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THE BRITISH SOCIETY OF RHEOLOGY



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EDITORIAL

Welcome to Volume 55 (issue #2) of the British Society of Rheology Bulletin. One of the best aspects of being Honorary Bulletin Editor is the unexpected things which keep appearing in my inbox. One such example has led to the lead article in this issue by Hans Hürlimann who wrote to say “Manfred Wagner encourages me to submit the joint-by paper on melt fracture to your Bulletin, as he thinks, that it fits to your ongoing search into some apparently never ending stories, including the missing data of F.N. Cogswell. Manfred hopes that we thus can contribute to revive the puzzling discussions on this topic in a creative way... Manfred and I are life long friends and both members of BSR and we both have a nostalgic empathy for the British way of handling things.”

Also in this issue, Simon Cox follows up on fractional calculus and following last issue's piece on the most cited articles in JNNFM, in this issue a similar treatment is provided for Rheologica Acta. Finally to celebrate Ken Walter's 80th birthday Bob Bird has provided a celebratory poem.

Rob Poole, Liverpool July 2014.

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 photo used to illustrate the cover was taken at the recent INNFM Meeting on Rheometry and General Rheology held at the Lake Vyrnwy Hotel and shows Prof. Ken Walters with a special rheology-themed cake presented to him to celebrate his 80th birthday. The photograph was provided by Prof. Manfred Wagner.

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.

If your work is concerned with rheology in any way, then you have much to gain by joining the British Society of Rheology, including

- advance your knowledge by attending our conferences
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Validation of Elongational Stress to Trigger Melt Fracture

Introduction

In 1926 Ostwald ²⁾ found for 'structural viscous fluids' a critical flow rate at the transition from the laminar to a new type of irregular flow, far below the rate for Reynold's established eddy turbulence. Tordella ³⁾ localized his LDPE melt flow instabilities in 1956, observing the partition of soft markers at the constriction of a glass pipe and tracing it to a crucial value of the shear rate in a corresponding capillary die. He also introduced the label 'melt fracture' after hearing a related crackling noise. Yet the expression 'flow instability' is to be recommended. In 1960 Reiner ⁴⁾ predicted, that the polymer fluid must lose structural coherence after the strain rate becomes larger than the rate of relaxation. In 1972 Hürlimann ⁵⁾ found, that a LDPE melt strand at the inlet of a die is stretched at a nearly constant elongational force, and that the flow transition occurs at a critical value of elongational stress. This dynamic property is much less dependent on temperature and other physical parameters than formerly used kinematic criteria. In extensive investigations, Cogswell ^{6,7)} also drew attention to the correlation of die inlet pressure loss, elongational stress and strain rate at the transition to flow instability. For now sixty years many more researchers ventured to find the key to these phenomena, but even an extensive compilation of 2011 ⁸⁾ spotted no conclusive interpretation. Let us return to the basic physics.

As a didactical help, a power-law model for stress vs. strain rate is introduced to illustrate the transition to flow instability ⁹⁾. Three supporting experiments are cited, using LDPE melts: First, an early experiment at a die inlet (Eulerian approach) ⁵⁾.

¹ BSR Bulletin Vol. **54**, 1, 20 (2013)

² W. Ostwald, R. Auerbach, Weitere Untersuchungen über Strukturviskosität Koll.-Zeitschr. **67**, p. 211-222 (1926)

³ J.P. Tordella, Fracture in the extrusion of amorphous polymers through capillaries, J. Appl. Phys., **27**, 454-458, (1956)

⁴ M. Reiner, Deformation, Strain and Flow, 2nd ed., Structural Turbulence, Lewis, London, p. 196-199 (1960)

⁵ H.P. Hürlimann, W. Knappe, Der Zusammenhang zwischen der Dehnspannung von Kunststoffschmelzen im Düsenanlauf und dem Schmelzbuch (The relation of elongational stress of polymer melts at a die entry and melt fracture), Rheol. Acta **11**, p. 292-301 (1972)

⁶ F. N. Cogswell, Stretching flow instabilities at the exit of extrusion dies, J. Non-Newtonian Fluid Mech., **2**, 37-47 (1977)

⁷ F.N. Cogswell, Polymer Melt Rheology, Woodhead (1994)

⁸ R. Koopmans, J. den Doelder and J. Molenaar ed., Polymer Melt Fracture, CRC Press, London, (2010).

approach)⁵⁾. A rheometric experiment with a twin clamp elongational rheometer at a high constant strain rate follows (Lagrangian approach)¹⁰⁾. Finally, a late rheometric investigation at constant elongational force also reports flow instability¹¹⁾. The data are assembled and superposed in graphs of elongational stress vs. strain rate and also of viscosity vs. time.

More complex types of polymer melt flow instabilities, to which the criterion of the critical value of elongational stress may also apply, are listed below.

Power-law model

The die inlet flow will be discussed at hand of a modeling power-law equation for stress vs. strain rate⁹⁾. Advantage is taken of the fact, that also a close-to-critical elongational flow of an LDPE melt is approximately unidirectional with focussing straight flow lines (Fig.1).

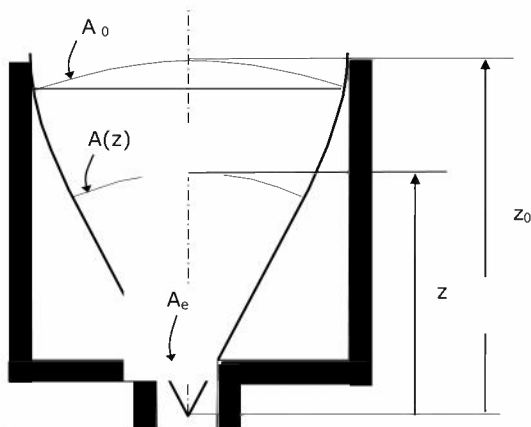


Fig.1 Spherical coordinate system for a model „sink flow“. This spherical flow system is uniaxial.

These are analysed in spherical coordinates. In Fig.1 the radial coordinate z of elongational flow begins at z_0 and $A(z)$ is the cross-sectional area of the conical

⁹⁾ H.P. Hürlimann, Zur rheologischen Deutung des Schmelzbruchs hochpolymerer Schmelzen bei verschiedenen Formen des Düseninlaufes (A rheological interpretation of melt fracture of polymer melts for different shapes of the die inlet channel), thesis Montanuniversität Leoben, 36-39 (1981)

¹⁰⁾ H. Münstedt, H.M. Laun, Elongational properties and molecular structure of polyethylene melts, Rheol.Acta **20**, 211-221 (1981)

¹¹⁾ M.H. Wagner, V.H. Rolón-Garrido, Constant force elongational flow of polymer melts: experiment and modelling, J. of Rheology **56**(5), 1276-1297 (2012)

strand, beginning at A_0

The equation of continuity is

$$\dot{q} = u(z) \cdot A(z) \approx u(z) \cdot \pi r^2 \quad 1,$$

where $\dot{q}$ is the volumetric rate of flow and $u(z)$ the flow velocity.

The HENCKY-rate of unidirectional elongation is

$$\dot{\varepsilon}(z) = -du(z)/dz \quad 2.$$

The elongational stress is

$$\sigma(z) = F/A(z) \quad 3.$$

F is a constant elongational force and $\sigma(z)$ is assumed to be constant across $A(z)$, which has been experimentally verified by a tracer-body strobo test ¹²⁾

$$[\sigma(z) / \sigma_0(z)]^k = \dot{\varepsilon}(z) / \dot{\varepsilon}_0(z) \quad 4.$$

The experimental method must ensure that $\sigma(z)$ and $\dot{\varepsilon}(z)$ match in time, as the elongational flow is usually undulating resp. non-steady. The index o is state of reference. If equs. 1 to 3 are introduced into equ. 4 and $\sigma(z)$, F and $v(z)$ are eliminated, the following differential equation results ¹³⁾.

$$-\dot{\varepsilon}_0/v_0) \cdot (z_0 - z) \uparrow$$

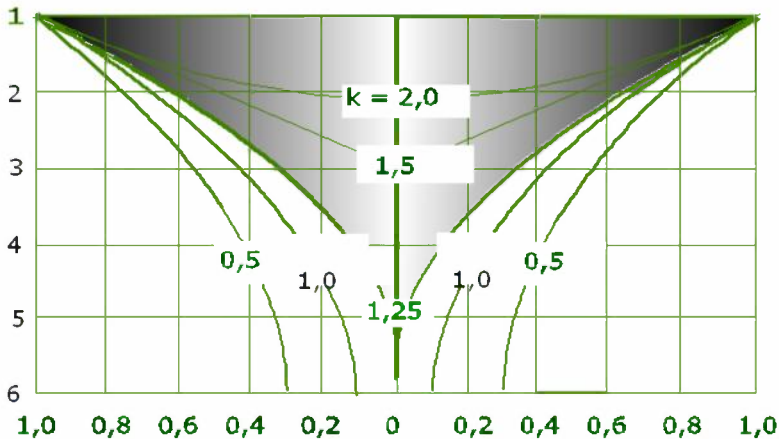


Fig.2 gives the normalized radii r/r_0 (equ.1, cylindrical coordinates) as a function for the normalized flow distance $z_0 - z$ for different exponents k . The tinted area is the upper end of a retracting strand.

¹²⁾ H.P. Hürliemann, An experimental rheologic interpretation of polymer melt fracture and its application to processing, Proceedings XIII Intl. Congr. on Theoretical and Applied Rheology, Cambridge 3, 146-148 (2000)

¹³⁾ A.B.Metzner, E.A.Uebler, C.F.Can Man Fong, Converging flow of viscoelastic materials, AIChE, 15, 750-758 (1969)

$$A(z)/A_o]^{k-2} d[A(z)/A_o] = (\dot{\epsilon}_o/v_o) dz \quad 5.$$

There are two different solutions⁹⁾:

$$\text{if } k = 1: \quad A(z)/A_o = \exp [(-\dot{\epsilon}_o/v_o) (z_o - z)] \quad 6a$$

$$\text{if } k \neq 1 \quad A(z)/A_o = [1 - (k-1)(\dot{\epsilon}_o/v_o) (z_o - z)]^{1/(k-1)} \quad 6b.$$

Fig.2 shows, that for a coefficient of $k = 1,0$ there is no necking and for $k = 1,25$ the flow is instable with necking.

Three supporting experiments

The two first experiments shows in Figs. 3 and 4 the visualizations of the die inlet flow of a LDPE melt to a capillary rheometer⁵⁾. The dye pattern on a



Fig.3 Flow visualization on a slice cut from the middle plane of the frozen LDPE slab after a stopped capillary rheometer experiment⁵⁾.

slice from the central, axial plane of the frozen cylindrical slab was removed after a suited experiment. The referring experimental procedure with alternately dyed tokens is discussed at extent elsewhere⁹⁾. The flow rate in Fig.3 refers to a laminar flow condition well below the critical level. The elongational strand around the midline enters into the indicated flat die below and does not neck. It is surrounded by an annular vortex that also drains into the capillary and is continuously alimented at ist top stagnant point from the main stream.

Fig.4 shows a situation very close to the transition to flow instability ⁵⁾. The annular vortex here is a closed fluid cushion supporting the wineglass-shaped elongational strand. The separating flowlines between the vortex and the elongational strand end rectangularly at the cylinder resp. capillary walls with stagnant points.



Fig.4 Visualisation of the close-to-critical flow of a LDPE melt Type I at 150°C ³⁾. The dye pattern in the sliced solidified strand around the center line converges towards the indicated capillary entry below. The circular vortex is a passive closed flow system.

Tab.1 gives the stress σ vs. the HENCKY-rate of $\dot{\epsilon}$, the viscosity η and the time t for Fig.4 ⁹⁾

$\dot{\epsilon} (\text{s}^{-1})$	$\sigma (10^6 \text{ Pa})$	$\eta (10^6 \text{ Pas})$	$t (\text{sec})$
equ.1,2	$= \eta \cdot \dot{\epsilon}$ equ.3	$= \sigma / \dot{\epsilon}$	equ.1, 2
0,46	0,084	1,8	28,0
0,65	0,112	1,7	28,3
0,83	0,146	1,8	28,7
1,07	0,19	1,8	28,9
1,38	0,24	1,7	29,1
2,23	0,30	1,8	29,2
2,23	0,39	1,7	29,3
2,84	0,50	1,8	29,4
3,67	0,62	1,7	29,5
4,88	0,79	1,6	29,5
5,98	0,99	1,6	29,6

Tab.1 shows the ultrashort time bracket required by the transit flow process at a nearly constant viscosity, which makes most other experimental set-ups for the purpose of analyzing the process of instability less appropriate.

The LDPE Type I in Fig.4 has been extensively used by BASF rheologists. Its molecular weight is $M_W = 482'000$ g/Mol. The temperature was 150°C

The problem often has been discussed, whether the energy dissipated in the shear layers between the elongational strand and the circular vortex is negligible compared to the total inlet pressure loss Δp_e ^{6,7)}. By an extensive evaluation ⁵⁾ for the close-to-critical flow in Fig.4, it has been calculated that the strand absorbs more than 95% Δp_e , and therefore the elongational force in the strand is close to constant. The tensile force was 10^4 N for this experiment. In a later investigation ¹²⁾ the polymer melt in the circular vortex was replaced by hot silicone oil without a change of inlet pressure loss. No further mention is given here to the well known cyclic necking and regenerating process of the instable elongational strand in the supercritical flow regime ²⁾.

The second experiment was performed at BASF with a twin-clamp elongational rheometer ¹⁰⁾. Only one test with a high strain rate ended in flow instability or fracture. These experiments have been reported according to the BASF tradition of plotting the elongational viscosity η vs. the time t beginning at the start of the test. The molecular weight of LDPE 6 $M_W = 467'000$ g/Mol comes close to Type I. The temperature was also $T = 150^\circ\text{C}$.

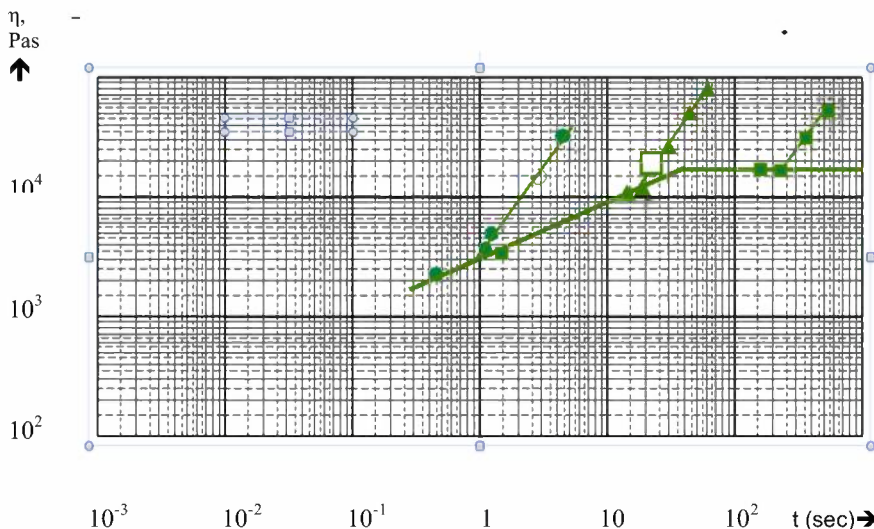


Fig.5 Icon $\circ$ stands for $\dot{\epsilon} = 1 \text{ sec}^{-1}$, $\triangle$ for 0.1 sec^{-1} and $\square$ for 0.01 shows the BASF tests (10). The open rectangular icon includes all data from Tab.1!

Fig.5 is a partial reproduction of the BASF data, superposed with the data of Tab.1. The latter show very little reduction of viscosity vs. time and therefore vanish in

σ 10 ³ Pa	$\dot{\varepsilon}$ sec-1	t sec	σ 10 ⁴ Pa	$\dot{\varepsilon}$ sec-1	t sec-1	σ 10 ⁴ Pa	$\dot{\varepsilon}$ sec-1	t sec-1
7,3	1	0,52	1,23	0,1	0,17	15	0,01	150
2	1	1,05	3,3	0,1	1,2			
50	1	1,1	10,5	0,1	16	33	0,01	320
160	1	2,5	50	0,1	35			
300	1	4,0	83	0,1	50		0,01	550

Tab.2 is integrated into Fig.5 and 6

the indicated open square icon. Obviously the traditional plot of viscosity vs. time does not elucidate the fast physical process of flow instability. It will be more favourably discussed at hand of a plot of stress vs. strain rate. The data for the third experiment have been transcribed electronically into Fig6.

Superposition of the three experiments

Figure 6 shows the superposed three experiments. The elongational stress σ is again plotted vs. the strain rate $\dot{\varepsilon}$ in log scales.

The first experiment is indicated by square dots. The straight rise of the curve at an angle of close to 45° indicates a constant viscosity (Tab.1). The process starts at a force of about 10⁴ Pa and ends after necking in the tinted transitional range of 10⁶ Pa.

The second experiment is indicated by six vertically rising single-dotted lines and end at their steady-state viscosities resp. stresses. Three of these lines for constant strain rates for 0,15, 0,7 and 3,5 sec⁻¹ end at lower than critical stresses and no instability was observed, even at very large elongations. The fourth line for a strain rate of 6 sec⁻¹ however, reaches the stress limit and the test ended in rupture of the probe. All tests at even higher rates (not reported here) also ended in instability at the critical level. The four indicated points for steady-state viscosities ¹⁰⁾ may be connected by a straight line pointing to the critical point of the other two experiments. This important observation, strengthens the energetic (stress vs. strain rate) view of the problem that escapes to the observer who relies on the plot of viscosity vs. time.

Of the third experiment, three ondulating curves are plotted for start-up stresses of 5000, 10000 resp. 20000 Pa. The curve in the middle corresponds to the starting stress of the first experiment of Tab.1.

The transition criteria of the three experiments match surprisingly well, which is the basic message of this paper. The molecular background of the flow instability is not yet fully understood. Some indications suggest a purely viscous disentanglement, some others an additional contribution of molecular degradation.

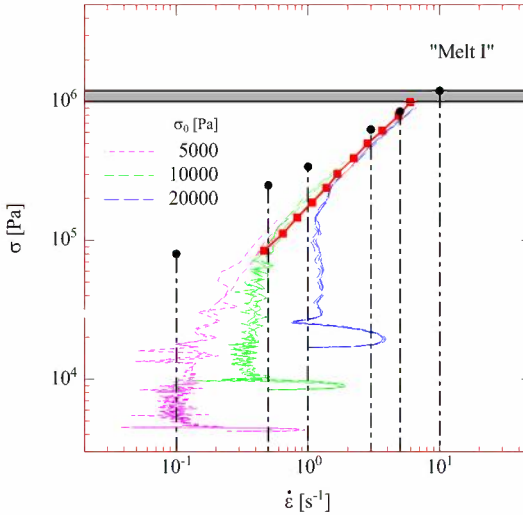


Fig. 6 Superposed graphs of elongational stress σ vs. strain rate $\dot{\epsilon}$ for the three experiments

The relation between the critical elongational stress and the melt temperature, as well as of the molecular weight, is reported to be moderate and proportional analogue to reports for the critical shear stress. The relation with the melt pressure is less than proportional. This has been reported for many different types of polymers (8). Linear molecular type polymer melts show an other type of stability (including high local heat dissipation) behaviour ^{12, 7)}

Conclusions

Three methodically different but in their result matching experiments, validate the critical elongational stress as the basic transition standard of little variance to the main physical properties. Elongational flows at higher HENCKY strain rates feature three structurally different segments. After a first one, dominated by entropic elasticity, follows a second at essentially constant (non-Newtonian) viscosity. Both segments are stable, laminar flows. If the process continues to a third segment up to the limiting range of elongational stress, the stress grows less than the HENCKY rate of deformation, resulting in a rapid loss of coherence. This process is extremely fast and further research requires well focussed high-speed, high-resolution camcording and a detection method for short-life radicals. For its analysis, a suitable choice of the variables is required for a cartesian plot. Some traditional choices rather obscure than illustrate the crucial process.

Polymer melt flows in industrial processes remain laminar, if adequate shaping of the flow channel avoids the stress range, where the flow gets instable. Considering more complex flow instabilities like shark skin on extrudates, rough surface in film blowing, or orange peel on calendared foils, it seems promising to reevaluate these

processes step by step with regard to local HENCKY-strain rates and consequent buildups of elongational stresses.

Ostwald used the expression structural viscosity and pointed out the difference to REYNOLD's eddy turbulence. The later expression of viscoelastic turbulence referred to irregular relaxation effects in the die capillaries. Later investigations ¹²⁾ modified the classic shear model for polymeric fluids by evaluating the elongational stress vector in the boundary layer of capillaries as a component of the vector triangle with the thrust vector (parallel to the wall) and the first normal stress difference. The elongational stress results in this case from a slow-rate CAUCHY elongation and does not reach the critical stress limit for instability in high-rate HENCKY deformations. This advanced view initiated a paradigmatic change of evaluating the kinematics at the verge of elongational polymer melt rheometry ¹⁵⁾. As a first verbal consequence, a difference of ‚soft’ and ‚hard’ flows was practiced. In passing, it may at the end be remarked here, that the strange spurt/slip flow instability of linear type polymers requires a basically different approach ¹⁴⁾, as intense local energy dissipation in the boundary layer of the capillary seems to be involved.

The limited rate of production of many polymer manufacturing processes call for a smart kinematic flow management to avoid instabilities. For this purpose conical or trumpet-shaped designs of the constrictive flow passages have been tested and yielded laminar flow rates up to a hundredfold ⁹⁾. Other practices make use of specific additives to the polymer fluid

Thanks go to Prof. Manfred Wagner who encouraged the contribution of the concerting experimental results to an apparently never ending story. The Bulletin recently claimed lost data of Cogswell, here we send our humble continental quest.

¹⁴⁾ J.P. Tordella, An instability in the flow of molten polymers,
Rheol. Acta **1**, 216-221 (1958)

¹⁵⁾ B. Zülle, J.J. Linster, J. Meissner and H.P. Hürlimann, Deformation hardening and thinning in both elongation and shear at LDPE melt.
J.of Rheology **31**, 583-598 (1987)

Hans P. Hürlimann

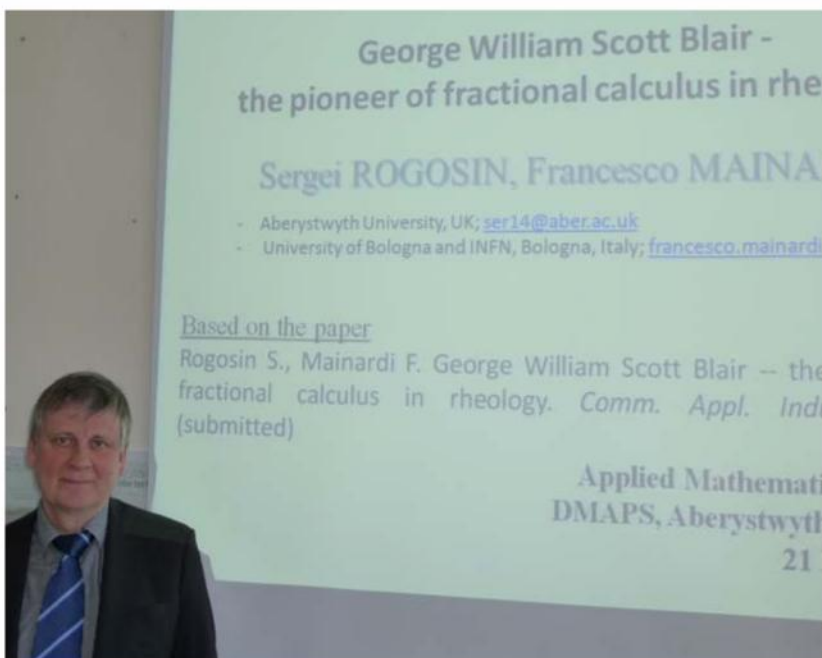
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From mathematical curiosity to practical significance.

Simon Cox

In March, mathematicians in Aberystwyth were treated to an historical review of GW Scott Blair's contributions to both philosophy and rheology, with particular emphasis on his development of fractional calculus from a mathematical curiosity to a tool of practical significance to rheology. The speaker, Professor Sergei Rogosin, is a Senior Marie Curie Fellow in the Department of Mathematics and Physics at Aberystwyth, on leave from Minsk University in Belarus. Professor Rogosin has worked on fractional calculus previously, and serendipitously discovered the BSR's Scott Blair Collection on arriving in Aberystwyth. He used the collection to discover more about Scott Blair's work on fractional calculus, and his talk was based on a recent paper with Francesco Mainardi (Bologna) [1].



As readers may know, not only did Scott Blair help found the BSR, and serve as one of its first presidents, he also contributed to the founding of the (American) Society of Rheology twenty years earlier. His interest in fractional calculus was motivated by trying to explain his experimental results on food rheology, trying to quantify effects such as "firmness" and "taste" and the influence of material

memory on rheological response [2]. Gareth McKinley spoke about the same topic in Chicheley Hall last year at the INNFM meeting [3].

Professor Rogosin explained how Scott Blair picked up on Nutting's theoretical work, and Gemant's experiments some time later, indicating that fractional exponents in constitutive relations offered a way to interpolate between Newtonian liquids and Hookean solids, and consequently introduced the idea of quasi-properties. The speaker made the link with Volterra integral equations, which had been developed earlier in the 20th century, providing a robust mathematical framework in which to explore these relationships (although Scott Blair himself probably did not recognise this). At the same time as Scott Blair was working in this area, both Gerasimov and Rabotnov were tackling this problem of interpolation in similar ways and publishing in the Russian literature (although Scott Blair spoke Russian, the 1940s were of course a difficult time to exchange scientific information!). In particular, Rabotnov recognised that using fractional exponents offered the possibility of predicting power-law decay in time, rather than exponential decay, allowing much better fitting of the rheological behaviour of complex fluids. He later acknowledged Scott Blair's contributions in a textbook published in the 1980s; indeed, Scott Blair's contributions were widely valued both by experts in fractional modelling [4] and by rheologists [5].

The seminar was followed by a discussion of nonlinear elasticity and integral equations, upon which I shall not report here.

The Scott Blair Collection of books on rheology continues to grow thanks to a financial bequest to the BSR. Donations are also welcome. Further details are available at <https://www.aber.ac.uk/en/is/collections/scottblair/>

Simon Cox, Aberystwyth, March 2014

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Most cited articles in Rheologica Acta¹

The first issue of Rheologica Acta was published in 1958 with all articles appearing in German. However from as early as the second issue articles started to appear in English (the first was the delightfully sounding “The rheological problem in chronic bronchitis” by J L White and P C Elmes, but this issue also contained papers by G W Scott Blair, B A Toms and A S Lodge)). Since that time more than 4000 articles have been published in over 50 volumes. The current Editors are Henning Winter and Jan Vermant.

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

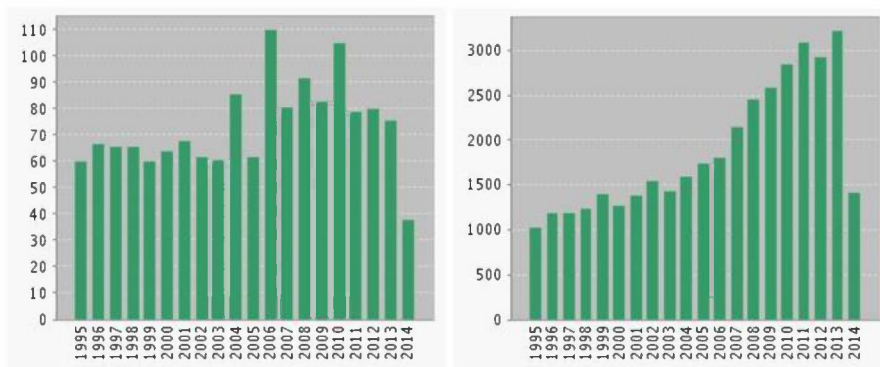


Figure 1: Number of papers published each year in Rheologica Acta (left hand side), number of citations to Rheologica Acta articles each year (right hand side)

¹Determined using Scopus, data in Figure 1 taken from Web of Science (all databases). Census date 15/07/2014

Of the 4,050 articles published at the middle of 2014, only 42 of these articles have been cited more than 100 times (roughly 1% of the total). The 10 most highly cited papers in Rheo. Acta are shown below:

Authors	Title	Year	Cited by
Palierne, J.F.	Linear rheology of viscoelastic emulsions with interfacial tension	1990	522
Larson, R.G.	Instabilities in viscoelastic flows	1992	500
Baumgaertel, M., Winter, H.H.	Determination of discrete relaxation and retardation time spectra from dynamic mechanical data	1989	258
Rajagopal, K.R., Na, T.Y., Gupta, A.S.	Flow of a viscoelastic fluid over a stretching sheet	1984	244
Barnes, H.A., Walters, K.	The yield stress myth?	1985	234
Leonov, A.I.	Nonequilibrium thermodynamics and rheology of viscoelastic polymer media	1976	228
Yasuda, K., Armstrong, R.C., Cohen, R.E.	Shear flow properties of concentrated solutions of linear and star branched polystyrenes	1981	222
Quemada, D.	Rheology of concentrated disperse systems and minimum energy dissipation principle - I. Viscosity-concentration relationship	1977	218
Mason, T.G.	Estimating the viscoelastic moduli of complex fluids using the generalized Stokes-Einstein equation	2000	213
Meissner, J., Hostettler, J.	A new elongational rheometer for polymer melts and other highly viscoelastic liquids	1994	211

Much as was the case for JNNFM (see last issue), review articles feature heavily in the list. BSR members feature much less than in the JNNFM top 10, but it is reassuring to see Barnes and Walters at number 5 with the original “yield stress myth” paper. The paper at #7 – by Yasuda et al – is the paper where the “Carreau-Yasuda” model first appeared.

The person who has published the most papers in Rheo Acta is Nam Phan-Thien: Nam’s 34 articles have been cited 518 times. His second most highly-cited paper concerns “Viscoelastic properties of pig kidney in shear, experimental results and modelling” which has been cited 61 times. Vinogradov and Giesekus have 33 papers each followed by Munstedt on 32. Roger Tanner is not too far behind with 29 articles (the earliest published in 1963 and the latest in 2013) cited 338 times in total.

Rob Poole, Liverpool



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Thermo Scientific HAAKE RheoScope module: image acquisition at (very) high shear rates using a stroboscope light source

Key words

Thermo Scientific HAAKE MARS, Thermo Scientific HAAKE RheoScope module, Stroboscope light source, Data acquisition at high shear rates, Emulsions, dispersions

The optionally available stroboscope light source extends the capabilities of the HAAKE RheoScope module, facilitating on the one hand an investigation of rheological phenomena on a structural level also at (very) high shear rates and providing on the other hand an improvement of the quality of the microscopic images at lower shear rates due to a shorter exposure time and a higher light intensity.

Thanks to the stroboscope light source, e.g. the behavior of paints and inks during the coating process can be investigated with the RheoScope or the coalescence of emulsion droplets under high shear rates. Shear-induced orientation and deformation in a sample as well as the structural disaggregation and recovery under defined temperature and shear conditions are further examples.

Instead of using a cold light source, a stroboscope (model BVS-II Woran, Polytech GmbH) can be connected to the RheoScope module using the same light guard. This modification can be made done by the user within seconds without any tools. The stroboscope light source is equipped with a Xenon flash lamp and has a maximum flash frequency of 200 Hz. In order to synchronize the microscopic data acquisition with the flash light of the stroboscope, only the integration time of the camera in the HAAKE RheoWin software needs to be adapted.

High quality images can be obtained up to a shear rate of $44\,000\text{ s}^{-1}$ using the HAAKE RheoScope camera in combination with the stroboscope light source. Based on experience and depending on the individual sample, images up to a shear rate of 2000 s^{-1} can be taken with a cold light source. This means, that the use of a stroboscope light source with the HAAKE RheoScope module extends the measuring range by factor of 20.



Thermo Scientific RheoScope module

In Fig. 1 microscopic images of a dispersion of mineral oil in silicone oil are depicted at three different shear rates using a cold light source (Fig. 1a - c) and a stroboscope (Fig. 1e - f). A plate/plate measuring geometry with a diameter of 35 mm and a polished surface using a measuring gap of $50\text{ }\mu\text{m}$ was used. Significant differences are already visible at a shear rate of 1290 s^{-1} (Fig. 1b and 1e): Images taken using a stroboscope have a much higher quality than those obtained with a cold light source.

Fig. 2 shows, that high quality images up to a shear rate of 44000 s^{-1} can be taken using a stroboscope light source.

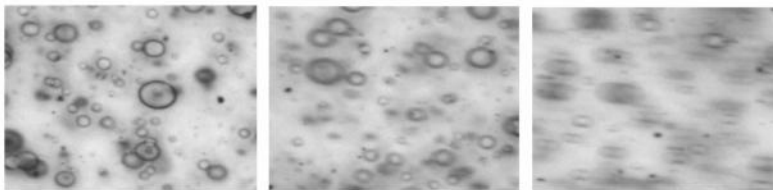


Fig. 1a - c: Images taken using a cold light source at different shear rates: 630 s⁻¹ (1a), 1290 s⁻¹ (1b) and 2520 s⁻¹ (1c)

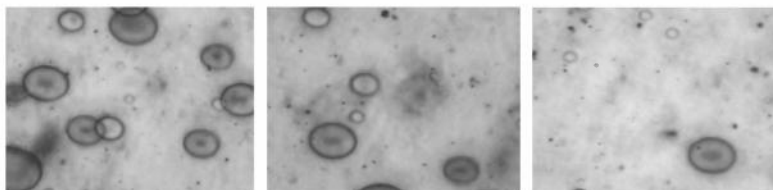


Fig. 1d - f: Images taken using a stroboscope light source at different shear rates: 630 s⁻¹ (1d), 1290 s⁻¹ (1e) and 2520 s⁻¹ (1f)

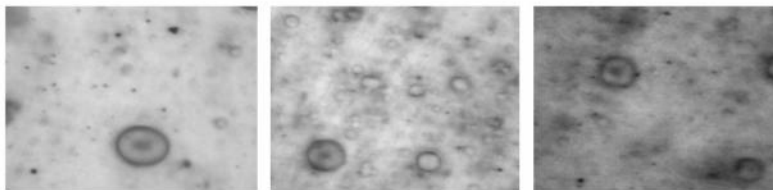


Fig. 2a - c: Images taken using a stroboscope light source at higher shear rates: 5670 s⁻¹ (2a), 12600 s⁻¹ (2b) and 44000 s⁻¹ (2c)

Order information

222-2050 Optional accessory for HAAKE RheoScope module: Stroboscope light source with Xenon flash lamp with maximum flash frequency of 200 Hz (85 V – 265 V / 50 Hz – 60 Hz)

thermoscientific.com/mc

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"From the archives"

Circular No. 8 December 1944

BRITISH RHEOLOGISTS' CLUB.

Address for communications :

c/o THE NATIONAL INSTITUTE FOR
RESEARCH IN DAIRYING,
SHINFIELD, READING.

Circular No. 8. December, 1944.

Issued for the information
of members of the Club only.

CLUB NOTES.

MEMBERSHIP. The Club now numbers over 280 members. This remarkable increase shows how wide is the interest in Rheology at the present time, and augurs well for the post-war development of the Club.

OUR HEARTIEST CONGRATULATIONS are extended to our Past-President, Sir Geoffrey Taylor, F.R.S., who has been awarded the Copley Medal of the Royal Society.

IT IS WITH DEEP REGRET that we record the death of Mr. H. W. J. Hathaway, who was killed as the result of an accident while engaged in war work, in July of this year. Mr. Hathaway joined the Club in August 1942. He showed great promise, and his death is a real loss to Rheology.

242. Flow of Visco-elastic Materials in Capillaries.

A. C. MERRINGTON. *Nature*, **152**, 663, 1943.

Viscosity determinations were carried out on rubber solutions using a viscometer in which the true pressure-drop along the capillary was measured directly. The measurements indicated the existence of an end effect. A typical family of flow curves was plotted in one rubber solution. These curves emphasise the importance of using long tubes, particularly at high stress, if the results are to be assumed to apply to an equilibrium condition. As the tube length decreases the end effect becomes large in proportion to the total length. The curves show that with increas-

5

ing stress the end effect increases in magnitude and that this end "correction" deduced from the flow curves and expressed in tube diameters is proportional to shearing stress. Tests made with mineral oils containing metallic soaps show that when the liquid emerges from the capillary it is still elastically deformed and will consequently tend to return to its former "unstretched" condition. This results in the swelling of the emergent column of liquid. Here, again, elastic recovery is proportional to stress, i.e. the "elastic end effect" which results in differences in the flow curves, and the swelling of the emergent column of liquid, are related, and either should give a measure of the elastic property of the material.

••TO KEN WALTERS ON HIS 80TH BIRTHDAY••
••••(Ruminations on things that might have been)••••

I am, as of now,
 a creaky, old nonagenarian,
 But you, my good friend,
 are a lively, young octogenarian.

You could have become
 a fussy old classics librarian,
 Or even a pinstriped
 and dignified parliamentarian,

Or an amiable agrarian
 or a prestigious neo-theologian.
 Instead you turned into
 a respected Oldroydian rheologist.

You might have been born
 a jolly and yodeling Bavarian
 Or maybe an Algerian
 or a basso profundo Bulgarian.

But to none of these groups
 did you really and truly aspire.
 You are all the way through
 a member of the British Empire.

You might have been married
to an famous and elegant princess
But then you'd have had
to live in a castle or fortress

And attend many teas,
surrounded by butlers and pages.
You'd be living like creatures
imprisoned in elegant cages.

Instead you found "Mayree"
a marvelous lady and friend
With whom you could go
on trips well beyond the Land's End.

You've gone off to meetings
in lands that are strange and quite alien.
You've heard many talks
using words that are sesquipedalian.

And now that you are
no longer a septuagenarian,
We wish you the best
on becoming an octogenarian.

...Bob Bird...

...(April 2014)...

BSR Student Travel Awards

The British Society of Rheology wishes to solicit applications for travel awards from its student membership, with the objective of encouraging students to disseminate their research.

Travel bursaries are available to student members of the Society to present their research at a conference that contains a strong rheological element, in situations where no other sources of funding are available to cover the whole cost of the meeting. Suitable conferences include the International Congress of Rheology, the Annual European Rheology Conference and conferences organized by the Society. Applicants for a student travel bursary must normally have been a member of the Society for 9 months, may be working worldwide and presenting research at a conference, by paper or poster. The grant will be made on receipt of a report on the event, suitable for publication in the bulletin of the society.

The next closing date for consideration of the award of a travel bursary is Monday 1st September 2014 with successful applicants notified by the end of September. Applicants should include in their submission the name and location of the conference, the title, authors and abstract of the paper submitted to the conference, a breakdown of the projected costs of attending the meeting and a supporting letter from their research supervisor. The support of the British Society of Rheology should be mentioned in the conference presentation. The Society's logo may be used for this purpose. Payment of the bursary will be made on receipt of a report on the conference, suitable for publication in the Bulletin of the Society.

Applications for a travel bursary should be sent to the Secretary (secretary@bsr.org.uk).

Simon Cox
BSR Honorary Secretary

BSR Annual Award 2014

Nominations are invited for the BSR Annual Award 2014. 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 2013 was Jason Stokes, in 2012 Tim Phillips, and in 2011 David James.

Nominations, with a brief supporting statement, should be sent to the President, on president@bsr.org.uk, by the end of August 2014.

Vernon Harrison Award 2014

In 2003 the British Society of Rheology decided to institute a new annual award for the most distinguished PhD thesis in rheology. The aim of this award is to recognise excellence, creativity and novelty in research. It will be awarded to the postgraduate student who, in the opinion of the adjudicating committee, has made the most original and significant contribution to any branch of rheological research (experimental, computational or theoretical) leading to the award of a PhD degree in a given academic year. This prize is partly supported by the Vernon Harrison Bequest. Dr Robin Cooke from Durham University was the 2013 winner, with his thesis on "Shear Banding in Time-Dependent Flows of Complex Fluids".

The prize for the award will be £500 and an illuminated certificate.

Entries for the 2014 Vernon Harrison Award should now be submitted. The deadline is 30 September 2014.

Any person who has submitted and successfully defended a thesis in any area of rheology at a higher education institution in the United Kingdom between 1 September 2013 and 31st August 2014 is eligible, whether a member of the Society or not. Each entry should consist of:

- * A two page summary of the research and the key achievements which especially distinguish it as a candidate for this award;
- * A letter from the thesis supervisor confirming the recommendation of the award of a PhD to the candidate and supporting the case for the award, highlighting the specific original contributions of the candidate;
- * The name and address of the external PhD examiner. The Committee may subsequently ask to see a copy of the final version of the thesis in reaching their decision.

An Adjudicating Committee appointed by the Council of the British Society of Rheology will consider the entries. Particular attention will be given to the originality and quality of the thesis. Entries will be selected by the Adjudicating Committee for presentation at a meeting of the British Society of Rheology in December. The Adjudicating Committee may award any number of first and secondary prizes. Travel funds will be available to assist candidates to attend the prize meeting.

Proposals should be sent to the BSR secretary at secretary@bsr.org.uk.

British Society of Rheology

Minutes of the 73rd Annual General Meeting (Draft)

The 73rd Annual General Meeting of the British Society of Rheology will be held at the Lake Vyrnwy Hotel, Powys, Wales on Tuesday 15th April 2014 at 5.15pm.

held at the Lake Vyrnwy Hotel, Powys, Wales

on Tuesday 15th April 2014, 5.40-6.05pm.

- **Present:** the President and 32 members. One vote was cast by email.
- **Apologies:** received from Bettina Wolf, Manlio Tassieri, Nick Hudson
- **Minutes of the 72nd Annual General Meeting:** These were agreed as a true record of the meeting and signed by the President.
- **Matters arising:** there were none.
- **Reports of the Officers:**
 - **President:** Rhodri explained that he had been working recently on the rheology of blood, and would deliver his report in the way in which a clinician would assess the state of health of a patient.
So what is the status of British Rheology? The life blood of the subject is students – they replenish and invigorate it. Yet only one travel award application was received in the last year. Is this a bad sign? There are plenty of students at scientific meetings; Rhodri therefor concludes that supervisors now have more funding available.
Another marker is PhD theses: last year's Vernon Harrison competition saw eight applications. Each one was scrutinized by a subcommittee of council. Each one merited an award. But one was chosen and the award was given at the Mid Winter meeting.
So, excellent PhD students are coming through the system, but there is a difficulty in getting on to the career ladder in academia. At the next council meeting, Rhodri proposes to discuss how the BSR can work with the EPSRC to use fellowships to help at this career stage for example by helping members to make plausible applications for postdoctoral positions and research fellowships.
In conclusion, rheology is alive and kicking; it is in a rude state of health. Finally, Rhodri thanked Bill Frith, immediate past president, for advice and support over the last year.

- **Honorary Treasurer:** Steve circulated a summary of the accounts and gave the following report: The BSR continues to have strong finances resulting from a steady income and continued reductions in expenditure.

The society began 2013 with a balance of £64,834.40. Membership subscriptions were down slightly but this was mainly as a result of some people paying two years membership in the previous year. Council expenses remained constant at around £1900.

Income from publishing increased slightly (by £260.63) whilst costs were reduced substantially by over £3,000 resulting in a good income of £3,589.48. The reduced costs came from the abstracts side of publishing being wound down. The website also made a slight profit for the first time in several years (£277.06) since we no longer pay quarterly bills for the maintenance of the website.

A deposit account with 4% interest produced a nice income of over £1600. The term of this investment expired last month but council are now looking to reinvest a large sum in a suitable investment scheme as soon as possible.

Miscellaneous income was up by around £1500 due to higher takings from the 2013 mid-winter meeting (MWM) in Cambridge. This meeting also incurred higher costs but these won't show on the balance sheet until 2014. The expenditure associated with the MWM was also considerably lower but this is because these costs came from the 2012 MWM in Aberystwyth.

Paypal charges increased but only because we received more money from this source in 2013. The total charges for paypal are commensurate with the standing charge we used to pay for a credit card facility with Lloyds bank. Paypal has been a good money saver for the society and has also accelerated the speed of payments paid and received. Insurance costs and prizes remain at a similar level to 2012.

As a result of the above income was boosted slightly by £541.48 to £18,516.18 whilst expenditure was reduced by £5,668.00 to £11,169.07. The final outcome is a net income of £7437.11 which gives the society a healthy final balance of £72,181.51.

- **Honorary Secretary:** Simon reported that

The 2013 Midwinter meeting was organised by Oliver Harlen and Ian Hutchings at the Institute for Manufacturing at the University of Cambridge. The theme was Coating, Printing and Painting, and the meeting was notable for having a high proportion of industrialists (and non-members) present (as usual, delegates were offered a year's

subscription as part of their registration fee). Thanks to Oliver and Ian for organising a successful meeting. The next Midwinter meeting will be in Durham, organised by Suzanne Fielding, in December.

The BSR's Travel Awards offer UK PhD students who are members of the society a contribution of £250 towards attending a rheological conference of their choice to present their work. There has only been one application in the two rounds: none in October and one in March, which we will discuss at our next council meeting. Please encourage your students to join the BSR so that they are in a position to apply.

In contrast, last year's Vernon Harrison Award attracted a remarkable eight entries. Not only that, but the standard was exceptionally high. A sub-committee of council agreed that the prize should go to Robyn Cooke from Durham, for her thesis on Shear Banding in Time-Dependent Flows of Complex Fluids. Robyn presented her work and accepted her award at the Midwinter meeting last December.

The 2013 Annual Award, as you've just heard, was given to Jason Stokes. There is also a call for nominations for this year's award, and it would be good to have input from as many members as possible (please contact Rhodri before the end of May).

- **Membership Secretary:** Tim reported that the current membership of the society consists of 373 members, including 77 honorary members. Of these, 267 are in the UK, 55 in Europe and 51 in the Rest of the World. Eleven new members were welcomed in the last year, and there have been a couple of resignations. There are still many inactive members, who have not paid for 2 or 3 years, and only about two-thirds of members have paid their 2014 subscriptions, so some chasing is required.

- **Bulletin Editor:**

In the past year three issues of the Bulletin have been published. Articles have included a tribute to Russell Davies on the occasion of his retirement by Bob Anderssen, on Bubble Dynamics by the Annual Award winner Tim Phillips, and on Shear Banding by Vernon Harrison Award winner Robyn Cooke. Other articles have been on Fractional Constitutive Equations by Adi Jaishankar and on the most cited papers in the Journal of Non-Newtonian Fluid Mechanics. We have also published a series of "From the archives" as the historical BSR bulletins have been digitized. The next Bulletin will include articles from the latest Annual Award winner - Jason Stokes - and from Hans Hurlimann and Anke Lindner.

Richard Buscall asked what proportion of bulletins are sent to members

overseas; this was deflected to the Publications Manager.¹

- **Abstracts Editor:** Nick reported *in absentia* that the last edition (Vol 56-3&4) was despatched in December. One subscriber opted to pay for perpetual access to the electronic copy of all Volumes. Having been editor on several occasions over the last 17 years, it is sad to see it disappear, but its time had come. The BSR published the last 20 volumes, and it has been a good source of income.
- **Publications Manager:** Nick reported *in absentia* that the latest Bulletin (55-1) was sent out on Tuesday 8 April.
- **Resolution:** Council proposed the following motion for consideration by the AGM. Following the decline in subscriptions to Rheology Abstracts and a majority of support from members through a survey by email, it was announced in Vol 54 No 3 2013 of the Rheology Bulletin that Rheology Abstracts would no longer be published. The post of Abstracts Editor is therefore no longer required. Council proposes to replace this with an officer responsible for the society's website and electronic communication with members. This entails the following changes to the constitution:
 - * 5(a): replace “Editor (Abstracts)” with “Editor (Web)”
 - * 8(h): replace “The Editor (Abstracts) shall be responsible for the preparation and circulation of the Society's publication entitled Rheology Abstracts” with “The Editor (Web) shall be responsible for the preparation and posting of material to the Society's website and other online forums”.

The resolution was passed unanimously.

- **Election of Officers and Council members:**

Rhodri begins his second year as president.

There being no further nominations, the nominations circulated with voting papers were approved without dissent by those present at the meeting. The Council for 2014-15 was therefore elected as follows:

¹ Nick Hudson has since reported that 31% of bulletins are sent overseas, including both overseas members and other society secretaries and libraries for legal deposit.

Hon. Treasurer
Hon. Secretary
Membership Secretary
Bulletin Editor
Web Editor

Mr S. Goodyer
Prof. S.J. Cox
Dr M. Charalambides
Dr R. Poole
Mr P. Hodder

Ordinary members of Council:

Dr B. Dobraszczyk
Prof. S. Fielding
Dr N. Hudson
Prof. T. N. Phillips
Dr M. Tassieri
Dr R. Watson

Bill Frith continues as Immediate Past President.

- **Any other business:** There was none.

Simon Cox
Honorary Secretary

P. Rhodri Williams
President

Report on 9th Annual European Rheology Conference April 8-11th, 2014, Karlsruhe, Germany

Thanks to the BSR-TA travel award, I was privileged to attend and present my research at the 9th Annual European Rheology Conference. The conference was held in the beautiful city of Karlsruhe, Germany, well known for both its cultural attractions and scientific research. Home to the Karlsruhe Institute of Technology, the city is at the heart of the Karlsruhe Technology Region, one of the most dynamic and successful economic regions in Europe. Although the city is currently undergoing building works for the construction of an underground metro system, the beauty of the city shone through and we were reassured by the Mayor during the welcoming ceremony that this transformation will ultimately improve the “rheology of the city”.

A huge thank you to Chairmen Norbert Willenbacher and Manfred Wilhelm, and their team of organisers for their time and effort coordinating what was a hugely successful meeting; the analogy between the local organising committee and a system of spring-dash-pots, as in the Maxwell model, certainly raised a few laughs. Additionally, we should acknowledge the generous support given to the conference by a number of sponsors, including Thermo Scientific, TA instruments, Anton Paar and Fresenius.

This year 441 abstracts were submitted, comprising of 327 contributions from European colleagues and 114 abstracts were submitted by fellows from 22 countries overseas. Furthermore, the scientific programme included 3 plenary lectures given by invited speakers Stephan Herminghaus, Erich J. Windhab and Dimitris Vlassopoulos, whose talk I particularly enjoyed; he presented the comb model for entangled polymers in order to explore the role of key molecular parameters and demonstrate the consequence of polymer architecture on rheological data and modelling predictions.

Over 200 oral contributions were selected and covered over 11 symposia, including my areas of interest “Colloids and Suspensions”, “Non-Newtonian Fluid Mechanics and Flow Simulations” and “Flow-Induced Phase Transitions and Flow Instabilities”. In particular, I enjoyed Christian Clasen's discussion of why highly polydisperse polymer solutions are desirable for electro spinning. Beyond this, almost 200 posters were displayed for the duration of the conference and I had the opportunity to discuss my research “Modelling Capillary Break-up of Particulate Suspensions” during the poster session. Furthermore, twelve companies were in attendance to demonstrate their latest developments in rheological equipment and measuring techniques.

The conference dinner was held at the ZKM Centre for Art and Media. The evening included a concert by the KIT chamber orchestra and also a special opening of the current ZKM interactive video art exhibition.

Overall, the 9th Annual European Rheology was a huge success and very enjoyable. I am looking forward to attending next year's meeting in Nantes, France, hosted by “Groupe Francais de Rheologie”.

Claire McIlroy, Leeds

British Society of Rheology Winter Meeting 2014



**Lindisfarne Centre, St Aidan's College, Durham University,
17th and 18th December 2014.**

The meeting will comprise of a mini-symposium on active fluids and a more general session on the flow of complex fluids, with the particular aim of encouraging collaboration between the active fluids and complex fluids communities.

Confirmed Speakers

Professor Raymond Goldstein, University of Cambridge

Professor Ramin Golestanian, University of Oxford

Professor Ignacio Pagonabarraga, University of Barcelona

Submitting an Abstract

Contributions for oral and poster presentations are invited. Please email your abstract to admin.bsi@durham.ac.uk.

To find out more about the 2014 British Rheological Society Midwinter meeting and to register please email bsr.midwinter2014@durham.ac.uk.

Institute of Non-Newtonian Fluid Mechanics
Spring meeting

Rheology of Structured Fluids

30th March – 1st April 2015

The meeting will be held at **Ruthin Castle** in North Wales, commencing at 12 noon on Monday 30th March and finishing just before lunch on Wednesday 1st April.

The main focus of the meeting is to share new results on experiments, simulations and theory of the flow of complex fluids with distinct microstructure. The current president of the BSR, Professor Rhodri Williams (Swansea), will give his Presidential Address, followed by the AGM of the Society.



The county town of Ruthin in the Vale of Clwyd is about 20 miles from Chester. It is close to Snowdonia National Park, yet only an hour's drive from Manchester airport.

The castle was built in the 13th century, heavily renovated in the 18th, and now provides luxury accommodation and dining, complete with a ghost. Early registration is recommended due to high anticipated demand and the limited number of bedrooms available.

The registration fee of £450 includes full board accommodation. The fee for accompanying people sharing a bedroom with a full delegate is £200.

For further information, including details of how to register, please visit the website <http://www.innfm.org.uk/>

or contact the organisers:

Simon Cox: foams@aber.ac.uk, tel. +44 1970 622764

Tudur Davies: itd@aber.ac.uk, tel. +44 1970 622813

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New Intelligent Rheometer Responds Intuitively to Individual Quality Control Demands

Breakthrough design with intuitive interface offers a new level of user confidence and ease of use

MUNICH – Analytica 2014 – (April 1, 2014) – Industrial QA/QC laboratories that analyze the rheological properties of a wide variety of samples can now increase efficiency and reduce user error with an intelligent rheometer that adapts to an individual's measurement routines and conditions.

The Thermo Scientific HAAKE Viscotester iQ rheometer's "Connect Assist" function automatically detects the measuring geometry and temperature module, providing real-time feedback that makes it easy for customers to set up sample testing procedures with minimal errors. **Thermo Fisher Scientific will debut the HAAKE Viscotester iQ during Analytica 2014 (Hall B1, Booth #101) being held at Messe München in Munich from April 1-4.**

Several new options make the rheometer more useful and versatile than the previous generation. The HAAKE Viscotester iQ rheometer can be used as a standalone instrument with its touchscreen interface or by using the unique Thermo Scientific HAAKE Viscotester iQ RheoApp software on



a USB flash drive to provide extended capabilities. In addition, the instrument can be operated with full software control from a desktop computer. The instrument's "Temperature Assist" function in concert with its Peltier temperature control system enables customers to measure the true sample temperature as well as reduce the measuring time.

"The HAAKE Viscotester iQ represents a significant evolution in our Viscotester portfolio," said Birgit Schroeder, product line director, material characterization for Thermo Fisher Scientific. "The instrument's new features are a significant improvement over the well established HAAKE Viscotester 550 instrument, and signal our continuing commitment to excellence in viscometry and rheometry."

In addition, the HAAKE Viscotester iQ rheometer offers:

- Modular design, allowing customers to quickly exchange accessories and customize the instrument to suit their needs;
- Self-contained Peltier temperature control for coaxial cylinders and parallel plates, allowing a broad scope of measurements over a wide temperature range and sample types;
- Enhanced measuring flexibility from single-point measurement up to a comprehensive rheological measurement using Controlled Rate or Controlled Stress mode;
- A carrying case for easy transport of the instruments and accessories to field sites.

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CONFERENCE DIARY

2014	CONFERENCES & MEETINGS
13 -17 Oct Philadelphia, USA	The Society of Rheology 86th Annual Meeting For updates see http://www.rheology.org/SoR/annual_meeting/2014Oct/
17 -18 Dec Durham	BSR MWM2014 Organising Committee: Suzanne Fielding (Durham), David Hoyle (Durham) and Ricard Matas-Navarro (Durham). https://www.dur.ac.uk/bsi/bsrwinter2014/
2015	
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/

2014	COURSES & WORKSHOPS
26th -27th November Bradford 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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