
THE BRITISH SOCIETY OF RHEOLOGY



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EDITORIAL

SUBMISSIONS TO THE BULLETIN

Submissions to the Bulletin may be made by any practical means – post, email, disk, fax, pigeon, donkey, guide dog, *et cetera* but electronically is preferred (saves typing...). Most packages supported (Word, TeX, LaTeX, WordPerfect, ASCII, RTF) but 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. As always, all contributions are gratefully received. Late copy can sometimes be accommodated, however the facilities of the BSR and ESR web sites may also be appropriate. Please contact the Editor (xue-feng.yuan@manchester.ac.uk) for details.

COVER ILLUSTRATION

The images in the cover show (left) computer renderings of 3D confocal microscopy images of a colloidal paste (volume fraction 62%) during steady shear. The bottom image has an accumulated strain of 6% with respect to the top image, the greyscale measures the change in local particle environment over the past 6% accumulated strain, red lines highlight local deformations. The relaxation occurs via temporally changing clusters where plastic rearrangements are concentrated. The right diagram shows the trajectory of a single particle in the shear plane, comoving with the flow, over 75 strain. Rearrangements of the 'cages' (indicated by circles) take place on considerably smaller scale than the particle radius ($a=0.85\mu\text{m}$). The data highlight the importance of heterogeneity in plastic flow of soft glassy materials. Courtesy of Rut Besseling and Wilson Poon, see also R. Besseling, E.R. Weeks, A.B. Schofield and W.C.K. Poon, Phys. Rev. Lett 99, 028301 (2007).

We are always looking for appropriate images for the front cover of the Bulletin and Rheology Abstracts (preferably of a rheological nature!). Please contact either Xue-Feng Yuan (xue-feng.yuan@manchester.ac.uk) or Nick Hudson (n.e.hudson@strath.ac.uk). Contributions are always welcome!

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 - publications, conferences and access to fellow members who, while working in a different discipline or industry, may be facing similar problems to yours. The Society is non-profit making and is registered as a charity.

You are warmly welcome to visit our web site <http://www.bsr.org.uk/>, and to apply for membership on-line.

Transforming from Time to Frequency without Artefacts

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Abstract

I review a simple method, recently introduced to convert rheological compliance measurements into frequency-dependent moduli. New experimental data are presented, and the scientific implications of various data conversion methods discussed.

This is an article about the sanctity of experimental data.

As the readers of this Bulletin will know better than I, there are many different ways to do rheology — many different experimental techniques by which to measure the mechanical properties of viscoelastic materials. Some techniques measure a compliance, others measure a modulus. Some measurements are most conveniently expressed as a function of time, others as a function of frequency. For instance, in a passive microrheology experiment, the time-dependent mean-square displacement of probe particles is measured as the particles perform Brownian motion within the viscoelastic medium. That increasing function of time is a measure of the fluid's time-dependent compliance [1, 2, 3]. There is often no alternative to such microrheological measurements, as sample volumes may be very limited, due to expense, or difficulty in producing or refining the samples [4]. The compliance is also provided by a macroscopic creep experiment where a stress step is applied to a material, and its resulting strain is followed as time proceeds. Even where sufficient material exists to use a conventional rheometer, a creep experiment is often the only feasible probe of the slowest relaxation modes of high-viscosity materials such as drilling muds or soft glassy materials including pastes and slurries. The raw data generated by those experiments look quite different from the frequency-dependent storage and loss moduli ($G'(\omega)$ and $G''(\omega)$) measured in oscillatory rheometry. Nevertheless, so long as the measurements were performed in the linear regime, the two experiments in fact probe exactly the same physical properties of the material, so that the time-dependent compliance and the frequency-dependent modulus data contain the same information.

This can be easily understood if one imagines performing oscillatory measurements at two different frequencies simultaneously — a technique known as multi-wave rheology. Applying a high-frequency oscillatory stress superimposed on top of a low-frequency oscillatory stress causes the material to respond at both frequencies simultaneously, and the high- and low-frequency parts of its strain

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can be separately measured, giving its moduli at both frequencies. The experimenter could add in more frequencies, to measure more points on the spectrum at once. Every schoolboy who has watched an oscilloscope screen as sine waves from different oscillators were added together knows that, by adding up the appropriate amounts of all the odd harmonic frequencies, one can generate a square wave. A single stress step is just a square wave of infinitely low frequency, and is therefore equivalent to performing oscillatory measurements at all frequencies at once.

Since the data from creep and oscillatory rheometry contain equivalent information, it is equally acceptable to express their results by plotting a graph of compliance versus time, or of storage and loss moduli versus frequency. It is useful to express the results from both experiments in the same format, so that they can be directly compared. In practise, the frequency-dependent moduli have become the more standard rheological measure, so the need exists to convert creep compliance data into $G'(\omega)$ and $G''(\omega)$, and therein lies a problem. How do we convert the data accurately, i.e. without introducing artefacts?

In principle, the conversion is absolutely straightforward, since the frequency-dependent moduli are inversely proportional to the frequency-dependent compliance. We have measurements of the time-dependent compliance, so we just have to identify how much of each frequency is contained in that time-dependent signal, i.e. Fourier-analyse it. There are plenty of standard tools available for Fourier-analysing a signal, but the compliance signal from a step-stress experiment has several features that over-tax the approximations inherent in those tools, liberally decorating the output with artefacts. We need to go back to the drawing board, and analyse closely what is involved in processing a signal, making sure not to violate basic principles of scientific method.

The main problem is one inherent in many experiments. We want to process (in this case, to Fourier-analyse) a signal that is a function of time. Unfortunately, we do not have access to the true function of time since, in practice, the data have three shortcomings: the measurements begin some short but non-zero time after the stress step was applied (due to the finite time resolution of the rheometer); the measurements are discrete, not continuous (also due to the temporal resolution); and the data terminate after some finite duration. The mathematical recipe for a Fourier transform requires as input a function that is defined for all values of the time t . So we have a dilemma: what continuous function of t should we substitute into the mathematics instead of the experimental data? The knee-jerk reaction to this question is one of horrified indignation: don't substitute an artificial function; just stick the experimental data into the Fourier-transformation formula. Sadly, the Fourier-transform formula demands a continuous function, so blindly substituting-in discrete data is equivalent to replacing a data-set such as that in Fig. 1a by the function in Fig. 1b. Clearly, some interpolation and extrapolation is unavoidable, and we need to find a fitting function that will be truest to the data. Those who try to avoid

choosing a particular function by simply substituting their data directly into the Fourier transform are unwittingly choosing to interpolate with a function such as that in Fig. 1b. There could hardly be a worse choice. It would be similarly unwise to evade the choice by entering the data into some proprietary spectrum analyser. The approximation scheme would then be hidden from the scientist, but the responsibility for the resulting artefacts would remain his. Let us review the scientific validity of some other popular choices of fitting function for the compliance data.

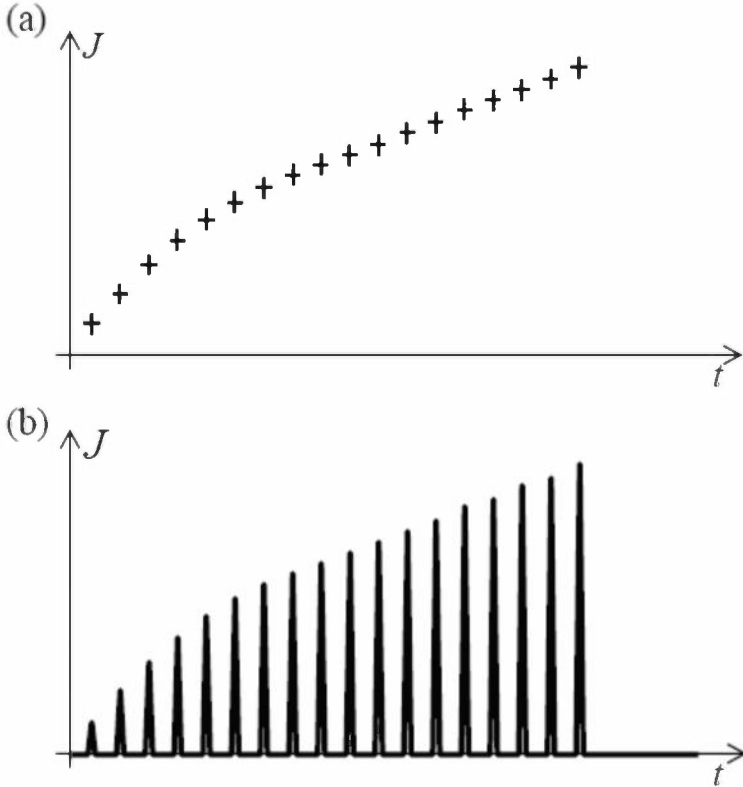


Figure 1: (a) Sketch of an example data set from experimental measurements of a time-dependent compliance J . (b) Naïvely substituting the data directly into a Fourier integral (replacing the integral by a summation over the data points, $\sum_p J_p \exp(i\omega t_p)$) is tantamount to replacing the data by the function shown (a series of delta functions), and thus assuming that the compliance has a value of zero at all times except for those when a measurement was taken. That is obviously a bad assumption.

A common approach is to fit the data to a theoretical model of viscoelastic fluids, such as the generalized Maxwell model, in which a number of Maxwell modes are added together to model relaxations in the fluid that occur at a range of different rates [5]. Each mode is characterized by an amplitude (how much of that mode is present) and a time scale. Thus the experimental compliance data are used to establish the values of a set of fitting parameters — two per Maxwell mode — and the frequency-dependent moduli of that best-fit model can then be plotted. The philosophy of such a scheme is difficult to justify, since it blurs the distinction between theory and data. Should the resulting graphs of $G'(\omega)$ and $G''(\omega)$ be regarded as the results of a model or an experiment? They can be legitimately interpreted as the output of a model, with the understanding that they therefore do not carry the weight of a true empirical observation. It would be unscientific to treat the results as measurements, since scientific methodology demands that experimental design must not allow data to be influenced by theoretical preconceptions. It must not be forgotten that experimental data, not theoretical models, are sacred.

In the same way that sine waves of different frequencies can be added together to reproduce any function (a Fourier transform), the same is true of decaying exponentials (a Laplace transform [6]); if one adds together sufficiently many decaying exponentials of appropriate amplitudes and rates, one can fit them to the experimental data with arbitrarily good accuracy. So a large series of exponentials need not be regarded as “Maxwell modes” derived from a theoretical model, but simply as a general smooth function with sufficiently many fitting parameters to give a good approximation of the data. Using that fitting function has the advantage that it is mathematically very easy to Fourier-transform, and thereby convert into graphs of $G'(\omega)$ and $G''(\omega)$. Philosophically, we are now of firmer ground. So long as the fitting function has enough flexibility (enough fitting parameters) to accurately reproduce the data set, it can be legitimately regarded as a true, unbiased representation of the experimental data, so that the resulting graphs of $G'(\omega)$ and $G''(\omega)$ are scientifically valid experimental results. But how many fitting parameters are enough? How close a fit to the data is close enough?

Intuition might suggest the following criterion. Data from the compliance experiment inevitably have some scatter, such as depicted in Fig. 2a. If a fitting function is so inflexible (like the dashed curve) that it can't be made to pass through the middle of that scatter, then it is clearly unsuitable, as it is a biased (inaccurate) representation of the data. If, on the other hand, by fitting many parameters, one can find a smooth fitting function that passes through the middle of the noise (like the solid curve in Fig. 2a), then it is usually assumed to be good enough. I disagree.

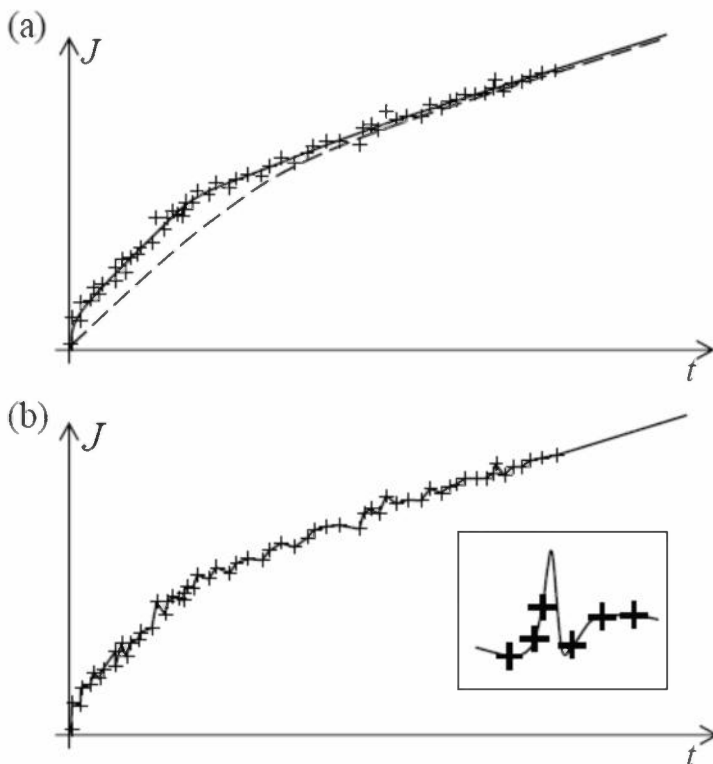


Figure 2: (a) Sketch of an example data set of a time-dependent compliance measurements with noise, and two alternative smooth fitting functions. (b) A piecewise-linear interpolation between the data point, and also piece-wise linear extrapolations. (Inset: An alternative interpolation scheme in which the curve is unnecessarily constrained to have continuous gradient at all points.)

It is our sworn duty as scientists not to doctor data, but to report them accurately, and every graduate knows that the best way to treat experimental noise and outliers is not to conceal them, but to present them for the reader's scrutiny. Therefore, I want to argue that the only acceptable fitting function is one that passes through every data point. Only then does the interpolating function truthfully report the results of the experiment; it is a true representation of the sacred experimental data. It is important to keep in mind the purpose of this exercise in interpolation and extrapolation, which is to allow us to Fourier-analyse the data, not to smooth them. On our quest to find a suitable interpolation scheme, we must not be beguiled by shiny things like the lovely smooth fitting

function in Fig. 2a. The assumption that the compliance should be smooth is a prejudice based on our preconceptions about fluids, but the experimental apparatus did not report a smooth function. We must put our preconceptions aside, and use the data.

So, to turn the discrete set of data points into a continuous function, suitable for Fourier analysis, we must join the dots, as in Fig. 2b. This still leaves us with an infinite choice of functions with which to connect the data points, and one might still be tempted to construct a locally smooth function by using, for instance, a piecewise cubic or a sinc series. However, such functions have a tendency to overshoot, as depicted in the inset to Fig. 2b. By insisting unnecessarily that the gradients match where the curves connect, in some cases one forces the curves into contrived shapes that actually lie far from the data set. As well as passing through every data point, and thereby telling the whole truth, the chosen fitting function must tell nothing but the truth, i.e. it must have no unwarranted behaviour in between the data points, as that would introduce spurious new information that was not present in the data. The only function that reliably introduces no new features between two data points is a straight line segment. So the most truthful interpolation of the data is given by a piecewise-linear function, as sketched in Fig. 2b.

To turn a finite data set into a function defined for all t , one must not only interpolate but also extrapolate to $t = 0$ and $t = \infty$, which we do with two additional straight-line segments. If the creep experiment was performed for sufficiently long to reach the terminal regime, where all elastic memory is lost, and the fluid flows with its long-time viscosity η , then the straight-line extrapolation to $t = \infty$ is uncontroversial. The final line-segment is given a gradient $1/\eta$, found by estimating the asymptote to the data by eye. Note that the human eye is the only good way to judge an asymptote to noisy or unpredictable data, as automated schemes are easily fooled. Similarly, the value J_0 of the compliance at $t = 0$ must be carefully judged from a linear or log-linear plot. If, on the other hand, the data do not reach the terminal regime, then no amount of analysis can recover the frequency-dependent moduli from the incomplete experiment.

It turns out to be straightforward to write down the exact Fourier transform of the piecewise-linear fit, yielding a simple formula. Plugging the data points into the formula is child's play, so that some standard laborious methods for approximate conversion are rendered redundant [1, 6, 7]. The simple formula can be found in Ref. [8], or can be downloaded for various standard data processing packages from www.pcf.leeds.ac.uk/research/highlight/view/4 but is also reproduced here

$$G'(\omega) + iG''(\omega) = i\omega \left/ \left[i\omega J_0 + (1 - e^{-i\omega t_1}) \frac{(J_1 - J_0)}{t_1} + \frac{e^{-i\omega t_N}}{\eta} + \sum_{k=2}^N \left(\frac{J_k - J_{k-1}}{t_k - t_{k-1}} \right) (e^{-i\omega t_{k-1}} - e^{-i\omega t_k}) \right] \right.$$

in terms of the two parameters J_0 and η , and the N data points (t_k, J_k) . This formula will return an answer for any value of frequency ω that is substituted into it. But, of course, the data only contain information about a limited range of frequencies. Specifically, the frequency window depends on the resolution (of order t_1 , the time of the first data point) and duration t_N of the data set, so that the formula returns real, scientifically valid information for frequencies in the range $t_N^{-1} < \omega < t_1^{-1}$, and artefact-dominated rubbish for frequencies outside that range. To be clear, outside that frequency range, the function is strongly influenced by the artificial features of the fit: the straight-line extrapolation to infinity and the sharp corners of the jagged function, whereas all features (including noise) that appear on the modulus graphs within the operational frequency range are genuine features of the data.

To demonstrate the efficacy of the conversion formula, new data are presented here (courtesy of Chirag Kalelkar, Complex Fluids and Polymer Engineering Group, National Chemical Laboratory, Pune, India) for a PAS melt. Figure 3 shows the compliance measured using CP-25 geometry on an Anton Paar MCR301 rheometer, at a stress of 200 Pa, averaged over 10 independent creep compliance runs with a duration of 600 s, combined with three measurements of duration 1 hour. It is clear from the figure that the duration was sufficient to reach the terminal regime, where the compliance asymptotes to a linear function (i.e. the Newtonian regime), with viscosity $\eta = 103600 \pm 100$ Pa s, as demonstrated by the linear extrapolation shown in Fig. 3. The inset to Fig. 3 shows the first few compliance data points on linear axes, allowing us to estimate the zero-time value as $J_0 = (1.12 \pm 0.09) \times 10^{-5}$ Pa⁻¹. Figure 4 shows the results of plugging the compliance data into the formula for $G'(\omega)$ and $G''(\omega)$ (continuous curves). Also, superposed are data from oscillatory measurements (frequency sweep) on the same material.

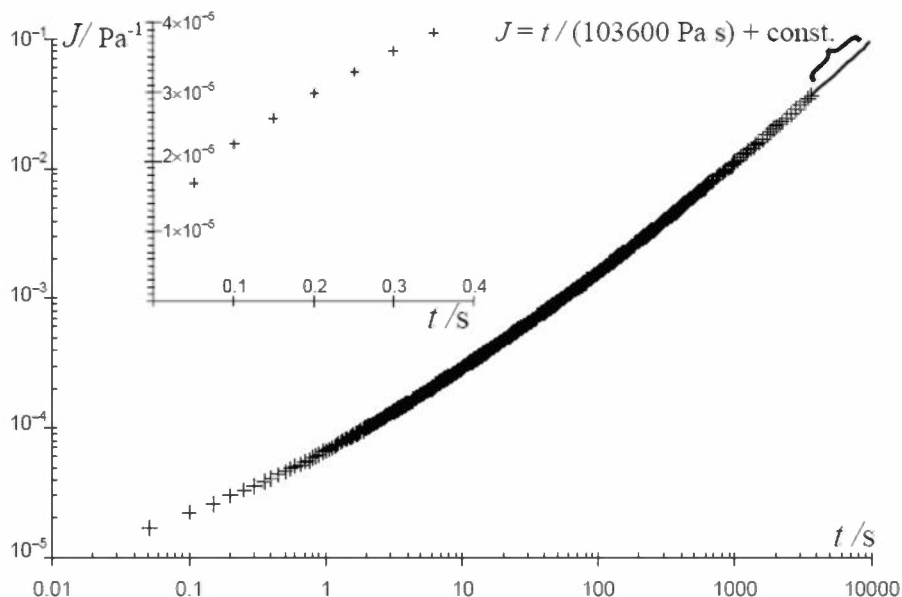


Figure 3: Creep compliance J versus time t for a polyalkylalkenylsiloxane (PAS) melt (molecular weight $M_w = 5 \times 10^5$ g/mol, polydispersity index $M_w/M_n = 1.83$) measured at room temperature using 25 mm cone-plate geometry on a stress-controlled Anton Paar MCR301 rheometer, at a stress of 200 Pa, averaged over 10 independent creep compliance runs up to time $t = 600$ s. Strain rate measurements averaged from three longer runs, also at 200 Pa, at lower temporal resolution were used to extend the range to $t = 3600$ s. The linear extrapolation beyond 3600 s is also shown, using the parameter $\eta = 103600$ Pa s. Inset: close-up on the early data points, shown on linear axes, to allow the zero-time extrapolation of J to be estimated. Data courtesy of Chirag Kalelkar, Complex Fluids and Polymer Engineering Group, National Chemical Laboratory, Pune, India

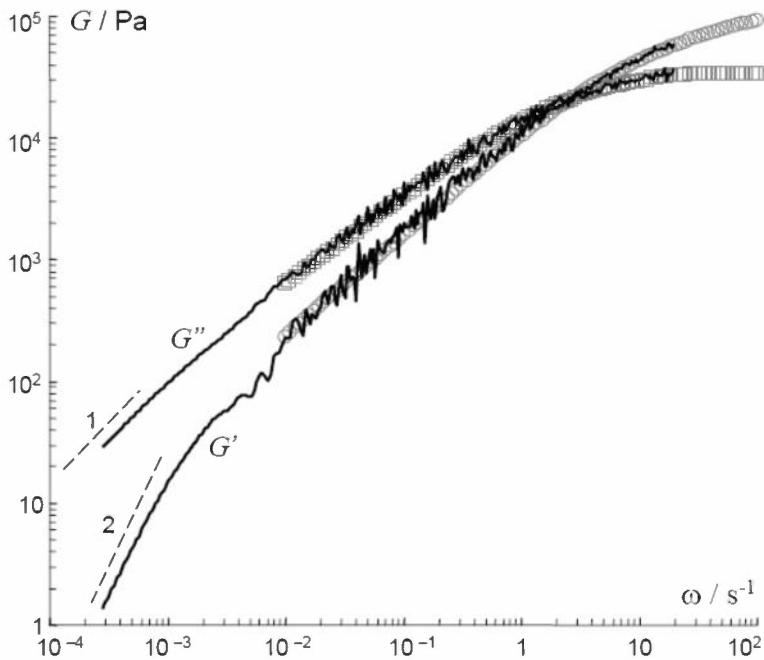


Figure 4: Storage and loss moduli as functions of angular frequency. The continuous curves were found by plugging the compliance data of Fig. 3 into the formula for $G'(\omega)$ and $G''(\omega)$. They are plotted only within the valid frequency range $t_N^{-1} < \omega < t_1^{-1}$, in this case $2.8 \times 10^{-4} \text{ s}^{-1} < \omega < 20 \text{ s}^{-1}$. Also shown for comparison are data (courtesy of Chirag Kalelkar) from oscillatory measurements (frequency sweep) on the same material (G' grey circles, G'' grey squares).

Note the striking agreement between the two measurements, confirming that the different experimental techniques probe the same material properties. Note also that the converted creep measurement just reaches the terminal regime (confirming that the compliance measurements were just long enough), where $G'(\omega)$ and $G''(\omega)$ at frequencies that are impractically low for oscillatory measurements. Since Fig. 4 displays only the relevant frequency range $t_N^{-1} < \omega < t_1^{-1}$, this low-frequency behaviour is *not* an artefact of the straight-line extrapolation; it is a result dominated by the late-time data that have reached the terminal regime in the creep experiment, while the straight-line extrapolation controls features at lower frequencies than those plotted in the figure. Only if a wildly inaccurate value of the viscosity were used, that was at odds with the data, thus introducing an abrupt corner into the overall shape of the fitting function,

would the resulting artefacts be so large as to leak into the operational frequency window.

The new conversion formula has already been applied to a number of different experimental systems in addition to the PAS melt reported above, including a polyisoprene melt in cone-and-plate geometry [8], magnetic microrheological measurements of F-actin solutions (a semi-flexible biopolymer) [9], and semidilute polyacrylamide solutions measured by both magnetic microrheology [9] and a new protocol for obtaining microrheological creep measurements using optical tweezers [10]. The technique has even been applied to non-equilibrium samples of aqueous wormlike micellar solutions [11], since it does not require the sample to be at equilibrium. So long as the sample's moduli evolve only slowly — on a much longer time-scale than the measurement — the conversion remains valid. This makes creep the measurement of choice for slowly evolving non-equilibrium samples, as it can be performed more quickly than the equivalent oscillatory frequency sweep. Of course, the formula should not be applied to non-linear rheology or to materials that are aging rapidly on the timescale of the measurements. In both of those cases the dynamic moduli are anyway not uniquely defined, as their definitions must then take account of coupling between harmonics [12] and of absolute time [13]. As the conversion method was published only a matter of months ago [8], the list of relevant literature is rather short, but growing rapidly due to the ease with which the formula can be applied.

ACKNOWLEDGMENTS: Many thanks to Chirag Kalelkar for experimental data and informative discussions, and to Dave Fairhurst and Manlio Tassieri for helpful advice. RMLE is funded by the Royal Society.

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BSR NEWS

Oliver Harlen BSR President 2009-2011



It was a great honour to be asked to become president of the British Society of Rheology. I was first introduced to Rheology by John Rallison, who set an essay topic on the flow of Non-Newtonian fluids past spheres. The subject excited me enough to decide to do a PhD on viscoelastic fluids under John's supervision. My thesis entitled "Strong Flows of Dilute Polymer Solutions" concerned the high stress boundary layers or "birefringent strands" generated by flow stagnation points where polymers experience very high strains.

After completing my PhD I spent a year at Cornell University with Donald Koch studying fibre suspensions in viscoelastic fluids before returning to Cambridge as a Research Fellow. Here I continued to work with John Rallison and John Hinch on modelling polymer solutions, and began developing the Lagrangian finite element method.

In 1994 I was appointed as a lecturer in Mathematics. I was soon introduced to a young professor of polymer Physics, Tom McLeish, who convinced me that polymers melts were at least as interesting as polymer solutions (and more challenging). I have enjoyed a long and productive collaboration with Tom, which has included developing the Pom-pom model for branched polymer melts and the Microscale Polymer Processing projects. Most recently I've returned to the topic of dilute polymer solutions in applications to inkjet printing.

Part of the attraction of rheology to me has always been its multidisciplinary nature, leading to collaborations between different scientific and engineering disciplines. The subject is too complex for any one person to truly master, and progress is often made by bridging between different disciplines.

I see the role of the British Society of Rheology to encourage and facilitate this interdisciplinary collaboration. As such we must be a "broad church" that welcomes members from all disciplines and does not define itself too narrowly. We do much to encourage young members, particularly Ph.D. students by providing travel grants, poster and thesis prizes. At the same time we must also remain attractive to members at all stage of their careers and welcome into the society those working in the broader area of complex fluids who do not necessarily consider themselves to be rheologists. Both industry and universities are experiencing tough economic conditions at present, so must remain active in promoting our field.

Rob Poole - New Council Member



I am a Lecturer in Engineering at the University of Liverpool. I have a degree in Mechanical Engineering from Loughborough University and a PhD from the University of Liverpool. My doctoral research was concerned with the turbulent flow of polymer solutions – in separating flows containing both shear and extension - and was completed under the supervision of Marcel Escudier. In between my

degrees I completed a brief summer project at Unilever and it was here that I was first introduced to rheology (of toothpastes or “tuffpastes” as my Wolverhampton accent used to pronounce them). Since joining the academic staff at Liverpool my rheological research interests have included shear and extensional measurements of polymer solutions and surfactants, laser velocimetry measurements in pipe, channel and contraction flows and numerical simulations. More recent work has focussed on purely-elastic instabilities.

Question to Readers: Very Early Rheology

Zvi Rigbi, who was a founder member of the BSR under his previous name of Z. Rogowsky and is now approaching 90, wrote to the Secretary with this query.

I have lately been leafing through a book called "God created the Integers" and I spotted a reference to the work of Laplace on elastic liquids, in which case he must be the second Rheologist in history, the first being the prophetess Deborah. I tried to find additional information in the French national library but could not keep up with the correspondence. Do you know anything about it?

If any members are interested in tracking down this lead, please do enlighten the Bulletin with your findings!

Helen J Wilson
September 2009

2009 BSR Annual Award

Dr Jeff Odell at H.H. Wills Physics Laboratory, University of Bristol is the recipient of 2009 BSR Annual Award. He will receive the award and give a lecture in the BSR midwinter meeting at University of Edinburgh in December 2009.

President's Reports

AERC 2009

In April the British Society of Rheology successfully hosted the 5th Annual European Rheology Conference in Cardiff. The move of the annual meeting to a more northerly latitude did not seem to deter attendance, and in addition to the many European rheologists a number of leading rheologists from North America and Asia also attended. Special thanks go to Professor Tim Phillips and his team for their superb organisation.

To mark hosting this meeting the BSR awarded its top honour, the Gold medal to two leading theoretical rheologists, Professor Michael Cates from University of Edinburgh and Professor Thomas McLeish from Durham University. Both began their rheological careers at the Cavendish Laboratory of the University of Cambridge where they once shared an office.

Future Meetings

- The next BSR Winter Meeting will be held from 14th to 15th December 2009 at University of Edinburgh on the theme of *Rheology and Soft Matter*. The local organisers are Job Thijssen, Rut Besseling.
- Next year's spring meeting co-hosted and organised by Institute of Non-Newtonian Fluid Mechanics will be from 29th to 31st March 2010 in the idyllic mid-Wales location of Lake Vyrnwy.
- The next meeting of the Non-Newtonian Club will be on 18th June 2010 at Schlumberger Cambridge Research. The club meetings are free and provide a forum for those practising rheology to meet in an informal atmosphere. Presentations from young rheologists particularly encouraged with a prize given for the best presentation. The meeting organiser is Steve Goodyear (Steve.Goodyear@anton-paar.com)

AGM and BSR Council

The BSR AGM was held during the AERC meeting in Cardiff. The Council for 2009-10 was elected as follows:

President	Dr. Oliver Harlen
Hon. Secretary	Dr. Helen Wilson
Hon. Treasurer	Dr. Dave Binding
Membership Secretary	Dr. Phil James
Bulletin Editor	Dr. Xue-Feng Yuan
Abstracts Editor	Dr. Nick Hudson

Ordinary Members of Council

Dr. Simon Cox
Mr. Steve Goodyer
Professor Tim Phillips
Dr. Rob Poole
Professor Mike Webster
Dr. Bettina Wolf

Rheology Reviews

Starting in 2003 the BSR has produced an annual book of review articles on subjects related to rheology authored by internationally renowned experts in the field. Recent issues have been delayed due to production difficulties, but the 2007 edition has recently appeared. It contains the following 4 substantial review articles referencing over 800 articles:

- Polymer melt viscoelasticity: what we can learn from molecular simulations (V G Mavrantzas)
- Quantitative tube model predictions for the linear viscoelasticity of linear polymers (E van Ruymbeke, C-Y Liu & C Bailly)
- Flows of viscoplastic materials: models and computations (E Mitsoulis)
- Model soft colloids out of equilibrium: glass-like and re-entrant transitions (D Vlassopoulos, E Stiakakis & M Kapnistos) .

BSR members received a complementary copy of Rheology Reviews 2007, which can be purchased from the BSR website (www.bsr.org.uk) along with all previous Reviews. Rheology Reviews 2008 will appear in the summer.

Oliver Harlen

BSR President,
School of Mathematics
University of Leeds

de Gennes Discussion Meeting, Chamonix, France

The Group Francais de Rheologie (GFR) and the European Society of Rheology (ESR) organised a highly successful “de Gennes Discussion Meeting” in the beautiful setting of Chamonix. The meeting took place between 1–5 February 2009 and twenty invited speakers presented papers that either reflected de Gennes’ past scientific interests, or presented new work that had emerged from his pioneering thinking in the general field of soft solids.

The ninety participants became actively involved in the meeting and the lack of parallel sessions and provision of copious excellent French cuisine, and wine, resulted in the meeting developing a real focus, enthusiasm and a high level. In addition to the daily scientific sessions, after superb evening meals, all the delegates returned to the lecture theatre to hear industrial perspectives of scientific work from senior representatives of, Total, L’Oreal and St Gobain.



Speakers at the Chamonix de Gennes discussion meeting. February 2009
(Photo Jean Francois Tassin)

This was a truly memorable meeting with as many delegates attending the first and last lecture; a rare event in this day and age. Subjects covered included polymers, mostly reptation related (Tom McLeish, Pino Marrucci, Ralph Colby, Robin Ball and Manfred Wagner). Interfacial properties (Masio Doi, Liliane Léger, Gerry Fuller, John Dealy and Jacques Guillet). Biological systems (Michael Rubinstein, and Mike Cates), and finally Supramolecular Structures (Ludwik Leibler).

The organisers are to be congratulated on providing a wonderful forum of genuine scientific debate.

Malcolm Mackley
June 2009

Polymer Processing at Goa

The 25th Polymer Processing Society (PPS) Annual meeting was held at the exotic and fascinating location of Goa in India over the period 1 – 5 March 2009. The current emergence of India as a major developing country added spice and local participation to the meeting and it appeared that nearly half of the 450 people attending were from India. The UK delegation was modest in size with representation from Aberystwyth, Bradford and Cambridge. I cannot recall seeing any UK industrial presence; clearly a sign of the times.



Delegates at the PPS India conference Goa

The scientific level within PPS meeting has steadily increased over the past decade and there has also been an increase in diversity of polymer processing aspects covered. Tam Sridhar from Monash University, Melbourne, Australia opened the proceedings with a review of filament stretching experiments and the experimental attainment of genuine steady state extensional viscosity measurements. Allen Windle (Cambridge) excited the audience with his group's ability to process fibrous yarns of carbon nanotube fibres. There were of course other excellent lectures too numerous to mention and in general the quality was good. In recognition of the 25th Anniversary of PPS there was a special symposium in honour of the founder of PPS, Professor James White. He attended the symposium which included a contribution on the history of the White Metzer model from Professor Ken Walters (Aberystwyth).

A clever and very effective feature of the meeting was the use of a judging competition for the poster presentation. The evening poster session was lubricated by thirst quenching beer and drinks in the outdoor hot and humid atmosphere. Six judges were assigned each day to mingle with the poster presenters, talk to them and also rank their posters. A shortlist of six was selected and then the whole judging team went to each shortlisted person and finally elected a \$1,000 prize winner for the day. The method helped ensure poster presenters were 'at their posters' and on their toes. The model worked very well and could be used for other meetings of similar size.

Malcolm Mackley
June 2009

Conference Report: 23rd Conference of European Colloids and Interface Society



The 23rd annual meeting of the European Colloids and Interface Society was held at the Letoonia Resort near Antalya, Turkey from 6th –11th September 2009. This meeting brought together over 350 academics and industrialist from a wide range of backgrounds and fields, from bio-medical research to polymer solution studies and nano-material formation to interfacial phenomena studies.

The meeting featured 3 award lectures (Rhodia Award 2008, Rhodia Award 2009 and Overbeek Award) and 6 plenary talks along with 83 oral and 314 poster presentations from contributors from all over the world. I presented two posters in the polymer solutions session of the conference proceedings, the first, entitled “Fully automated combinatorial exploration of rheological properties in multi-component systems with a standard rotational rheometer” demonstrated the unique automation system that we have developed here in Manchester to allow the automation of our standard Bohlin C-VOR rheometer. The second poster, entitled “Analysis and prediction of the behaviour of multi-component, polymer based fuel oil additive formulations” displayed our current work attempting to understand the mechanisms behind the build up of structure within the polymer solutions at cold temperature which we are tracking via the viscosity of the systems.

Some highlights of the conference were Gordon Tiddy's highly entertaining Rhodia 2008 award lecture and Ian Hamley's talk on the fibrillation of peptides, with a view to preventing the onset of diseases such as Alzheimer's.

Gordon Tiddy talked about his work in Gel (L_β) phases, where the gel phase creates a semi-crystalline equilibrium state at the surface. He talked through the process by which various surfactants can be combined to form differing structures and compositions of surface gels. The use of X-ray diffraction was particularly interesting as this area overlaps well with my work using X-ray diffraction to look at the structures with these semi-crystalline phases. Ian Hamley's work into the causes of diseases such as Alzheimer's, caused by the fibrillation of certain peptides, was particularly relevant to current affairs as the day before his talk related medicines had reached the headlines of the European media. It was very interesting to hear how the selective PEGylation of certain peptides can cause modification of the micelle formation mechanism in aqueous solution, which can be used to prevent the formation of Alzheimer's disease causing fibrillated peptides.

My poster presentations were well received, with several attendees asking questions about my work and engaging me in valuable discussion about the possibilities of where this work could lead and other areas where I could apply my rheological analytical techniques and knowledge.

Attendance at this well organised, informative and luxuriously located conference has helped me to gain valuable experience, feedback and knowledge from others in my field of research. I would like to thank the British Society of Rheology for kindly awarding me a travel grant, which enabled me to undertake the journey to Antalya to attend the conference.

Matthew Hudson
School of Chemical Engineering and Analytical Science,
University of Manchester, UK.

From the Atom to the Part!

A workshop held at Ecole Centrale, Nante, 21 – 23 October

A remarkable title and a remarkable Workshop! Professor Paco Chinesta masterminded a gathering of people interested in modelling different aspects of "parts" from microstructures, nanostructures, molecules and even atoms! This is of course an ambitious dream that in the past a number of rheologists have made significant contributions.

The width of topics covered in a three day meeting was just astonishing and exciting too. Prof Denis Aubry, Ecole Centrale, Paris, spoke on how solving Schrodinger's equation can be used to predict elastic constants of solids and Prof Jean Francois Molinari, Ecole Polytechnic, Switzerland, showed how modern

numerical techniques in both molecular dynamics and finite element elasticity (FEE) can start to predict tribology frictional slip behaviour. Nearer to home for rheologists, Dr Adrian Leygue, Ecole Centrale, Nantes, gave an excellent account of ‘repetition rheology’ and Prof Rene De Borst continued with combining molecular dynamics with FE to predict fast crack propagation. Prof Tim Phillips (Cardiff) gave an excellent account of recent developments in Lattice Boltzmann modelling of both Newtonian and Non Newtonian flow.



Malcolm Mackley (left), Damien Vadillo (centre) and Paco Chinesta (right) relaxing in the Brasserie Cigala, Nantes

And so it went on with different authors showing that the last decade of numerical techniques now offers the real chance to link solid and liquid microscopic properties from first principle atomistic concepts. Rheology of course plays an important part in relation to modelling macroscopic properties and it is exciting to think that this “dream” of going from the atom to the “part” is a realisable objective even for a “part” made of say a semi crystalline polymer, ice cream or even an aeroplane wing. If you think rheology is going through a quiet period, think again! Go for the width, the length scales and probably accept numerical techniques will be as important as a rheometer!

Malcolm Mackley
October 2009

RHEOLOGY REVIEWS 2008

(ISBN: Book: 978-0-9547414-8-8; CD: 978-0-9547414-9-6)

The field of rheology is extremely broad and continues to grow rapidly. With applications in almost every walk of life, important work is published in a very large number of journals and other media. Although modern computer-based technology enables the location of relevant studies satisfying certain criteria, it cannot determine the importance, or indeed, the significance of the studies. For this, it is necessary to tap the knowledge and experience of the world's most prominent specialists in rheology. This publication aims to achieve this.

Rheology Reviews 2008, 1-46, 181 references.

STRONG FLOWS OF VISCOELASTIC WORMLIKE MICELLE SOLUTIONS

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ABSTRACT

The unique rheological properties of viscoelastic wormlike micelle solutions have led to their broad use as rheological modifiers in consumer products such as paints, detergents, pharmaceuticals, lubricants and emulsifiers. In addition, micelle solutions have also become increasingly important in a wide range of industrial and commercial applications including agrochemical spraying, inkjet printing, turbulent drag reduction and enhanced oil recovery. Until recently, our knowledge of the rheology and flow behavior of these fluids was limited to linear viscoelasticity measurements where wormlike micelle solutions have been shown to behave as ideal Maxwell fluids, and steady shear rheology measurements where wormlike micelles often demonstrate shear banding. In this review, we survey recent experimental and theoretical developments for nonlinear rheology of viscoelastic wormlike micelle solutions and the response of these complex fluids to strong flows. Specific emphasis will be placed on extensional rheology measurements and complex flows having strong extensional components. In many of these flows, viscoelastic wormlike micelle solutions behave in a manner very similar to polymer solutions. Wormlike micelle solutions demonstrate strain hardening of their extensional viscosity which can result in an increased resistance to complex flows such as the flow past a sphere or the flow through porous media. Additionally, the large extensional viscosity of these fluids has led to significant drag reduction in turbulent flows. However, wormlike micelles are self-assembled

and as such are quite different than polymer solutions. Under large elastic stresses, wormlike micelles can break apart. This failure and the resulting morphological changes have been linked to a number of newly discovered elastic instabilities not present in polymer solutions. As this review will show, strong flows of wormlike micelle solutions hold a wealth of interesting flow phenomena much of which is yet to be explored.

KEYWORDS: Surfactant solutions; Viscoelastic wormlike micelle solutions; Extensional rheology; Shear rheology; Elastic instabilities.

Rheology Reviews 2008, 47-70, 88 references.

RHEOLOGICAL ISSUES IN THE PAPER INDUSTRY

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ABSTRACT

The paper industry has a number of processes where the rheology is complex and critical to control for trouble free operation. The rheological properties of pulp suspensions and paper coatings are reviewed here. The flow, rheology and other various phenomena are discussed for pulp suspensions. The particle level models that have been developed for pulp suspensions are compared to experimental results. Paper coating suspension rheology and the coating flow fields are described. Particle level models are discussed and compared to various rheological properties and process issues. Some open questions are identified.

KEYWORDS: Suspension rheology; pulp rheology; coating rheology; Stokesian Dynamics; viscoelasticity; yield stress

Rheology Reviews 2008, 71-135, 120 references.

FLOW AND TEXTURE MODELING OF LIQUID CRYSTALLINE MATERIAL

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ABSTRACT

A review of flow and texture modeling of liquid crystalline materials with emphasis on carbonaceous mesophases is presented. Two models of nematodynamics are presented and discussed in terms of their ability to resolve time and length scales likely to arise in typical rheological and processing flows. Defect physics and rheophysics are integrated with nematodynamics and specific

mechanisms of defect nucleation and annihilation are used to derive texture scale power laws. The integrated nematodynamics models specialized to carbonaceous mesophases are used to analyze: (i) linear and nonlinear viscoelasticity, (ii) rheological flows, and (iii) carbon fiber and flow-induced textures. The linear and nonlinear viscoelasticity reveals the essential nature of these materials : coupling between flow-induced orientation and orientation-induced flow, elastic storage through orientation gradients, and anisotropy. The rheological flow simulations, shown to be in excellent agreement with experimental data, reveal several liquid crystal specific rheological characteristics including shear thinning due to anisotropic viscosities and flow-induced orientation, and negative first normal stress difference due to orientation nonlinearities in the shear stress. Nematodynamic predictions are shown to follows a Carreau-Yasuda liquid crystal equation. Nematodynamics predictions rationalize shear-induced texture refinement in terms of defect nucleation and coarsening mechanisms and are used to derive texture scaling relations in terms of macroscopic, molecular, and flow time scales. This knowledge is then condensed into a generic texture-flow diagram that specifies the required temperature and Deborah number required to produce well oriented monodomain materials. The fine details of mesophase structuring by flow through screens are shown to be captured by nematostatic simulations. Finally the mechanisms behind the carbon fiber textures produced by melt spinning of carbonaceous mesophases are elucidated. The proven range and predictive accuracy of nematodynamics to simulate flows of textured mesophases and the ever-growing industrial interest in lower cost high performance super-fibers and functional materials will fuel the evolution of liquid crystal rheology and processing science for years to come.

KEYWORDS: Rheology of carbonaceous mesophases; Discotic liquid crystals; Defect rheophysics; Flow structuring; Carbon fiber structures



The Non-Newtonian Club (NNC) is an informal rheology discussion group which provides low-cost, informal, one-day meetings which provide an excellent forum for industrial and academic rheologists to meet together informally to present work in progress, raising key needs and concerns, and discussing unresolved practical and modelling issues that may be inhibited at more formal conferences. The agenda of the most recent BSR NNC meeting and the corresponding abstracts can be found at <http://innfm.swan.ac.uk/bsr/frontend/nonnewtonianclub.asp>.

The Non-Newtonian Club Meetings are held 2 - 3 times a year and provide a forum for those practicing rheology to meet. Presentations (typically 20-30 minutes) are made by academic and industry-based scientists, as well as young scientists, presenting on a range of topics that involve rheology in a relatively informal and friendly environment. To encourage phd students and 'young' scientists to present, we offer an award for the best presentation from phd students or 'young' scientists. We endeavour to keep these meetings free. Should you wish to host, sponsor, or participate in such an event, please let me know.

The next NNC meeting will take place in Schlumberger Cambridge Research sometime in June 2010. We are still looking for speakers from anyone involved with rheology as long as their material relates to the subject. Attendance is free of charge and includes tea/coffee and lunch courtesy of Schlumberger Cambridge Research. The best young speaker will receive a prize sponsored by Anton Paar. For further information visit the BSR website or contact steve.goodyer@anton-paar.com

Steve Goodyer

UNIVERSITY OF WALES
INSTITUTE OF NON-NEWTONIAN FLUID MECHANICS
Lake Vyrnwy Hotel, Wales U.K.

March 29 - 31, 2010

Programme

The meeting will commence at 12 noon on Monday March 29th, 2010 and finish at lunchtime on Wednesday March 31st.

The emphasis will be on advances in rheometrical theory, experimentation, instrumentation and interpretation of data. The meeting will include an instrument exhibition and a dedicated poster session. A **Special Issue of the *Journal of Non-Newtonian Fluid Mechanics*** will be devoted to the Proceedings.

Plenary Speakers will include: C.Bailly, D.Baird, D.Biberg, D.Boger, A.Burbidge, R.Buscall, J.M.Dealy, G.Fuller, C.Gallegos, J. Giacomini, K.Hawkins, I.Emri, D.F.James, O. Kulikov, P.Luckham, J.Maia, G.Maitland, G.H.McKinley, P.Moldenaers, J-M. Piau, M.Srinivasarao, M.H.Wagner, H.H. Winter and X-F. Yuan.

Venue

The meeting will be held at the Lake Vyrnwy Hotel, Llanwddyn, Montgomeryshire, Mid Wales, (<http://www.lakevyrnwy.com>), set in a 24,000 acre country estate, in a spectacular mountainscape overlooking the lake on the edge of Snowdonia, with dramatic, tranquil surroundings. The hotel offers excellent dining, accommodation and conference facilities. It is also equipped with a **spa** and fitness centre. Early registration for accommodation at the Lake Vyrnwy Hotel is advised due to high anticipated demand. Some alternative accommodation will be available in the nearby village.

Llanwddyn is approximately 1.5 hours by road from Manchester or Birmingham international airports and 3.5 hours from London.

Costs

The total cost of £400 includes the registration fee and full-board accommodation from Monday lunch to Wednesday breakfast. An accompanying person, sharing a room with a conference delegate, will be required to pay £150.

UNIVERSITY OF WALES
INSTITUTE OF NON-NEWTONIAN FLUID MECHANICS
Lake Vyrnwy Hotel, Wales U.K.

March 29 – 31, 2010

Prospective speakers should return this form, together with appropriate payment and a 200 word Abstract, no later than February 1st, 2010. Full manuscripts of papers will be required **at the Meeting**.

Block letters throughout please

Title.....Surname

Forename(s)

Organization

Full address
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.....

Tel Fax Email

- ☐ I wish to attend the conference and I enclose a cheque for £400 made payable to the University of Wales Institute of Non-Newtonian Fluid Mechanics.
- ☐ I shall be accompanied by and I enclose a cheque for £150 made payable to the University of Wales Institute of Non-Newtonian Fluid Mechanics.
- ☐ I wish to present a paper and I enclose an Abstract.

Please return this form to:

Professor P. Townsend,
Institute of Non-Newtonian Fluid Mechanics,
Computer Science,
University of Wales Swansea
Singleton Park,
Swansea SA2 8PP
U.K.

Tel: 01792 234376
Email: p.townsend@swansea.ac.uk

Macro2010: 43rd IUPAC World Polymer Congress

SECC, Glasgow, UK

11-16 July 2010

The 43rd IUPAC World Polymer Congress, 'Macro2010', is the latest in the series of the biennial meetings of the IUPAC Polymer Division. The series has been running for several decades and is the largest international multi-symposium conference dedicated to all aspects of polymer science and engineering.

Macro2010 will have an overall focus on *Polymer Science in the Service of Society*. The programme is split into 28 symposia, details of which are available on the website.

The Macro2010 call for papers is now open online. Submissions are invited for both oral and poster presentations from scientists working in all disciplines related to polymer science.

Oral abstract submission deadline: 29 January 2010

Poster abstract submission deadline: 9 April 2010

Visit www.macro2010.org to find out more.

INDUSTRY NEWS

Anton Paar

LAOS functionality for MCR Rheometers

Large amplitude oscillatory measurements (LAOS) are used to investigate the non linear behaviour of soft solids. A waveform monitor can be used to observe and store the sample stress / strain plots either on a time axis or versus each other on a Lissajous plot. Analysis of the Lissajous plot enables users to calculate Chebyshev coefficients. Existing MCR users can upgrade if they wish to incorporate this facility (instrument must have DSO option).

Ex-Demo MCR501

An ex-demo MCR501 has recently become available and the system is on offer to Universities in the UK and Ireland. The instrument will be fully serviced before installation, will include a 12 month warranty and be sold on a first come, first served basis.

Rheology Workshop 25th -26th November

This years winter workshop will take place at Bradford University. The course is an ideal introduction to rheology for both newcomers and those involved for a few years who wish to strengthen their knowledge. The course includes a free copy of "The Rheology Handbook" by course leader Thomas Mezger and also incorporates hands on practical sessions with modern rheometers.

For further information on any of the above items please contact: steve.goodyer@anton-paar.com, telephone Anton Paar on (01992) 514730 or visit www.anton-paar.com.

Thermo Fisher Scientific

Thermo Fisher Scientific Launches Next Generation Rheometer at ACHEMA 2009

Frankfurt, Germany, (11th May 2009) – Thermo Fisher Scientific Inc., the world leader in serving science, today announced the launch of its next-generation rheometer, the Thermo Scientific HAAKE MARS III. The company will showcase the latest model of its high-end rheometer platform and introduce a variety of new features promoted under the motto “Discover the MARS factor!” on booth B1-C11 in hall 6.1 at ACHEMA 2009 in Frankfurt, Germany, from May 11-15.

The innovative HAAKE MARS system was designed for flexibility and meets the most demanding requirements in research and development with an architecture that permits integration of custom modules. The concept is designed to meet today's and future rheology needs while protecting prior accessory investments.

“The MARS factor makes the difference,” said Markus Schreyer, vice president and general manager of Thermo Fisher Scientific's material characterization business “The breadth and depth of our customers' needs are our foundation, when it comes to developing flexible and future-secure rheometers. And the new HAAKE MARS III supports this goal for new and existing customers and is complemented by our tailored service portfolio.”

The new HAAKE MARS features include:

- New temperature modules with enhanced temperature control accuracy and expanded temperature module range for applications like starch and polymers
- New comprehensive accessory range to meet individual measuring needs like simultaneous measurements of rheology and optical properties, new measuring geometries and sample protection
- Optimized frame and easy handling due to quick-fit connections, user-friendly display and control panel
- Improved low-torque performance for sensitive samples
- Investment protection with compatibility for predecessor accessories
- Performance upgrade option allows existing HAAKE MARS customers to benefit from latest developments
- Multi-lingual Thermo Scientific HAAKE RheoWin software with fully automatic measuring and evaluation routines for professionals and beginners

The broad Thermo Scientific portfolio offers comprehensive workflows that go

beyond rheology. For example, in the polymer and pharmaceutical industry, customers can benefit from complete workflows that cover sample processing (extrusion) and sample preparation up to material characterisation, such as rheology.

As a pioneer in rheology, Thermo Fisher Scientific supports a wide range of industries with its comprehensive Thermo Scientific Material Characterization solutions. These products analyze and measure viscosity, elasticity, processability and temperature-related mechanical changes in plastics, food, cosmetics, pharmaceuticals and inks, coatings, or petrochemical products. For more information, please visit www.thermo.com/mc.

Thermo Scientific is part of Thermo Fisher Scientific, the world leader in serving science. For a full list of all press releases announcing new products atACHEMA 2009, please visit the online media room at [**www.thermofisher.com/achema09**](http://www.thermofisher.com/achema09).

CONFERENCE DIARY

2009	CONFERENCES & MEETINGS
14-15 Dec. Edinburgh	BSR Midwinter Meeting 2009 - The Flow of Soft Matter Contact: Job Thijssen:j.h.j.thijssen@ed.ac.uk http://www.bsr.org.uk/meetings.asp
13-17 Dec. Florida USA	3rd International Conference on Mechanics of Biomaterials and Tissues Hilton Clearwater Resort, Florida, United States - C. Wilkins - - ch.wilkins@elsevier.com - www.icmobt.elsevier.com
2010	
21-26 Feb Lynn Walker USA	Colloidal, Macromolecular & Polyelectrolyte Solutions Gordon Research Conference Contact: Lynn Walker http://www.grc.org/programs.aspx?year=2010&program=colloidal
29-31 March Lake Vyrnwy Wales	Institute of Non-Newtonian Fluid Mechanics Easter Meeting Contact: Professor P. Townsend, p.townsend@swansea.ac.uk http://www.bsr.org.uk/meetings.asp
7-9 April Göteborg Sweden	AERC 2010 – 6th Annual European Rheology Conference Alexandra Andrén E-mail: aerc2010@rheology-esr.com http://www.rheology-esr.org/AERC/2010/
11-16 July Glasgow	IUPAC 2010 World Polymer Congress (Macro2010) Contact: Professor Peter A. Lovell, School of Materials, The University of Manchester, email: pete.lovell@manchester.ac.uk ; Tel: +44(0)161 306 3568; Fax: +44(0)161 306 3586.
1-6 August Sapporo Japan	5th Pacific Rim Conference on Rheology Hokkaido University, Sapporo, Hokkaido, Japan Conference Website: http://prcr2010.com

2009**COURSES & WORKSHOPS**

25-26 Nov
Bradford
UK

Rheology Workshop from Anton Paar
Steve Goodyer, Anton Paar Ltd, 13, Harforde Court,
John Tate Road, Hertford, SG13 7Q
T: +44 (0)1992 514730; F: +44 (0)1992 514739
E: steve.goodyer@anton-paar.com

25-26 Nov
Crawley

TA Rheology Training Course: For further information, contact
Olivia Gibson; TA Instruments, Fleming Centre, Fleming Way,
Manor Royal, Crawley, West Sussex, RH10 9NB;
T: +44 1293 658900; F: +44 1293 658901;
e-mail: Olivia.gibson@taeurope.co.uk

2010

12-15 Jan
Glasgow
Scotland

Process Rheology: For further information, contact Dr N E Hudson,
Dept of Pure & Applied Chemistry, University of Strathclyde,
295 Cathedral Street, Glasgow G1 1XL.
Tel: +44 141 5482162; Fax: +44 141 5484822;
e-mail: n.e.hudson@strath.ac.uk

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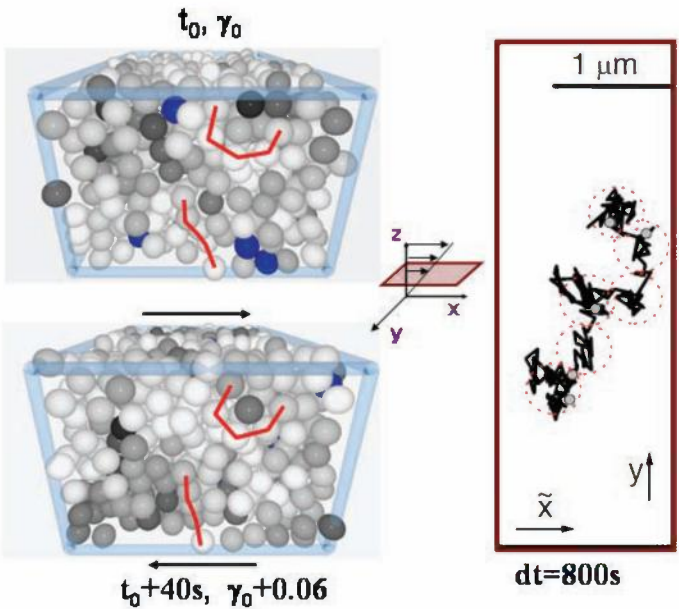
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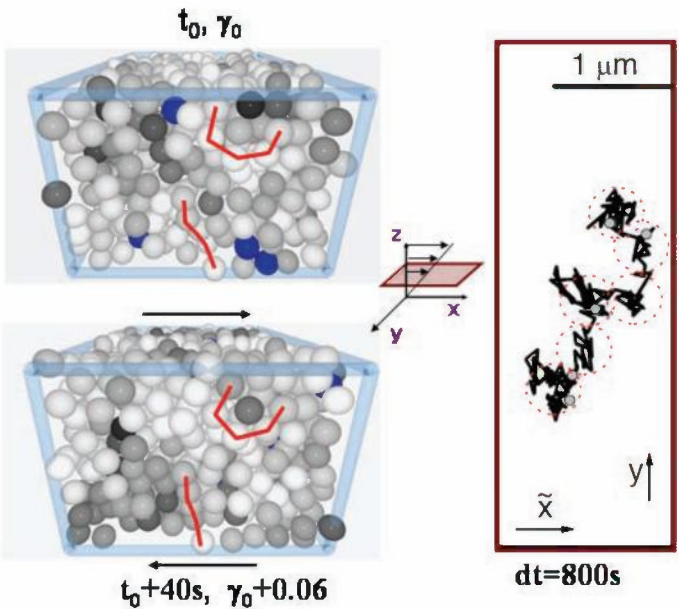
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