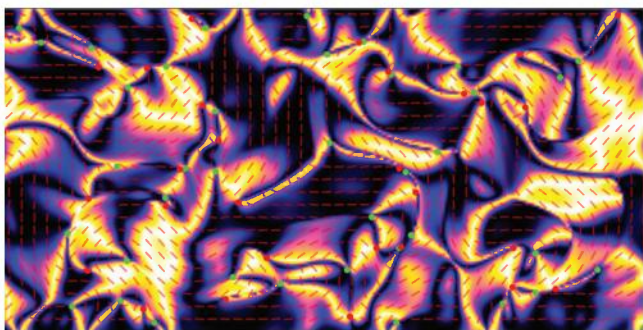

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EDITORIAL

Welcome to Volume 56 (issue #1) of the British Society of Rheology Bulletin. We have another in-depth article by Richard Buscall and collaborators and an article concerned with “Ken, Rheology and Life” by Ralph Oliver. Finally we have an analysis of the highest cited papers from the Journal of Rheology (from 1978 onwards) together with the usual mix of BSR and Industry news.

Rob Poole, Liverpool March 2015.

SUBMISSIONS TO THE BULLETIN

Submissions to the Bulletin are welcomed. Electronic submissions by email to the Editor (bulletin@bsr.org.uk) are preferred in word format (e.g. .doc or .docx). Please always provide a contact name, address, e-mail, or telephone number in case of problems. The deadline for submission is Feb. 15th, June 15th and Oct. 15th, respectively, for three issues annually.

COVER ILLUSTRATION

The cover image shows active nematics in the turbulent phase. Plotted is n (red lines), the director describing the average local orientation. The colourmap shows the Schlieren pattern, also plotted are the positions of topological defects (red circles $-1/2$, green circles $+1/2$). For complete details see: E. J. Hemingway, A. Maitra, S. Banerjee, M. C. Marchetti, S. Ramaswamy, S. M. Fielding, M. E. Cates, (2015) Active Viscoelastic Matter: from Bacterial Drag Reduction to Turbulent Solids. Phys. Rev. Lett. 114, 098302

AIMS OF THE SOCIETY

The way liquids flow and solids deform affects all aspects of life.

Extraction and processing of crude oil, moulding of plastics, use of toothpaste, spreading of margarine, painting and the lubrication of joints in the human body are all examples of processes depending upon rheological behaviour. Rheology is defined as the science of the deformation and flow of matter.

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The constitutive behaviour of strong cohesive particulate gels undergoing consolidation.

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Rather than continue with the theme of rate-dependent yield, another aspect of cohesive suspension behaviour will be addressed this time, although we may come back to the dynamics of yield in a later edition. Please note though that there were one or two errors in our article in the last Bulletin [55(3), 79-88], the correction of which changes the figures slightly, albeit without affecting any of the take-home messages or conclusions. Please see the 'Errata' appended at the end of this article for details of the corrections.

Introduction

Now to the topic at hand: the particulate matrix of a cohesive particulate gel undergoes compression when it is caused to consolidate by some means or another – in, say, gravity batch settling, or in centrifugation, or pressure-filtration, or, for that matter, drying. Since the particles are sticky and since a resolvable volumetric strain cannot sensibly be distinguished from a change in the local solids volume fraction ϕ in practice, a volumetric Hencky strain increment can be defined in terms of volume fraction as $\delta \ln \phi$. The bulk modulus of the network can then be written as $K(\phi) = dP(\phi)/d \ln \phi$ [1] where P is the pressure supported by the network. A simple prescription for the pressure P required to take the

concentration from a starting value ϕ_0 to any value $\phi > \phi_0$ then follows by integration [1,2],

$$P(\phi, \phi_0) = \int_{\phi_0}^{\phi} K(x) d \ln(x) \approx \alpha \int_{\phi_0}^{\phi} G(x) d \ln(x) . \quad (1)$$

On the right-hand side of (1) the K has been related through to the shear modulus G by assuming for simplicity that the Poisson's ratio of the network is independent of ϕ as a first approximation. The reasons for doing this will become apparent below. Please note that Eqn (1) is intended to apply to strongly bonded systems only; i.e., those where there is no possibility of bulk viscous creep on the timescale of interest. More generally, the modulus would need to be a function of time at the very least. Please note also that the use of the bulk modulus K carries the implication that the strain is isotropic in uniaxial confined loading (typical consolidation experiment), just as it would be, say, for a colloidally stable suspension exhibiting osmotic pressure. For a particulate network, though, it is not so obvious that the normal strain need be isotropic necessarily. At the other extreme it could be purely uniaxial, in which case K would need to be replaced by the confined modulus C , being related to K by $C = 9K/5$ for isotropic materials. That the ratio $K:C$ is an order-one constant means that ignorance of the actual state of strain of any real network need not concern us too much for the many purposes, perhaps.

The prime experimental reason for favouring eqn 1 is that it accounts for the widespread observation that P , K and G are similar in magnitude [1- 4]. The shear strength (yield stress), by contrast, is usually found to be one to two orders of magnitude smaller [1,3,4]. It is typically found too, that consolidation seems to be fully irreversible; that a critical pressure needs to be reached before anything happens and that the strength P can appear to be independent of ϕ_0 [3-6]. These features do not sit too well with eqn 1, which, even given that the modulus is a strong function of ϕ [1,3-7], predicts that consolidation should be reversible in part; that P should

depend upon ϕ_0 , albeit weakly away from the gel-point, and that there should not be a threshold pressure at any ϕ_0 . An alternative is to regard the pressure itself as a definite material function; viz. to say that the network has a compressional yield stress $P(\phi)$ [8], a description that turns out to be convenient for many purposes [4,8]. More fundamentally, though, one cannot have one's cake and eat it, the notion of 'ratchet poroelasticity' not withstanding [2], and eqn (1) simply accounts for too much for it to be abandoned lightly. Another possibility, though, is that it is merely incomplete. Laboratory experiments tend inevitably to be performed on a small scale, where walls and boundaries are never far away, and most cohesive suspensions are adhesive as well as cohesive. The problem with eqn 1 then, is that it neglects the possibility that the network might be partly or even wholly supported by adhesion to nearby walls [9-12]. If, on the other hand, consolidation cannot proceed without yield and then slip at walls [9,10], then the inconsistencies or contradictions mentioned above can be resolved [9-12].

It is convenient to characterise wall adhesion by means of a wall shear stress σ_w [9]. This will be assumed to be smaller than yield stress of the network itself, σ_y , but of the same order of magnitude [13], viz.

$$\sigma_w(\phi) \leq \sigma_y(\phi) \equiv \gamma_c(\phi)G(\phi) . \quad (2)$$

On the right of (2) the shear yield stress has been factored into the product of an *apparent* yield strain γ_c and the linear shear modulus G . γ_c , defined thus, is found to vary relatively weakly with ϕ and hence it provides a convenient way of parameterizing or quantifying the intrinsic shear strength of any particular system [7,10,11]. γ_c is found to be of order ~ 0.01 or less, typically [3-7,10, 11,13].

Wall adhesive effects can be neglected when $\frac{20L\gamma_c(\phi)G(\phi)}{3wP(\phi)} \ll 1$ [9-11],

where w and L are the width and height of the sample (assumed to be

confined in a cylindrical tube for simplicity), but not otherwise. Nor, from eqns 1 and 2, can adhesion ever be neglected when ϕ is *very* close to the gel-point ϕ_g , unless, that is, $\gamma_c \approx 0$, which in practice seems to mean $< 10^{-4}$ [9-11], since, again from (1) and (2), the shear and compressive strengths are expected to become comparable near ϕ_g . The latter point translates in practice into meaning that whereas wall effects can be very important in gravity batch settling in small tubes, where there is relatively little compression, [9,10] they can be much less important in centrifugation and pressure-filtration, where the pressures and volume-fractions are higher [12].

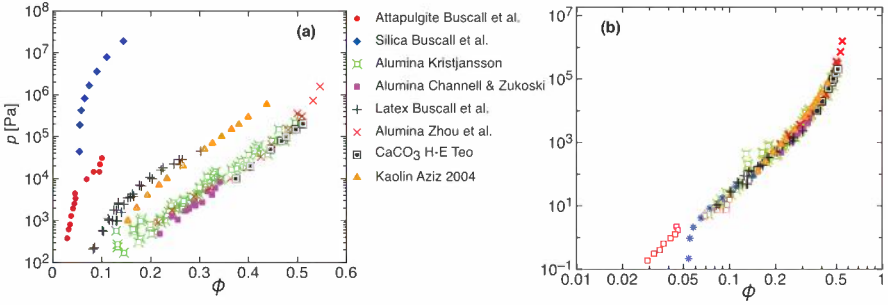


Fig. 1 Plots, semi-log and log, of compressive strength versus volume-fraction for a range of mineral suspensions and PSL [3-7,16]. In fig. 1(b) the data in 1(a) have been scaled by shifting data on the ordinate.

Experimental trends.

Fig. 1a shows a compilation of compressive strength data for some coagulated systems, including several sets of data for AKP-30 colloidal alumina from 2 different labs and 4 different workers. The data shown have not been corrected for wall adhesion since they were obtained under testing conditions where such corrections are expected to be smaller than the scatter [12]. That this is so will be demonstrated explicitly for alumina later. Most of the data in fig. 1 pertain to spheroidal or tuberoidal particles, although data for fine kaolin (lozenges) and attapulgitte (long needles) is

shown too. The particle size range covered for the spheroids and tuberoids is almost two decades (from 4.5 μm for CaCO_3 down to 26 nm for SiO_2).

The right-hand fig.1b shows the same data shifted in the ordinate direction so as to scale them together. Something approaching a master curve results. The only significant departure from a common curve is shown by SiO_2 , which displays an obvious gel-point. The SiO_2 gels were however very strong by virtue of their small particles size (26 nm dia.) and it was only in this case that it was possible to get very near the gel-point with the methods used (centrifugation and pressure filtration, variously). It turns out, though, that the gel-point of the tuberoïdal colloidal alumina happens to be very similar: That it must be <0.06 is clear from fig. 2, which shows the shear yield stress for the same alumina, whereas sensitive gravity batch settling tests performed by one of us implied a value of 0.05 [16]. The superposed alumina data and hence the common curve can be fitted by

$$P \propto \phi^{3.8} (0.64 - \phi)^{-1.8}.$$

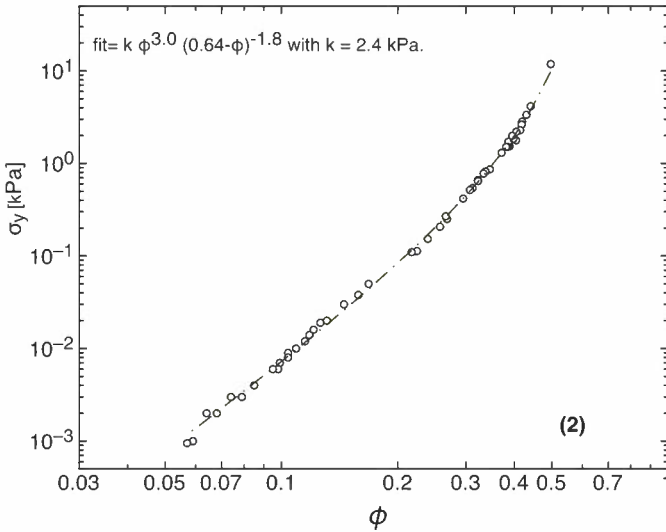


Fig. 2 Plot of shear yield stress [16] versus volume-fraction for AKP-30 Alumina, fitted as shown.

The concentration dependence of the shear yield stress can (from fig. 2) be seen to be weaker than that. The power-law exponent of 3.0 derived from fig. 2 is typical for the yield stress, whereas the shear modulus is found to show an exponent of ~ 4 , typically [1,3-7]. That means that the apparent critical strain defined by the right-hand side of eqn 2 increases with concentration in this case.

If eqn 1 is valid, then it should be possible to predict the compressive strength from the shear strength using eqns 1 and 2, under circumstances where wall adhesion is unimportant at least, which, in the present context means at volume-fractions $\phi \geq 2\phi_g$ [12]. The blue and red lines in Fig. 3a show the result of such predictions.

The blue (upper) continuous line was obtained by supposing that γ_c is constant ($= 0.005$) for the purposes of comparison only, since we know that it is not, and the red (lower) full line by assuming that γ_c is directly proportional to ϕ . The agreement between the red line experimental data is excellent for $\phi < 0.4$. Above that it is not, although there are good reasons why there might be a difference there, neglect of the osmotic pressure of the particles being one since this must diverge at jamming, regardless of the state of aggregation of the particles. The agreement below $\phi < 0.4$ is however gratifying, given that the compressive strength ranges over 4 decades.

Direct experimental evidence in favour of the model encoded in eqns 1 and 2 is shown in the fig. 3b where the experimental ratio of shear to compressive strength is plotted against ϕ , together with an indication of the experimental uncertainty. The curves imply that the ratio starts at unity and decays rapidly with increasing volume fraction. This is exactly what eqns 1 and 2 predict must happen by embodying the idea that particulate gels are strain-hardening in compression and ‘short’ in shear, as they do. It alone is powerful evidence that eqns 1 and 2, simple though they are, capture most of the action in the absence of significant wall adhesion.

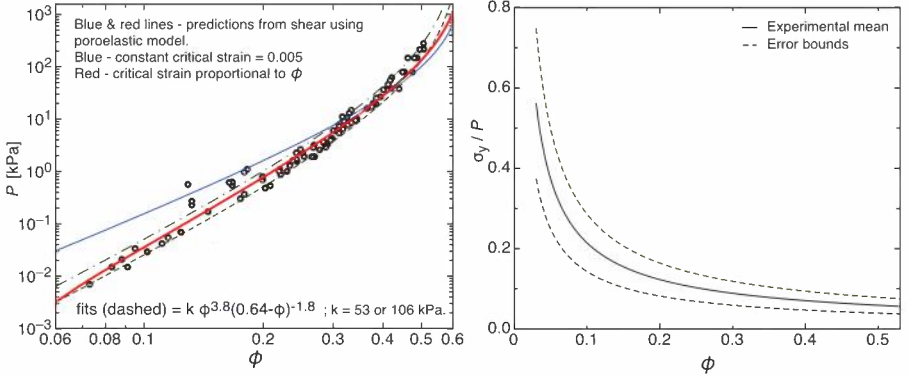


Fig. 3a - Compressive stress for AKP-30 Alumina, fitted as shown and compared with predictions made from the data in fig. 2 using eqns 1 and 2 (see text). Fig. 3b – plot of shear to compressional strength ratio obtained from the fits shown in figs 2 and 3.

Interim remarks:

The scalings described here strongly favour the simple constitutive behaviour encoded in eqns 1 and 2, insofar as it goes. The fact that both particle size [4] and now, seemingly, shape can be scaled together (fig. 1a) seems remarkable. That the simplest of constitutive models does not more generally account fully for irreversibility, nor for critical or yield-like behaviour were concerns until recently, although wall adhesion now looks to be capable of accounting for these anomalies [9-11,12], just as Michaels and Bolger [9] would have expected, no doubt.

Comparison of the new shear data for alumina with that of Channell & Zukoski [5].

Whereas fig. 3 contains direct evidence in support of the simple constitutive model embodied in eqns 1 and 2, it might be thought that the comparison of the experimental data for alumina with predictions made from the shear yield stress, using eqns 1 and 2, amount to little more than curve-fitting. That would certainly be true had $\gamma_c(\phi)$ been allowed to float

arbitrarily. A linear dependence was however used advisedly, on the basis that the exponents of the concentration dependence of the shear yield stress and the shear modulus have generally been found to differ by a unity (being ~ 3 and ~ 4 typically [4,8 loc. cit.]). We do not ourselves have a complementary set of shear modulus data to accompany the yield stresses shown in fig. 2 though. Furthermore, we have ignored the shear data of Channell and Zukoski for AKP-30 [5], who could fit both their shear and compressive strength data using the essentially the same exponent, meaning that, whereas their compressive strength data agree with ours, as shown in fig. 1, their shear yield stress data do not, as can be seen from fig. 4 below.

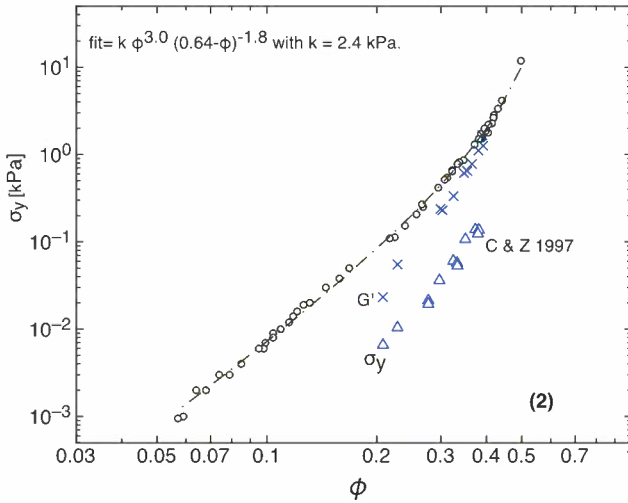


Fig. 4 – Comparison of the current shear yield stress data with that of Channell and Zukoski [5]. Also shown is their G' data.

It can be seen that not only are Channell and Zukoski's yield stresses about an order of magnitude smaller on the average, their shear moduli have smaller values than our yield stress too. The large exponent and much lower magnitude are causes for concern. Unlike us though, Channell and Zukoski used smooth concentric cylinders to perform their measurements, hence a likely explanation of the difference is that they were in fact measuring premature wall yielding and slip. An alternative possibility

perhaps is that their material might possibly have undergone the type of shear induced densification or granulation described by Firth [14] and Mills et al. [15], who showed that shear flow may or may not cause irreversible changes in microstructure, depending upon the nature of the shear-rate history. Having said that, we strongly suspect that slip probably suffices to explain the difference, not least because it is known that materials of this type will slip at an outer cylinder, even when vane inner tools are used, should the gap not be wide enough to prevent it [13].

Shear to compressive strength ratios corrected for wall effects.

Had the material of construction of our centrifuge tubes been the same as for Channell and Zukoski's rheometer tools then we could perhaps have taken their yield stress data for σ_w and used it to correct figs 1, 3 and 4 for wall adhesion using the methods described in [12]. Even had we done so, though, we would however have found the corrections to be small. In the absence of rheometric data obtained using smooth tools of the appropriate construction, it is possible, nevertheless, to calculate an upper bound correction from the true yield stress plotted in fig. 2 on the basis that $\sigma_w < \sigma_y$. The upper continuous line C1 in fig. 5a shows this corrected upper bound curve.

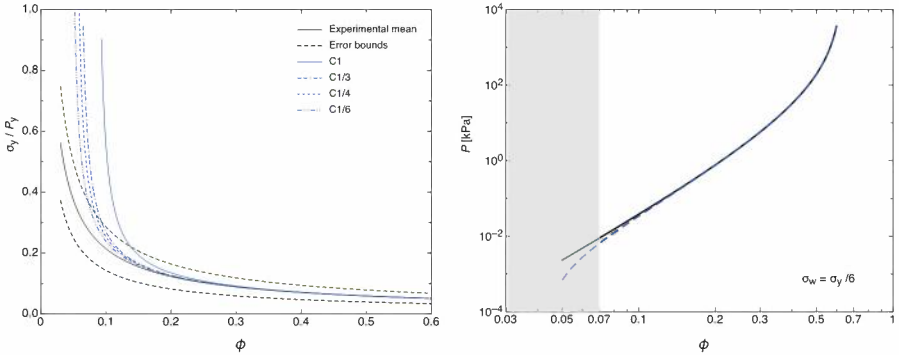


Fig. 5a – Over-corrected strength ratios are shown in blue (see text). Fig. 5b – Smoothed compressive strength data from fig. 3 (full line) corrected (dashed line) using $\lambda = \sigma_w / \sigma_y = 1/6$. The actual experimental data do not extend below 0.07.

We can be certain that C1 is an over-correction because its divergence implies a gel-point of ca.0.09, whereas the σ_y data in fig. 2 extend below imply a gel-point of < 0.06 and settling tests gave a value of ≤ 0.05 [16]. The correction C1 can thus be iterated by assuming that the ratio $\lambda = \sigma_w / \sigma_y$ is a constant and then finding the value of λ by shooting needed to pull the divergence down to 0.05 (cf. the upper set of three broken curves in fig. 5a). In this case a value of a little less than 1/6 is required. The second plot, fig. 5b, shows (the fit to) the original compressive strength data corrected using $\lambda = 1/6$. The lowest experimental data point was at 0.07 (where the shading starts) and the correction there is still less than the typical experimental scatter seen in fig. 2. The corrections are small in part because fairly wide centrifuge tubes (26mm) were used in this instance. These corrections near the gel-point would be proportionally larger with tubes of 10mm diameter or less, whereas it is not uncommon to use tubes of that size in practice [12]. Nevertheless, in centrifuge and pressure-filtration testing, wall adhesion corrections are only really expected to be significant at lower volume-fractions $\phi \leq 2\phi_g$ [12], whereas in gravity batch settling errors due to neglect of wall adhesion can be fatal everywhere [10,11]. It is somewhat ironic perhaps that, whereas in shear rheometry of cohesive suspensions wall slip is a major source of error and confusion, in the compressional testing or particulate networks, wall adhesion complicates life. Or perhaps that is just one of nature's little jokes at the expense of the poor rheologist.

Concluding remarks

Strong cohesive particulate gels have variously been described as being ‘ratchet (poro)elastic’, on the one hand, and as having a yield stress in compression on the other, to the point where the same groups of workers have used both descriptions at one time or another. The dichotomy is real though as such gels do show a somewhat puzzling elastic-plastic duality. This can be explained in part by the strong concentration dependence of the modulus, since this leads to irreversible volumetric strain-hardening, in

effect, but only in small part. The real problem seems to be that, until very recently, most work on consolidation has neglected what Michaels and Bolger [9] told us to do over 50 years ago, viz. to take into wall adhesion into account, most cohesive particulate gels being adhesive too. Since wall adhesive failure is plastic in character, the simplest non-linear elastic model of compressive strength can be combined with the simplest possible model of wall debonding to produce an approximate complete constitutive description. Examples of the use of such a description in detailed modelling of consolidation equilibrium can be found in [10-12]. Consolidation dynamics with wall adhesion is a substantial modelling challenge remaining to be tackled.

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Errata: RB apologises for errors in 55(3) pp. 79-88. The scalar Hencky strain

equivalent should have read $\gamma_H = 2 \ln \left(\gamma / 2 + \sqrt{1 + \gamma^2 / 4} \right)$, where $\gamma = \dot{\gamma} t$ is

the engineering shear strain in step-strain rate flow start up. There was an error in fig. 1 too, which affected other figures, albeit not seriously. The corrected figures can be found in an updated and revised version of ref. 8 (of 55(3) pp. 79-88) to be found at <http://arxiv.org/abs/1410.0179>, which gives a full account of the dynamic behaviour. The figures corresponding to the four in the Bulletin article are 1, 4, 6 and 16 respectively.

Ken, Rheology and Life

D.R. Oliver

Summary

A brief glimpse is given of Ken Walters' life in relation to our rheological work at Birmingham. It is striking that Ken's mathematical background in no way inhibited his helpful interaction with experimentalists and engineers. Four different experiments are mentioned which led to different forms of cooperation and, unusually, more personal stories are linked to the various phases of work. No apology is made for these deviations from the rheological theme, but the more personal approach may fit well with Ken's concept of a rheological "family" within the worldwide scientific community.

Introduction

I first heard Ken lecture in the early 1960's in Aberystwyth and told the young man I couldn't read his writing! No thanks to me, his many later talks have been models of clarity, presentation and humour, even on such practical topics as the Worthington jet. We travelled in a party to the World Rheology Congress in Kyoto in

1968 – which produced many tales – and played squash and golf together, often in the company of Jim Ferguson and Eirean Jones. Neither of us had skied before the age of fifty, but meetings on Rheology in the Vosges and at L'Alpe d'Huez set a trend which continues to this day.

But the main cross-linking between us has been the science of Rheology, and it was clear that Ken had influenced several of our projects in addition to giving editorial help in many J.N.N.F.M. publications. This leads to the current unorthodox style of presentation, which I have not attempted before, a blend of science and life: the rheological background, Ken's influence and a few related anecdotes.

JET THRUST

The jet thrust method of normal stress measurement, devised by Harris⁽¹⁾ and used by Shertzer and Metzner⁽²⁾ (figure 1), depended on the axial stress in a viscoelastic liquid as it left the nozzle reducing the jet thrust when compared with that of a Newtonian liquid at the same Reynolds number.

An early student of mine was due to have his PhD thesis on the subject examined and I had chosen John Harris to be the external examiner. Ken warned me against this and Harris himself said that this was a subject “close to his heart”! The upshot was a convoluted five hour viva after which the examiner said he would “forgo his fee”, by which he meant to act as though no viva had occurred! Ken never said “I told you so”, but re-examined and passed the student within three weeks.

The jet thrust method became controversial because flow is not steady state at the tube exit; the fluid near the wall accelerates rapidly and the consequent hybrid flow gives increased apparent normal stress⁽⁸⁾ (figure 2). This was carefully examined by Davies, Hutton and Walters⁽³⁾ who showed significant divergencies between

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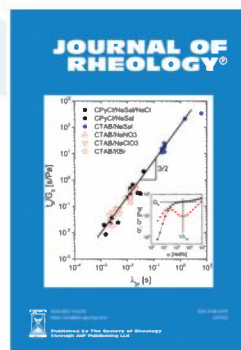
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Editor: Prof. Ralph H. Colby, *Penn State University*

Guest Editor: Prof. Suzanne Fielding, *Durham University*

Expressions of intent to submit a paper are invited for a special issue of the *Journal of Rheology*. Scheduled for publication in spring/summer 2016, this issue will focus on shear banding in complex fluids, with particular emphasis on the dynamics of shear-banded flows and on shear banding in time-dependent flow protocols. Papers concerning wall slip and edge fracture as they pertain to issues of shear banding are also encouraged. Submissions are welcome from experimentalists and theorists, and from all parts of the soft matter and rheology communities: from those concerned with yielding in disordered soft 'glassy' materials, to those with interests in shear banding in polymers and wormlike micelles.



EXPRESSION OF INTENT

If you plan to submit a paper, expressions of intent are encouraged at your earliest opportunity, as it would be useful for us to have a list of potential contributions prior the submission deadline.

- Please inform Ms. Marcy Fowler, Editorial Assistant, by E-mail JOR-EditorialOffice@aip.org
- Please use **INTENT - Special Issue/Shear Banding** in the Subject header of your message.
- Please indicate the area you propose to address in your manuscript.
- Please include contact author's name, institution and email, and those of known or proposed co-authors.

SUBMISSION OF PAPERS

ONLINE AT: <http://jor.peerx-press.org>

SELECT: **Special Issue/Shear Banding** when completing submission data online.



DEADLINE FOR SUBMISSIONS: September 15, 2015
Early submission is strongly encouraged.

Journalofrheology.org

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Gold Medal winner, Gareth McKinley,
receiving his award from BSR president Rhodri Williams



jet thrust and torsion balance rheometer data (figure 3). I later found that jet thrust was a good method of ranking the elasticities of multigrade motor oils at high shear rates.

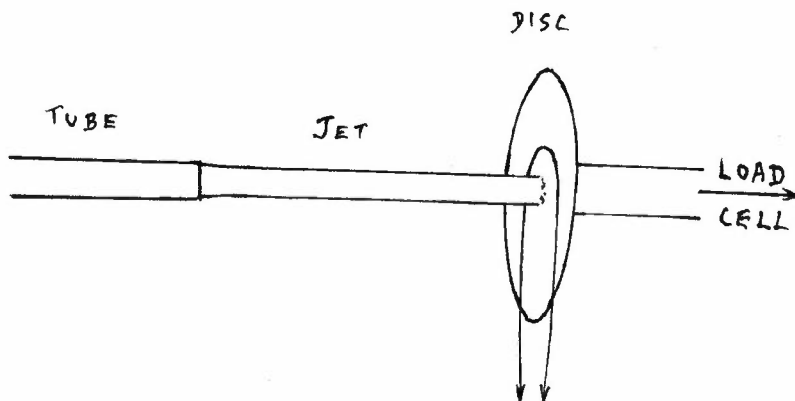


Figure 1. The jet thrust experiment

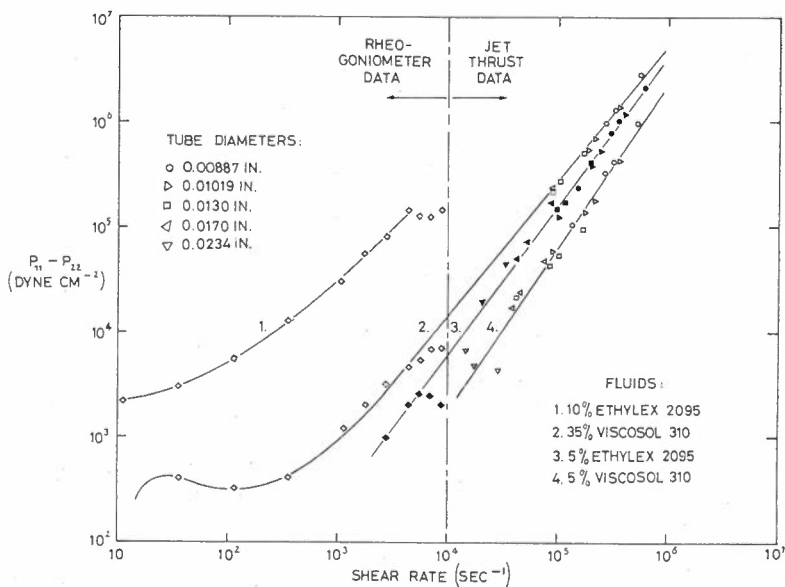


Figure 2. Jet thrust and rheogoniometer data for starch solutions compared

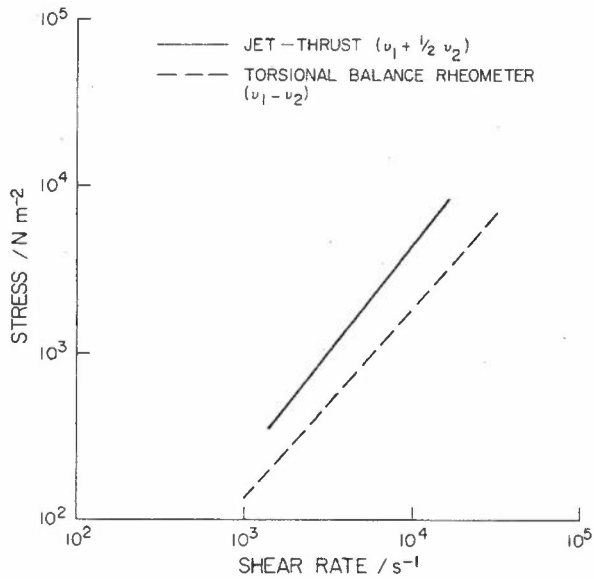


Figure 3. Jet thrust and torsional balance rheometer for polyisobutylene in decalin compared

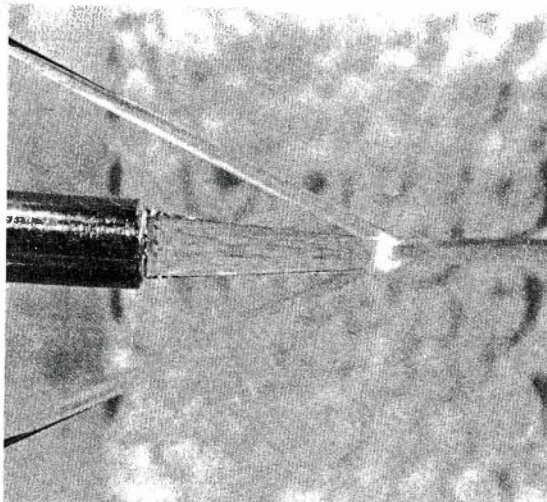


Figure 4. The triple jet experiment for a solution of polyacrylanide in water

TRIPLE JET

The triple jet⁽⁴⁾ was a means of stretching a viscoelastic liquid jet by means of impact by two faster moving outer jets (figure 4). The idea came from the burner of a liquid-fuelled rocket motor, where many “triple jets” had oxidant in the central jet and fuel in the outer ones. At low speeds, a viscoelastic stretching jet had a smooth trumpet shape, consistent with a near-constant extensional viscosity, but at high speeds the surface showed “stretch marks” and the shape became conical, as in figure 4. This behaviour is now rubberlike, in which stress depends on square of the principal extension ratio (after Treloar). I always had the feeling that Ken disapproved of the idea of a viscoelastic jet suddenly turning into a rubber band!

At the World Rheology meeting in Kyoto in 1968, Ken heard the shocking news that several of us has visited the local Japanese baths. Whatever his previous ideas, we told him of a rather expensive but wonderful experience. Steam bath, whole body wash, shower, swim in Romanesque pool and comprehensive massage were performed by your personal young lady dressed in gym clothes. Capped by a drink in an armchair and, for the first time, coloured television! After much thought, Ken decided to try it out and then became such an enthusiast that he wanted to go again!

STRETCHING FLOW USING ROTATING CYLINDER

The device shown in figure 5 is like a horizontal form of Jim Ferguson’s spinline rheometer, the force on the jet being given by the change of torque on the rotating cylinder ⁽⁵⁾⁽⁶⁾. Easier to use than the triple jet, it was used to test international fluids M1 (Monash), A1 (Aberystwyth), and S1 (Strathclyde). Ken’s idea was to compare different laboratories’ data on the same fluid, which was prepared in bulk. The data on stretching flows showed wide inconsistencies, probably because of the common assumption that axial stress was controlled by axial strain rate alone. Actually, the fluid’s rheology could change along the jet and was dependent on its history or strain

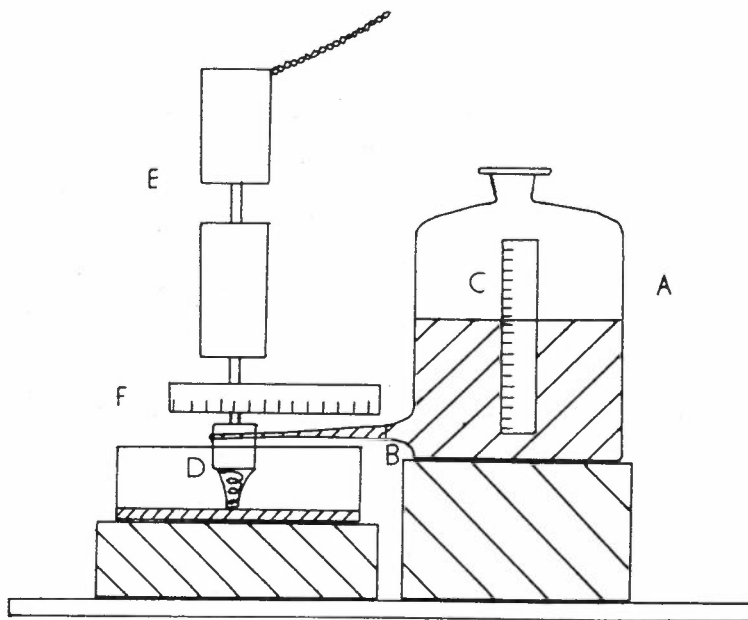


Figure 5. Stretching flow of polymer solution using horizontal jet.

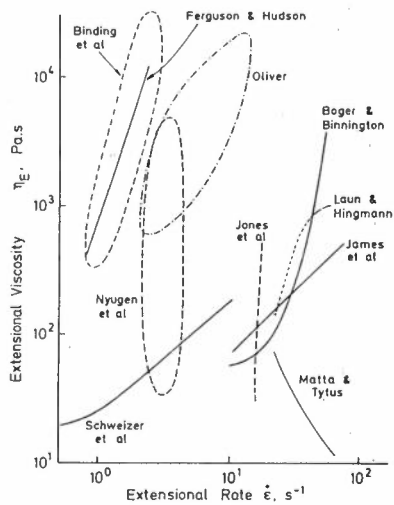


Figure 6. Extensional viscosity measurements on the M1 fluid

itself. The summary of ten different sets of extensional data on fluid M1 by James and Walters⁽⁷⁾ (figure 6) illustrates the point clearly. The techniques used included spinning devices, open siphon flows, opposed jets and contraction flows. Doubts were cast on the general use of the term “extensional viscosity”, but it was pointed out that the devices could be useful for quality control in industry.

Ken was a member of Aberystwyth Golf Club, and visiting rheologists were often invited to join him for a round after attending a conference or PhD viva. Ken knew all the wrinkles on a hilly course and was very difficult to beat off (what appeared to be) a generous handicap! Unfortunately, Ken’s various injuries eventually stopped these enjoyable trips to the links.

JOURNAL BEARING SIMULATOR

After work on squeeze-film flow and flow between externally contacting cylinders, we used a simple apparatus in which the oil is contained between the cylinders (figure 7). An eccentric cylindrical rotor within a slightly larger cylinder exerted a force on the outer cylinder when lubricant filled the gap. The geometry is that of the main bearing of a car engine, with the added feature that the intermittent side loads caused by the firing of the cylinders may be simulated by the rotor running offset (wobbling) on its own shaft. It was found that dissolved polymers in the oils gave significant improvement in the load bearing properties, which varied with the polymer in use and diminished with increasing temperature. A well-known company supported this work and also a parallel theoretical research programme in Ken’s school at Aberystwyth, thus providing another link between their work and the more experimental rheology carried out at Birmingham.

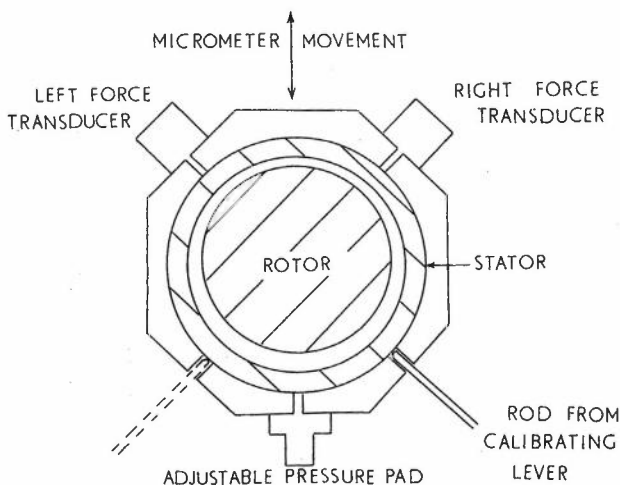


Figure 7. The journal bearing simulator

CONCLUSION

So, what have been the main highlights? The blending of theory and experiment in Rheology has been crucial, but so has the mixing of worldwide Rheologists in a variety of attractive venues. Ken is in his element when gathering the clans for the latest meeting and adds to this his status in Rheology and flexibility as a speaker. Earlier World Congresses in Japan and Acapulco were memorable, as were European meetings in Graz and Seville. My own preference is for more intimate meetings like those in Lake Vyrnwy or in the Alps, where the added attraction of skiing was unusual for scientific meetings. The formation (in Wales) of the Institute of non-Newtonian Fluid Mechanics has also been most successful, and for a recent meeting emerged from the hills of Owen Glendower to hold a meeting at Chicheley Hall, in England. Long may this valuable work continue!

References

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2. Shertzer, C.R. and Metzner, A.B., Trans Pl. Inst. London, 31 (1963) 148 and 32 (1964) 217.
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4. Bragg, R. And Oliver, D.R., Nature Physical Science, 241 (1973) 131.
5. Oliver, D.R., J. non-Newt. Fl. Mech., 35 (1990) 251.
6. Oliver, D.R., The Chem. Eng. J., 48 (1992) 129.
7. James, D.F. and Walters, K., “Techniques for Rheological Measurement”, A.A. Collyer, Chapman & Hall, Chapter 2, p38, 1993.
8. Oliver, D.R., and Macosporran, W.C., Rheol. Acta. 8 (2) (1969) 176.

Most cited articles in Journal of Rheology (1978 onwards)¹

The publication of *Journal of Rheology* has seen three phases. First published as *Journal of Rheology* between 1929 and 1932, in 1933 the journal was subsumed as a section (called Rheology Numbers) of the journal Physics, and then the Journal of Applied Physics. From 1957, the Society of Rheology re-established the journal as a separate publication, initially named Transactions of the Society of Rheology, and then renamed *Journal of Rheology* from 1977. Citation information is currently only available from 1978 onwards (Volume 22 Issue 1).

Figure 1 below shows the number of papers published in each year (left hand side plot) together with the number of citations in each year (right hand side plot) for the past 20 years.

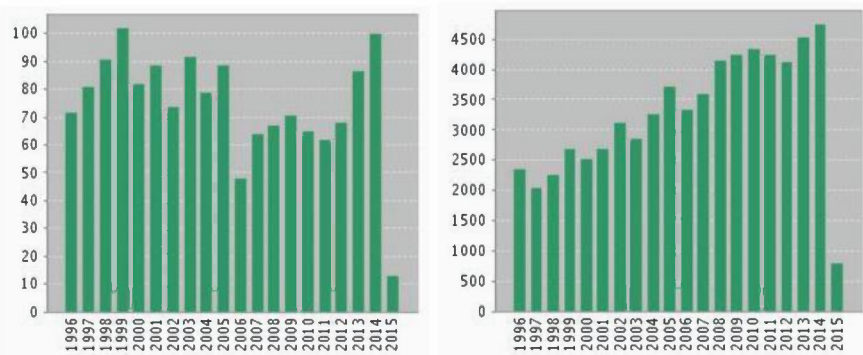


Figure 1: Number of papers published each year in Journal of Rheology (left hand side), number of citations to Journal of Rheology articles each year (right hand side)

¹Determined using *Scopus*, data in Figure 1 taken from *Web of Science* (all databases). Census date 26/03/1978

Of the 2,070 articles published since 1978, 80 of these articles have been cited more than 100 times (roughly 4% of the total). Only 153 papers have never been cited. The 10 most highly cited papers in Journal of Rheology are shown below:

Authors	Title	Year	Cited by
Winter, H.H, Chambon, F.	Analysis of linear viscoelasticity of a crosslinking polymer at the gel point.	1986	1093
Bagley, R.L., Torvik, P.J.	Theoretical basis for the application of fractional calculus to viscoelasticity.	1983	516
McLeish, T.C.B., Larson, R.G.	Molecular constitutive equations for a class of branched polymers: The pom-pom polymer	1998	449
Barnes, H.A.	Shear-thickening (“dilatancy”) in suspensions of nonaggregating solid particles dispersed in Newtonian liquids	1989	434
Papanastasiou, Tasos C.	Flows of materials with yield.	1987	430
Walton, O. R., Braun, R.L.	Viscosity granular-temperature, and stress calculations for shearing assemblies of inelastic frictional disks.	1985	413
Bagley, R.L., Torvik, P.J.	On the fractional calculus model of viscoelastic behaviour.	1986	370
Ramamurthy, A.V.	Wall slip in viscous fluids and influence of materials of construction.	1986	349
Metzner, A. B.	Rheology of suspensions in polymeric liquids.	1985	335
Dzuy, N. Q, Boger, D.V.	Yield stress measurement for concentrated suspensions.	1983	307

In contrast to Rheologica Acta and JNNFM, review articles feature less heavily. BSR members also feature much less than in the

JNNFM top 10, but it wouldn't be a top-ten rheology journal list without a review from Howard Barnes in it (at number 4). The paper at #5 – by Papanastasiou – is the paper where the exponential regularisation form of the Bingham model first appears for yield stress materials. Given the recent articles published in the Bulletin on the topic, it is interesting to note that two papers, which deal with fractional calculus, are in the list (both by Bagley and Torvik).

The individual who has published the most papers in JoR is Ron Larson: Ron's 45 articles have been cited an impressive 2083 times which corresponds to an *average* of 44 cites per paper. Even more incredibly, Gareth McKinley (BSR Gold Medal winner) is second with 28 papers which have been cited 1355 times which corresponds to an average citation rate of 48 cites per paper.

British Society of Rheology News

NOTICE of the 74th Annual General Meeting

The 74th Annual General Meeting of the British Society of Rheology will be held at Ruthin Castle, Denbighshire, Wales, on Tuesday 31st March 2015 at 5.15pm. The draft minutes of the 73rd Annual General Meeting were printed in the Bulletin previously (Vol 55, No 2), and are available on the BSR website at <http://www.bsr.org.uk/getFile.php?id=512>. Members are reminded that, under rule 7(b), the business of the meeting includes:

- * Election of Officers and Council members.
- * Receipt of a report and accounts from Council.
- * Dealing with matters raised by Council or by any other member and receiving suggestions from members for consideration by Council.

Council's nominations for Officers and Council members are:

President	Dr H. Wilson
Hon. Secretary	Prof. S.J. Cox
Hon. Treasurer	Dr R. Watson
Membership Secretary	Dr M. Charalambides
Bulletin Editor	Dr R. Poole
Web Editor	Mr P. Hodder

Ordinary members of Council:

- * Dr B. Dobraszczyk
- * Dr S. Fielding
- * Mr S. Goodyer
- * Dr K. Hawkins
- * Dr M. Tassieri
- * Dr P. Threlfall-Holmes

Note that council proposes that Simon Cox serve an exceptional fifth year in the absence of any nominations for Honorary Secretary.

Further nominations for Council or for any of the Offices are invited. Nominations should be sent to the Secretary or made at the meeting (rule 5(b)). Nominees must be members of the Society, must confirm in writing that they are willing to stand and must be proposed and seconded by two members of the Society. The Hon. Secretary would be pleased to receive notice of any matter that any member wishes to raise at the AGM.

Members who cannot attend the AGM are invited to make nominations or approve Council's nominations by email or post to the Honorary Secretary:

Prof. S.J. Cox
Department of Mathematics
Aberystwyth University
Aberystwyth SY23 3BZ
Email: secretary@bsr.org.uk

BSR Annual Award

Nominations are invited for the 2015 BSR Annual Award. Each year the BSR makes an award to an individual in recognition of their contributions to rheology. The criteria for the award focus on the scientific merit of the candidate: a person who has made a significant contribution to rheology either through a single paper or more sustained activity. The recipient in 2014 was Simon Haward, in 2013 was Jason Stokes, and in 2012 Tim Phillips.

Nominations, with a brief supporting statement, should be sent to the President, on president@bsr.org.uk, by the end of May 2015.

Simon Cox
BSR Honorary Secretary

Commentary on the 343rd Council Meeting of the BSR – Durham University December 18th 2014

As a very successful Midwinter meeting closed, the council adjourned to the Garden Room of the Lindisfarne Centre in Durham University for this final council meeting of 2014. A near full house gathered and quickly but methodically worked through the minutes and actions from the last meeting before getting down to business discussing the topics of interest.

The officer reports were full of promise as opportunities for the BSR to play active roles in furthering the profile of rheology in the academic communities. Reflections on the recent Gold medal and Vernon Harrison Awards means that it seems a wealth of future content for bulletin seemed almost guaranteed. The transition of publication responsibilities with Nick's retirement (our 25 year special award winner) to Manlio also seems well in hand.

The proposal to work towards a better website was discussed further and a comprehensive review of the needs and functions required seems sensible to ensure the future demands of our membership is possible.

As the meeting drew to a close an extensive list of future meetings were updated, so all in all the future of the project and plans of the BSR looked bright.

Peter Hodder

Conference report on the British Society of Rheology Annual mid-Winter Meeting: “Active and Complex Fluids” Durham, 17-18 December 2014.

I had the pleasure of attending the 2014 British Society of Rheology mid-Winter meeting in Durham this December, organized by Suzanne Fielding. Every year this meeting has a specific theme, and the focus of this year's meeting was on active fluids, with the particular aim of enhancing collaboration between the active fluids and complex fluids communities.

The first day focussed on active materials, in which energy sources within objects and swimmers in fluids, rather than pressures or boundary driven flows, lead to fascinating interactions and patterns. Increasingly this area is incorporating non-Newtonian fluids (e.g. when swimming in bodily fluids), which leads to non-trivial interactions and of course interesting rheology. The ‘applications’ of non-Newtonian rheology in interactions and collective behaviour is a fruitful counterpart to structure formation and rheology in passive filled materials such as fibre-reinforced composites and nanoparticles in polymer melts.

Ray Goldstein’s (Cambridge) keynote lecture kicked off the pre-Holiday fest with a tour through a world of interesting fluid mechanics issues in cytoplasmic streaming (in plant cells), complete with wonderful historical anecdotes stretching back a few centuries. Vincent Martinez from Edinburgh studied how flagella swim in non-Newtonian fluids; for highly entangled solutions their helix speed departs from the Newtonian result, which they attributed to the nm-width helix exploring the microviscosity between the polymer mesh.

Ramin Golestanian's (Oxford) keynote lecture divided active matter into mechanically and chemically active matter, and culminated in a dramatic demonstration of the effects of long-range interactions induced by chemically active swimmers, which lead to unexpected and delightful clustering and phase diagrams. It was followed by Rhoda Hawkins' (Sheffield) invited lecture about how the splay instability inherent in active materials leads to motion in active droplets. This was followed by talks from Armando Maestro (Cambridge) and Joakim Stenhammer (Edinburgh) about synchronization of colloidal rotors and phase behaviour of active Brownian particles.

The final active session was led by Ignacio Pagonabarraga from Barcelona, whose keynote lecture addressed Lattice Boltzman models for interacting squirmers, in which he showed how squirming activity can lead to clustering and phase separation-like behaviour. Alex Morozov spoke about swimming of waving sheets in viscoelastic liquids, Thomas Montenegro-Johnson stood in for Eric Lauga from Cambridge and spoke about cooperation and interactions among cilia in "Kupfer's Vesicle", and Tyler Shendruk (Oxford) described a computational method for using multiparticle collision dynamics to study active polar and nematic materials.

The second day saw a return to more 'traditional' rheological topics. Professor Gareth McKinley from MIT was awarded the BSR's Gold Medal, and gave a typically masterful and scholarly lecture on the roles of extensional rheology in breakup of droplets and fluids, which spans phenomena such as sprays, sneezing, combustion, and atomization. On the way he demonstrated how "fractional calculus" can usefully model materials that interpolate between solids (stress proportional to strain or mathematically the zeroth order time derivative of strain with respect to time) and fluids (stress proportional to the first time derivative of strain). Such a materials was said to have a "springpot", to interpolate between spring and dashpot. Gareth played some rare audio recordings in which Scott Blair discussed the inception of the (US) Society of Rheology and the British Society of Rheology.

This was followed by Oliver Harlen's lecture on modeling droplet breakup in inkjet printing, in which droplets are a problem, rather than the feature of McKinley's lecture. David Hoyle presented a comprehensive

study of necking instabilities in extension, which generalizes and updates the familiar Considère criterion to the dynamic realm. The final session of the conference had a clear lecture from Ivo Buttinonoi (ETH Zürich) about rheology and shear banding in 2D colloidal monolayers at the air water interface, another exceptionally clear talk from Claire McIlroy from Leeds about elastic effects on coatings of fibers, and culminated with the Vernon Harrison Award Winner, Nafiseh Badieh from the University of Swansea, who spoke about linking structure and rheology in fibrin-thrombin gels (which is crucial for blood clotting).

The stimulating meeting also had room for a poster session, with the Best Poster Award (sponsored by TA Instruments) going to Elsen Tjhung (Montpellier) for work performed while at Edinburgh, on a simple model for cell crawling. Finally, a Special Award was presented to Nick Hudson for his long and distinguished service to the British Society of Rheology. In his 25 years on council, he has been responsible for managing publications, particularly Rheology Abstracts.

Peter Olmsted
Georgetown University
Washington, DC

INDUSTRY NEWS

News from Anton Parr

Academic Advantage Program for 2015

Anton Paar are pleased to announce our Academic Advantage program which entitles institutions providing further education to an array of benefits including :

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one of the front windows, gives feedback to the humidity controller and transfers the data to the rheometer software. A water tank is part of the humidity generator to feed the dry gas up to the required water content. The design of the convection oven is optimized for the work with high humidity and prevents cold spots that could turn the wet air back into water. For further information please contact info.gb@anton-paar.com or visit the Anton Paar web site.

World of Rheology website

Visit our new “World of Rheology” website for applications help, tips and tricks, e-learning courses and a comprehensive glossary of rheological terms provided by Thomas Mezger.

www.world-of-rheology.com

Welcome to Craig Smith

Craig Smith joined our UK rheology team at the end of 2014 and is now up and running as our rheology specialist in the South of England and South Wales. He was previously representing the Mettler Toledo range of thermal analysis equipment and already had a good knowledge of solids rheology / DMTA measurements. Craig can be contacted on craig.smith@anton-paar.com

News from TA Instruments

New DMA Mode for Solids Testing

TA Instruments already offer two dedicated DMA's, but have recently added the unique flexing/bending DMA mode has been added to the Discovery Hybrid Rheometer (DHR) allowing a new dimension for testing of solid and soft solid materials. Plate/plate and rectangular/cylindrical torsional modes already existed but the unique design of the patented magnetic bearing and active Force Rebalance Transducer (FRT) allows for a controlled amplitude linear vertical oscillatory deformation. This DMA mode capability is available in all of the key solids testing geometries, film tension, free and clamped bending and compression. This new mode has already been seen to provide reliable measurements of modulus of elasticity or Young's Modulus over the instruments full temperature range of the ETC.

New mechanical chiller option: an alternative to liquid nitrogen

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CONFERENCE DIARY

2015 CONFERENCES & MEETINGS	
30 Mar - 1 Apr Ruthin Castle, Wales	INSTITUTE OF NON-NEWTONIAN FLUID MECHANICS “Rheology of Structured Fluids”. Conference Contact: Simon Cox: foams@aber.ac.uk, tel. +44 1970 622764 Tudur Davies: itd@aber.ac.uk , tel. +44 1970 622813
14 -17 Apr Nantes, France	10th Annual European Rheology Conference (AERC 2015) Organiser/Contact details: Michel Cloitre, Lionel Choplin, Jean-François Tassin Conference website: http://rheology-esr.net/events/aerc-2015-nantes/
26th May Glasgow, Scotland	Rheologists in Scotland Meeting II The meeting will be held at The University of Strathclyde in Room TG310 of the Thomas Graham building, 295 Cathedral Street, Glasgow G1 1XL, starting at 11am. The theme of the meeting is “ <i>Young Researchers in Scotland</i> ”. Conference Contact: Nick Hudson: n.e.hudson@strath.ac.uk , tel. +44 0141 548 2795
1 – 3 June Edinburgh, Scotland	Dense Suspension Flow Wilson Poon, Mike Cates, Dimitris Vlassopoulos Conference website: http://events.ph.ed.ac.uk/softcomp
7- 9 Sept Coimbra, Portugal	IBEREO 2015 Challenges in rheology and product development Maria Graça Rasteiro (Chair) (University of Coimbra and CIEPQPF-UC) Conference website: http://www.uc.pt/en/events/ibereo15
11 – 15 Oct Baltimore, Maryland USA	87th Annual Meeting of The Society of Rheology More information can be found at the SoR web page in due course.
14 – 15 Dec Glasgow, Scotland	The British Society of Rheology Winter Meeting 2015 The meeting will be held at The University of Glasgow, Wolfson Medical Building: Yudowitz Room, with a theme of “ <i>Micro rheology & Microfluidics</i> ”. Conference Contact: Manlio Tassieri: Manlio.Tassieri@gla.ac.uk , tel. +44 0141 330 8116 Nick Hudson: n.e.hudson@strath.ac.uk , tel. +44 0141 548 2795 More information can be found at the BSR web page in due course.
2015 COURSES & WORKSHOPS	
24th-25th June 2015 Nottingham University, UK	Rheology Workshop Steve Goodyer, Anton Paar Ltd, Unit F, The Courtyard, St. Albans, Hertfordshire, AL4 0LA T: +44 (0)1992 514730; F: +44 (0)1992 514739 E: steve.goodyer@anton-paar.com



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Highlight 1 of 6 **Stagnation plane**

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