aspects of the structure-property relationship in determining the yield and fracture properties."
- W. Retting, 67 Ludwigshafen, BASF G201, Germany.
"Molecular orientation, viscoelastic functions, and ultimate properties of drawn polymers."
- D. C. Blackley, National College of Rubber Technology, Polytechnic of N. London, Holloway, N.7.
"Viscoelastic properties of fibre-filled elastomers."
- K. J. Miller, Engineering Department, University of Cambridge, Trumpington Street, Cambridge.
"Effect of hold time on crack propagation rates."
- M. Bevis, Dept. of Metallurgy and Materials Science, University of Liverpool, P.O. Box 147, Liverpool.
"The microstructure of crazes."
- D. V. Quayle, Dept. of Metallurgy, Sheffield Polytechnic, Sheffield S1 1WB.
"Influence of microstructure on the yield and deformation characteristics of reinforced thermoplastic elastomers."
- J.-C. Bauwens, Institut des Materiaux, 87 avenue A. Buyl, 1180 Bruxelles, Belgium.
"The physical meaning and the applicability of a yield criterion proposed for glassy polymers."
- P. Beardmore, Scientific Research Staff, Ford Motor Co., Dearborn, Michigan 48121, U.S.A.
(a) "Cyclic deformation and fracture of polymers."
(b) "Relationship between bulk flow and crazing in fracture of polymers."
- E. Baer, Case Western Reserve University, Cleveland, Ohio 44106, U.S.A.
"Fracture of amorphous polymers at cryogenic temperatures."
- S. S. Sternstein, Material Division, Rensselaer Polytechnic Institute, Troy, N.Y. 12181, U.S.A.
"Multiaxial viscoelasticity (and/or) multiaxial yielding."

- A. S. Argon, Massachusetts Institute of Technology, Dept. of Mechanical Engineering, Cambridge, Massachusetts 02139, U.S.A.
- (a) "A molecular mechanism of yielding in glassy polymers considering the mutual constraints between molecules by the theory of elastic disinclinations"
or
(b) "The course of toughness in high impact polymers with special emphasis on the effect of the form of dispersion of particles on the toughness."
- D. Hansen, Materials Division, Rensselaer Polytechnic Institute, Troy, N.Y. 12181, U.S.A.
"Large strain cyclic simple shear experiments on polyethylene."
- P. P. Benham, Ashby Institute, Queen's University, Belfast.
"Investigation of the basic parameters for the fatigue of thermoplastics."
- C. B. Bucknall, Department of Materials, Cranfield Institute of Technology, Cranfield, Bedford.
"Mechanism of creep in ABS and ABS/PVC blends."
- G. F. Hardy, Celanese Research Co., Summit, New Jersey 07901, U.S.A.
"Delamination resistance of bi-orientated plastic films."
- M. W. Darlington, Dept. of Materials, Cranfield Institute of Technology, Cranfield, Bedford.
"Volume changes and stress history effects in creep of short fibre reinforced thermoplastics."
- W. Döll, Institut für Festkörpermechanik, 78 Freiburg i. Br Rosastrasse 9, Germany.
"The influence of molecular weight on the fracture properties of PMMA."
- A. D. Wilson, Laboratory of the Government Chemist, Cornwall House, Stamford Street, London S.E.1 9NO.
"Glass ionomer cements."
- J. Roberts, Royal Armament Research and Development Establishment, Fort Halstead, Sevenoaks, Kent.
"A critical strain parameter defining the quasi limit of elasticity for rigid polymers."
- B. J. MacNulty, Non-metallic Materials, ERDE, Ministry of Defence, Powder Mill Lane, Waltham Abbey, Essex.
"Polymers with phenylene groups in the main chain: solvent effects on morphology and crystallinity."
- G. M. Bartenev, Chernyachovskaya Str 5, App. 135, Moscow A-319, U.S.S.R.
"Connection between the structure and relaxation processes in rubberlike polymers."
- D. Kranz/L Morbitzer, Leverkusen/Germany Farbenfabriken, Bayer AG.
"Deformation and craze-behaviour of two-phase-polymers (ABS) with special grafting structures."

NEWS FROM THE SOCIETY OF RHEOLOGY (U.S.A.)

The 42nd Annual Society of Rheology Meeting held at the University of Tennessee at Knoxville was highlighted by the presentation of the Bingham Medal of the Society to Dr. Arthur S. Lodge, Professor of Rheology at the University of Wisconsin at the Bingham Award Banquet, October 26, 1971. Dr. Lodge was introduced and his work cited by Professor R. B. Bird, also of the University of Wisconsin who noted Lodge's contributions to theoretical continuum mechanics, molecular theories of flow of concentrated polymer solutions and experimental methods of measuring normal stresses. The medal was presented to Professor Lodge by Dr. Herschel Markovitz, outgoing Society president.

A native of England, Professor Lodge was educated at Oxford and later moved to Manchester where he researched and wrote many of his best known papers when with the British Rayon Research Association and the University of Manchester Institute of Science and Technology. In 1964 he published his well known monograph, *Elastic Liquids*. Dr. Lodge joined the University of Wisconsin in 1969 where he holds the unique title of Professor of Rheology.

The Knoxville Society of Rheology Meeting featured a Symposium on Fibre Spinning which contained papers by numerous American and foreign scientists and engineers including Dr. A. Ziabicki of the Polish Academy of Sciences, Dr. K. Katayama of Asahi Chemical (Japan), Dr. Anton Peterlin of the Camille Dreyfus Laboratory, and Dr. F. N. Cogswell of Imperial Chemical Industries of the United Kingdom. The Symposium, organised by Professors D. C. Bogue and J. L. White, was held at Knoxville both because of the significant current research in the melt spinning process and because Knoxville lies in the heart of the area of the American synthetic fibre industry. Other distinguished foreign speakers included Professor Y. Mori of the University of Tokyo and Dr. J. Meissner of BASF (West Germany). The meeting also featured an Instrument Exhibition.

Professor Frederick Eirich of the Polytechnic Institute of Brooklyn was elected president of the Society for the next two years. He was succeeded as vice-president by Professor Ronald S. Rivlin of Lehigh University.



Prof. Arthur S. Lodge (right) was awarded the Bingham Medal at the 42nd Annual Society of Rheology Meeting at The University of Tennessee, Knoxville. President of the Society, Prof. Herschel Markovitz presented the award. Mrs. Lodge is in the background.

RHEOLOGY OF LUBRICANTS

Lists of Papers for Conference on "Rheology of Lubricants" to be held at Trent Polytechnic, Nottingham, on 6th-7th July 1972 under the joint auspices of the Institute of Petroleum, Institution of Mechanical Engineers and British Society of Rheology.

1. Review Paper "Petroleum based Lubricants and Greases"
by J. F. Hutton (Shell Research, Thornton).
2. "Rheological Properties of Multigrade Lubricants"
by J. A. Spence and D. E. S. Middleton (University of Dundee).
3. "The Rheology of Carbon-black Filled Lubricating Oils"
by J. Harris and E. T. Busby (University of Bradford).
4. "Low Temperature Rheological Properties of Polymer Treated Lubricating Oils"
by J. N. Slimming, I. R. H. Crail and P. J. Hattersley (Edwin Cooper and Co. Ltd.).
5. "The Behaviour of Non-Newtonian Lubricants in Journal Bearings—A Theoretical Study"
by J. M. Davies and K. Walters (University College of Wales, Aberystwyth).
6. "The Problems of Measuring the Rheological Properties of Grease in Rotating Geometries"
by G. R. Dobson and A. C. Tompsett (BP Research Centre, Sunbury).
7. "A Limitation on the use of Cone and Plate Rheometers for the Study of Grease Rheology"
by J. F. Hutton (Shell Research, Thornton).
8. Review Paper "Rheology of Biological Lubricants"
by Prof. V. Wright and Prof. D. Dowson (University of Leeds).
9. "Bio-Lubricants"
by J. Ferguson (University of Strathclyde).
10. "The Development of a New Absolute High Pressure Viscometer with Preliminary Results"
by W. R. D. Wilson, A. W. Birks and Prof. B. Crossland (Queens University, Belfast).
11. "The Improved Prediction of Lubricating Oil Viscosity at High Pressure"
by R. F. Pywell (BP Research Centre, Sunbury).
12. Review Paper "New Concepts in Theoretical and Experimental Rheology"
by K. Walters (University College of Wales, Aberystwyth).

DIARY

1972

- 11-13 April.** Conference—Polymers in the Transportation Industry, Joint I.Prod.E./P.I./I.E.D./S.E.E. Meeting.
- 15-18 May.** Conference—International Rubber Conference, Brighton I.R.I.
- 22-24 May.** Conference—Plastics in Mechanical Engineering, I.Mech.E./P.I.
- 6-7 July.** Conference—Rheology of Lubricants. Joint Inst. Pet./I.Mech.E./B.S.R. at Trent Polytechnic, Nottingham.
- 4-8 September.** Congress—6th International Congress on Rheology, Lyon, France.
- 12-14 September.** Symposium—Mechanical Design and Manufacture of Instruments, City University, London.
- 25-26 September.** Conference—Electro-Optic Systems in Flow Measurement, University of Southampton.

See B.S.R. *Bulletin* 1971, No. 4, Vol. 14, for list of Plastics Institute Meetings.

WE WOULD LIKE TO HEAR FROM YOU

B.S.R. members are reminded that the Editor of the *Bulletin* is always interested in receiving informative articles, comments, news and other material which would help to make the *Bulletin* one of the more welcome sights in the flood of reading matter to which most of us are accustomed and resigned.

Suggestions of possible improvements in the *Bulletin* would also be welcome. So if you have a thought and a minute to put pen to paper why not let us hear about it?