The News and Information Publication of The Society of Rheology
Volume 76 Number 2 July 2007

Rheology Bulletin

Inside:

Table of Contents

On the Cover:

A rheological experiment is recognized in the Guinness Book of World Records as the longest-running laboratory experiment in the world. The Pitch-Drop Experiment, started by physics Professor Thomas Parnell in 1927 at the University of Queensland in Australia, is currently maintained by Professor John Mainstone (shown at right). The pitch flows slowly from an upper reservior drop by drop. The eighth drop fell in 1990; the viscosity of the pitch is calculated to be 100 billion cp. (www.physics.uq.edu.au/pitchdrop/pitchdrop.shtml)

The *Rheology Bulletin* is the news and information publication of The Society of Rheology (SOR) and is published twice yearly in January and July. Subscription is free on membership in The Society of Rheology.

Change of address or letters to the editor: rheology@aip.org

Standing Committees

Membership Committee (2005-2007)
- Patrick T. Mather, chair
- Patrick D. Anderson
- Shelley L. Anna
- Charles P. Lusignan
- H. Henning Winter

Education Committee (2005-2007)
- Michael J. Solomon, chair
- Robert J. Butera
- Andrea Chow
- Anthony J. McHugh
- Jan Vermant

Meetings Policy Committee (2005-2007)
- Robert K. Prud'homme, chair
- Antony N. Beris
- Albert Co
- Gerald G. Fuller
- Savvas Hatzikiriakos
- Jules Magda
- Robert L. Powell
- Eric S. G. Shaqfeh

Bingham Award Committee
- Andrea Chow (2004-2007), chair
- William Hartt (2005-2008)
- Ole Hassager (2006-2009)
- Ronald G. Larson (2005-2008)
- Giuseppe Marrucci (2004-2007)
- Jay Schieber (2005-2008)
- Norman Wagner (2006-2009)

Webmaster	Albert Co
Editor, Rheology Bulletin	Faith A. Morrison
Associate Editor for Business, Journal of Rheology	A. Jeffrey Giacomin
Representative to AIP	Morton M. Denn
Representative to AIP Committee on Public Policy	Kalman Migler
Representative to and Chair AIP Publications Services Subcommittee	A. Jeffrey Giacomin
Rep. to U. S. National Committee on Theoretical and Applied Mechanics	Michael D. Graham
Delegate to International Committee on Rheology	Andrew M. Kraynik

Brady to Receive 2007 Bingham Medal

Profile by Andreas Acrivos

John F. Brady is the Chevron Professor of Chemical Engineering (since ’99) at the California Institute of Technology where he is also a Professor of Mechanical Engineering (since ’05). In ’75, John graduated from the University of Pennsylvania with a B.S. in Chemical Engineering and, after spending a year at Cambridge University as a Winston Churchill Scholar, entered the Chemical Engineering graduate program at Stanford University from where he received an M.S. in ’77, followed by a PhD three-and a- half years later. His PhD thesis, under the supervision of Andy Acrivos, was entitled “Inertial Effects in Closed Cavity Flows and their Influence on Drop Breakup”, and dealt with the application of asymptotic analysis to the solution of several fundamental problems in viscous flow theory. Following a year as an NSF-CNRS US-France Exchange Scientist (’80-’81), which he spent at the Ecole Superieure de Physique et de Chimie Industrielles de la Ville de Paris (ESPCI) directed by P-G. de Gennes, John joined the Chemical Engineering department at the Massachusetts Institute of Technology as an Assistant Professor. In ’85, he was lured away by Caltech where he has been ever since, first as an Associate Professor (’85-’89) and then as Professor of Chemical Engineering (’89-present). He also served as the Executive Officer of Chemical Engineering at Caltech (’93-’99) and was a holder of a part-time Chair in Applied Physics at the University of Twente in the Netherlands (’02-’06).

John is known internationally as one of the brightest, original & most accomplished Chemical Engineers-Fluid Dynamicists for his seminal & wide ranging contributions to the study of “complex fluids”.

Examples of such fluids include suspensions, emulsions, colloidal dispersions, ceramics, liquid crystals, ferrofluids, electro-and magneto-rheological fluids, polymer solutions, etc, all having diverse & important scientific and technological applications.

Three of John’s numerous achievements stand out. The first was the creation and development (together with his French collaborator Georges Bossis) of Stokesian Dynamics (SD) — a molecular-dynamics-like method for predicting the microstructural and macroscopic properties of complex fluids. Prior to SD, theoretical studies of suspensions, which had steadily progressed since the original work of Einstein, had reached an impasse owing to the impossibility of dealing numerically with the complicated many-particle interactions. The creation of SD, however, radically changed this by providing a computational avenue to the study of the dynamics of dense disperse systems which compliments the traditional approaches of analytical theory and laboratory experiment. Thus, SD ushered in a new era of investigation, not only for suspensions but for multiphase flows generally, in that it allowed one to rigorously solve many long-standing problems and, more profoundly, to pose new questions. Also, a remarkable feature of SD is the spectrum of physical forces (hydrodynamic, electrostatic, colloidal, Brownian, etc.) and the range of length and time scales (tens of angstroms to centimeters and

Brady and his research group celebrate the February 2007 Ph.D. defense of Aditya Khair. Left to right: Ubaldo Cordova-Figueroa, Aditya Khair, Manuj Swaroop, Andrew Downard, James Swan, John Brady.

microseconds to days) encompassed by one technique. This method has now been refined to the point where it can effectively handle an infinite number of particles.

SD has already yielded quantitative a priori predictions of suspension behavior that are in excellent agreement with experiments for a variety of systems, ranging from the structure, diffusion and rheology of colloidal dispersions, to yield stresses in electro-rheological fluids, and finally to the self-induced concentration inhomogeneities in pressure driven flows. More fundamentally, new insights into microstructured fluid behavior, such as the profound importance of cluster formation, have emerged from such simulations. Ultimately, the understanding brought about by simulating the relationship between the microstructure and macroscopic properties of suspensions will permit the design and engineering of novel materials to meet desired applications. All these advances have been achieved not only by John himself but by numerous other investigators using John's code, which he has generously and selflessly shared, for the asking, over the years.

The second major contribution of John's in complex fluids is his development of a scaling theory for the diffusive and rheological behavior of concentrated colloidal dispersions. Specifically, he has shown, in a series of papers, how the most important effects of hydrodynamics can be included by a simple rescaling of the time or the shear rate by the concentration dependent self-diffusivity. This observation has lead to quantitative a priori predictions of the singular dependence of the suspension viscosity on the solids concentration at high concentrations, thereby explaining experimental observations spanning a period of over 50 years. This theory also suggests a universal scaling for the rheological behavior of any suspension of non attractive particles. This scaling has also been demonstrated experimentally and can be used to correlate a vast array of rheological responses displayed by colloids.

The third landmark event in the field of suspension rheology was John's development (with P.Nott) of the so-called suspension balance model to serve as a constitutive equation for the macroscopic description of such systems. Some years earlier, Leighton & Acrivos, motivated by an idea originally due to Ascher Shapiro as well as by several earlier observations by Francis Gadala-Maria, proposed a so-called trajectory model of shear induced particle diffusion which, although somewhat heuristic, was able to account for a number of puzzling experimental results such as the shear-induced re-suspension of heavy particles. In spite of its initial success, however, the trajectory model was found to

(continues page 27)

Join us in Salt Lake City

SOR October 2007

The 79th Annual Meeting of the Society of Rheology will be held 7-11 October 2007 in scenic Salt Lake City, Utah. Two short courses will be offered: "Beginning Rheology" taught October 6-7 by Faith Morrison and Jeff Giacomin, and "Microfluidics for Rheologists" taught October 7 by Todd Squires, Shelley Anna, and Patrick Doyle. Please plan to attend. The short courses and technical sessions will be held at the Hilton Salt Lake City Center in downtown Salt Lake City (phone 801-328-2000). The technical program for the meeting is available on the SOR website (www.rheology.org). Salt Lake City, the site of the 2002 Winter Olympics, is located in a mountain valley (elevation 4400 ft.) approximately 40 minutes from world class ski resorts like Snowbird, Alta, and Park City. The meeting hotel is within walking distance of over 90 restaurants and brew pubs, three shopping malls, the Delta Center, Salt Palace, Temple Square, and City Creek park for hiking and biking. A free TRAX light-rail system is also available in the downtown area.

The welcome reception for the meeting will be held from 6:00 pm to 8:00 pm on Sunday, October 7 in the Alpine Ballroom at the Hilton Salt Lake City Center. The Society Reception will be held at the Museum of Utah Art & History (www.muahnet.org) from 6:30 pm to 9:00 pm on Monday, October 8. The museum is located 0.4 miles from the Hilton Salt Lake City Center. All attendees are encouraged to attend the annual business meeting of the Society of Rheology on Tuesday, October 9 at 6:10 pm in the Alpine Ballroom of the Hilton Salt Lake City Center. The Bingham Award Reception will start at 7:00 pm on Tuesday October 9 in Grand Ballroom C at the Hilton Salt Lake City Center. This will be followed by the Bingham award banquet honoring Professor John Brady of Cal Tech at 8:00 pm. There is no charge for entry to the Bingham reception; banquet tickets can be purchased with meeting registration (see meeting registration link at www.rheology.org). The poster session and reception will be held from 6:10 pm to 8:10 pm on Wednesday, October 10 in Grand Ballroom C at the Hilton Salt Lake City Center.

The conference rate for a standard room at the Hilton Salt Lake City Center is $109 USD per night plus tax for single or double occupancy. Hotel reservations may be made via the weblink given at the meeting registration website at www.rheology.org. Please reserve by 14 September 14 2007 and indicate that you are an attendee of the 79th Annual Meeting of the SOR to receive the conference rate.

Local Arrangements:

Jules (Jaye) Magda
Department of Chemical Engineering
50 S. Central Campus Dr., Rm. 3290
University of Utah
Salt Lake City, UT 84112-9203
Phone: (801) 581-7536
Email: jj.magda@m.cc.utah.edu

Andy Kraynik
Department 1514 MS 0836
Sandia National Laboratories
Albuquerque, NM 87185-0836
Phone: (505) 844-9696
Email: amkrayn@sandia.gov

Sensi·mojo·tivity \sen-see-mo-jo-ti-ve-te\

adj. 1. a term often associated with the performance of an AR-G2 Rheometer.

TA Instruments...redefining Rheometer performance.

WWW.TAINSTRUMENTS.COM

How do I know if my phase angles are correct ?

δ?

δ?

Sachin S. Velankar, University of Pittsburgh and
David Giles, University of Minnesota

1. Introduction

A large fraction of rheological testing involves small-amplitude oscillatory shear, sometimes referred to as "dynamic" experiments, which yield the complex modulus G* of the sample. The results of such tests are often represented in terms of the storage and loss moduli G′ and G″, but it is conceptually useful to instead think of G* in terms of its magnitude |G*| and its phase angle δ. How can these quantities be validated? If a rheometer reports, say, |G*| = 12,755 Pa, and δ = 88.78 degrees, how closely can the user trust these values?

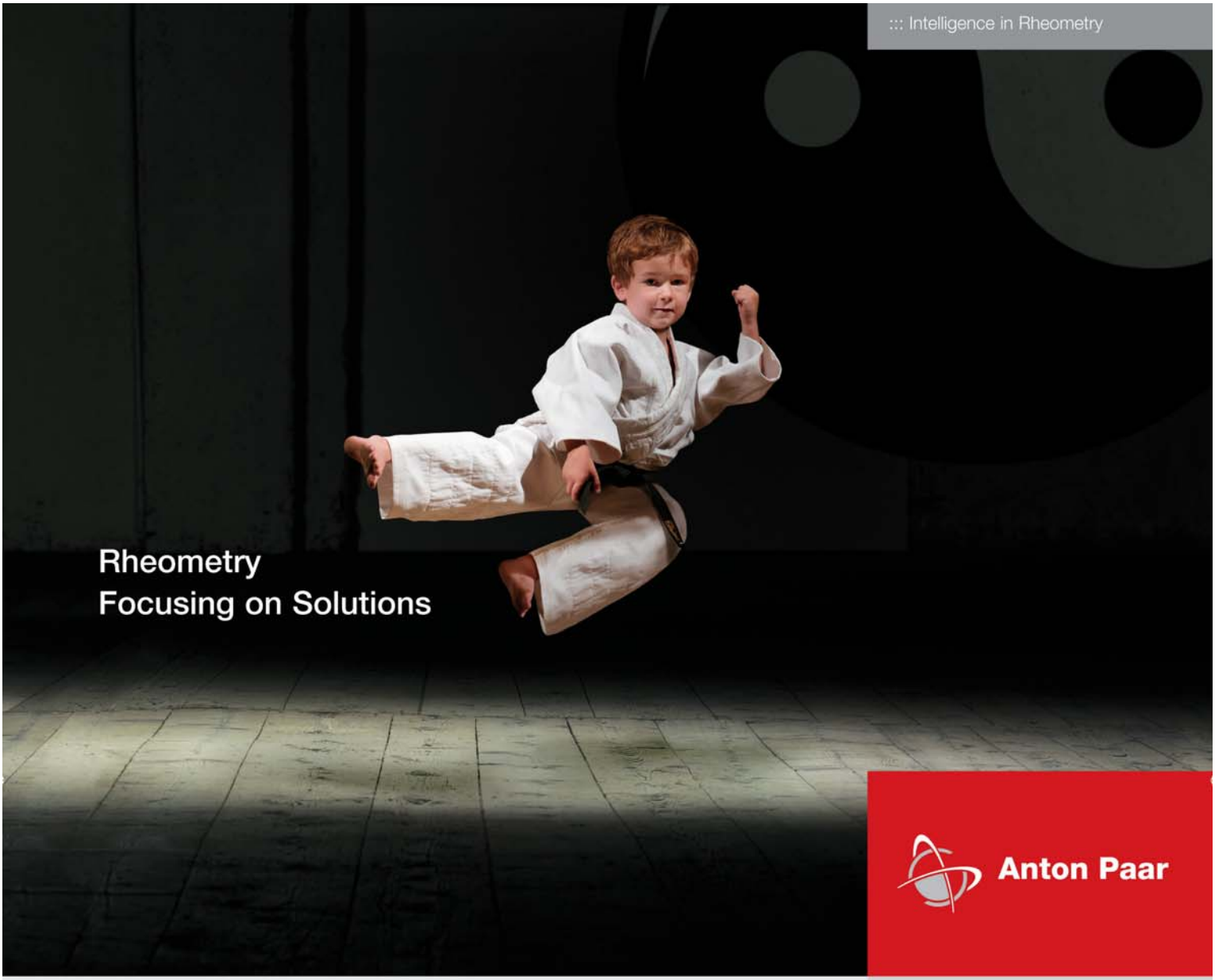
The magnitude |G*| can be validated easily with Newtonian calibration standards of known viscosity. There have also been excellent studies of the reproducibility |G*| of molten polymers, which is important for quality control applications of rheometry[1-5]. Even in the absence of any rigorous validation, the specifications on the torque, angular displacement, and frequency range of the rheometer provide guidance on when the range or sensitivity of the instrument is exceeded, and hence large errors in |G*| can be expected.

In contrast, it is much more difficult to judge the accuracy of the phase angle, δ. We are not aware of studies that evaluate the accuracy of phase angle measurements. Furthermore, rheometer manufacturers do not provide specifications for phase angle, and hence there is no clear guidance on when the range or resolution of the rheometer is exceeded. It is not difficult to understand why phase angle specifications are generally missing: phase angle resolution and accuracy will surely depend on the quality of the torque and angular displacement signals. Approaching the low end of the torque or displacement range, it might still be possible to measure the average magnitudes of these signals (allowing determination of |G*| within some well-defined, reasonable certainty), while the signal quality becomes too poor to accurately resolve the phase shift between them. How can a rheologist establish conditions under which his or her rheometer can measure phase angles within some well-defined certainty?

A broad validation of phase angle measurements is beyond the scope of this short article. We will concentrate on validating phase angle measurements close to 90 degrees. This is important for practical purposes, not least because δ approaching 90 degrees corresponds to the terminal region of most viscoelastic materials, where significant connections between the rheology and structure can be made. For example, fluids such as entangled polymer melts and polymer solutions generally show "standard" liquid-like terminal behavior ($G' \sim \omega^2$ and $G'' \sim \omega$), which can be often be related quantitatively to specific microscale dynamic processes. In other cases, e.g. block copolymers, gels, or particle-filled systems, we are often interested in deviations from standard liquid-like terminal behavior to help identify, for example, an order-disorder transition or a liquid-to-gel transition. A recent article[6] in the Rheology Bulletin has also discussed the challenge of measuring terminal viscoelastic properties in the context of calculating the relaxation function G(t).

When attempting to validate phase angle measurements, a significant problem is the choice of a viscoelastic standard for calibration: while viscosity standards are readily available, materials with standard viscoelastic properties are less easy to come by. In the absence of standards, some laboratories validate a δ = 90 degrees using a Newtonian fluid, δ = 0 degrees using a steel test specimen, and presume that phase angles between 0 and 90 degrees are accurate. Some rheology labs have a standard PDMS putty with a broad spectrum of relaxation times whose phase angle at a particular temperature and frequency has been specified by the supplier. The National Institute for Standards and Technology (NIST) has developed standard reference materials for viscoelastic measurements, most recently the SRM 2490 and SRM 2491 polymer solution and melt[7,8]. However most laboratories do not have these fluids, and some questions have also been raised about the validity of the viscoelastic specifications given for SRM 2490[9]. It would be very useful for experimental rheologists to have a testing protocol, along with different viscoelastic calibration standards, to validate oscillatory measurements on their own rheometers.

Here we show that a linear, monodisperse, and well-entangled polymer melt can serve as an excellent viscoelastic calibration standard when δ is close to 90 degrees. Such a material has a sharp transition to its



Rheometry
Focusing on Solutions

Anton Paar

If you are focused on insights, you will want the best possible view…

Provided by this great range of optics and accessories for your rheometer.

- Visualize the effect of shear and deformation on the sample structure with the Rheo-Microscope
- Determine rheological data and structural information simultaneously with the modular Rheo SALS (Small Angle Light Scattering) system
- Gain extensive insights in high-precision rheology tests with the new CTD 450 camera
- Perform rheo-optical measurements and measure curing behavior with the UV Cell accessory

Anton Paar® USA
Density meters, rheometers, viscometers, chemical synthesis

800 722-7556
info.us@anton-paar.com
www.anton-paar.com

terminal region as frequency is reduced (see details†), and thus is in the terminal region even when δ is still far from 90 degrees, and hence still easy to measure. Phase angles close to 90 degrees can then be validated by verifying that the rheometer reproduces the expected terminal behavior ($\tan\delta$ proportional to $1/\omega$) at lower frequencies.

In essence, this phase angle validation is a test of self-consistency of the rheometer: (1) use the rheometer to characterize the terminal behavior of the fluid when δ is not very close to 90 degrees, and (2) use the now-characterized terminal behavior to test the rheometer performance under adverse conditions (e.g. δ approaching 90 degrees closely, lower displacements, lower torques, etc.)

2. A brief primer on dynamic oscillatory measurements

Theory

Most dynamic oscillatory tests are performed in controlled strain mode. A sinusoidally-varying strain:

$$\gamma = \gamma_0 \sin(\omega t) \tag{1}$$

is imposed on the sample. Here ω is the frequency and γ_0 is the strain amplitude. The stress in the sample follows:

$$\sigma = \sigma_0 \sin(\omega t + \delta) = |G^*| \gamma_0 \sin(\omega t + \delta) \tag{2}$$

where σ_0 is the stress amplitude and $|G^*|$ is the magnitude of the complex modulus. Most commonly, analysis is performed in terms of the storage and loss moduli:

$$\sigma = \gamma_0 [G' \sin(\omega t) + G'' \cos(\omega t)] \tag{3}$$

$$\text{where } G' = |G^*| \cos(\delta) \text{ and } G'' = |G^*| \sin(\delta) \tag{4}$$

Even if the tests are performed in controlled stress mode, the same equations can be used to calculate the moduli. We can take the first step in error analysis as:

$$dG' = \cos(\delta) d|G^*| - |G^*| \sin(\delta) d\delta \tag{5}$$

$$\frac{dG'}{G'} = \frac{d|G^*|}{|G^*|} - \tan(\delta) d\delta \tag{6}$$

$$\text{Similarly, } \frac{dG''}{G''} = \frac{d|G^*|}{|G^*|} + \frac{d\delta}{\tan(\delta)} \tag{7}$$

In Eqs. 6 and 7 above, the left hand side is the fractional error in G′ and G″, the first term on the right hand side is the fractional error in the magnitude of the complex modulus, and the last term reflects the error in measuring phase angle. It is clear that as δ approaches 90 degrees, the fractional error in G′ grows without bound even when the error in phase angle $d\delta$ remains finite. This is just a quantitative way of stating that it is difficult to characterize the elasticity of weakly-viscoelastic materials. The situation is reversed when δ approaches 0 degrees: then the error in G″ becomes large, whereas the error on G′ remains finite. In short, when one modulus is much smaller than the other, little of the total signal comes from the response associated with the smaller modulus, and more error is likely in its measurement. Here, we will focus on the case of δ approaching 90 degrees, where the elasticity is becoming very weak.

The above equations suggest that rather than δ itself, it is better to work in terms of $\tan\delta$ (or $1/\tan\delta$) since these directly relate to the accuracy and precision of the dynamic moduli. We will reiterate this point at the end of the following section.

Practical measurements

Assuming a parallel plate geometry with plates of diameter 2R and gap of h, oscillatory measurements generally depend on applying a displacement:

$$\theta = \theta_0 \sin(\omega t) \tag{8}$$

and measuring a torque:

$$T = T_0 \sin(\omega t + \delta) \tag{9}$$

Here θ_0 and T_0 are the displacement and torque amplitudes respectively. For the parallel plate geometry, one can obtain[10]:

$$\gamma_0 = \frac{R\theta_0}{h} \; ; \; \sigma_0 = \frac{2T_0}{\pi R^3} \text{ , and hence } |G^*| = \frac{\sigma_0}{\gamma_0} = \frac{2T_0 h}{\pi R^4 \theta_0} \tag{10}$$

Slightly different equations can be derived for other measurement geometries[10]. Thus, dynamic oscillatory measurements on rotational rheometers depend on measuring three quantities: θ_0, T_0 and δ. Conceptually, these three quantities can be measured by plotting the displacement and torque signals, as illustrated in Fig. 1. The factors limiting the accuracy of $\tan\delta$ are clear from this diagram: As with any experimentally-determined quantities, there are some errors associated with measuring displacement and torque. For example, if θ_0 or T_0 are

† Any linear viscoelastic fluid can be represented as a sum of Maxwell modes. In a linear, monodisperse, well-entangled polymer, higher order relaxation modes are much faster and much weaker than the longest mode. Therefore the terminal region, i.e. the region in which the longest mode dominates, ranges from from $\tan\delta \to \infty$ ($\delta = 90$ degrees) down to about $\tan\delta \approx 10$ ($\delta \approx 84$ degrees). In contrast, in most other fluids, higher order modes become important when $\tan\delta$ is still large (δ is still close to 90 degrees).

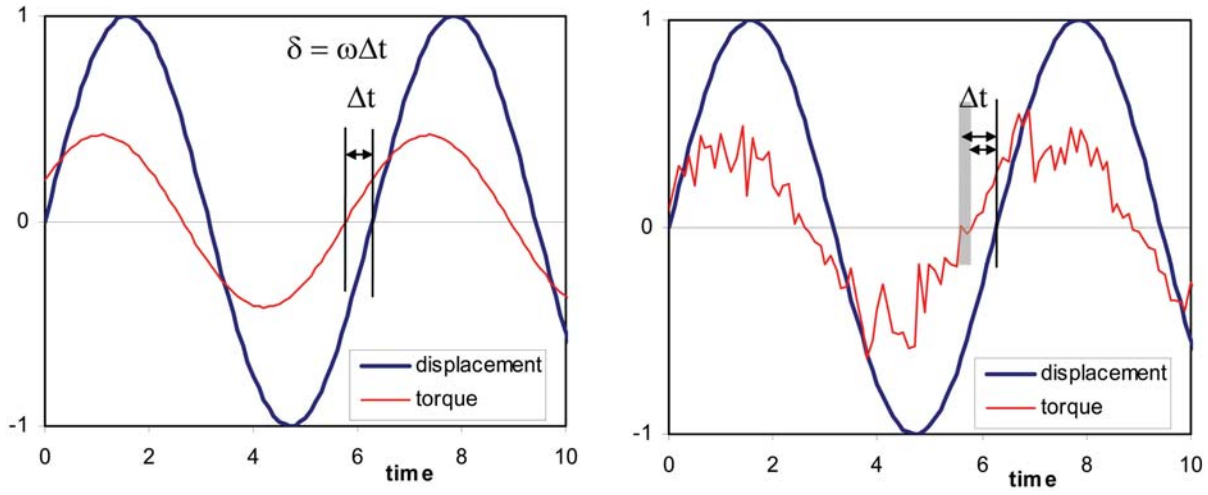


Fig. 1: a. The zero crossing of the sinusoidal displacement and torque signals give the phase lag, from which the phase angle δ can be calculated. b. If the one or both of the signals are noisy, it will cause some uncertainty in the zero crossing (illustrated by the shaded line), and hence error in measuring δ.

small, the displacement and torque signals can show substantial noise, as illustrated in Fig. 1; such noise was indeed evident in our experiments (discussed below) at small displacements or torques. There may also be minor drifts in the instrument baseline (e.g. the residual torque in an air bearing) over the timescale of a single oscillation. Regardless of cause, these errors in displacement and torque cause errors in the phase angle.

Early rheologists measured θ_0, T_0 and δ quite literally as illustrated in Fig. 1 by plotting the torque and displacement signals output from the rheometer on chart paper (see Appendix 2 in Walters[11] for a detailed graphical procedure). Modern rheometers on the other hand use signal processing techniques, often in the digital domain, to obtain phase angles from the raw signals. One approach is to use a cross-correlation method of beating the torque against two reference signals, one in phase with the displacement and the other 90 degrees out of phase with the displacement[10]:

$$S_1 = \frac{\omega}{\pi N}\int_0^{\frac{2\pi N}{\omega}} T\sin(\omega t)dt = T_0\cos\delta \quad ;$$

$$S_2 = \frac{\omega}{\pi N}\int_0^{\frac{2\pi N}{\omega}} T\cos(\omega t)dt = T_0\sin\delta \qquad (11)$$

where N is the number of cycles. Thus, the T_0 and the phase angle can be obtained independently:

$$T_0 = \sqrt{S_1^2 + S_2^2} \quad \text{and} \quad \tan\delta = \frac{S_2}{S_1} \qquad (12)$$

Once again we note that it is $\tan\delta$, and not δ, that is the more natural quantity for analysis. Actual implementation of Eqs. 11 and 12 change from one instrument to another, the raw signals are often digitized before any analysis, and inertial corrections and baseline subtraction may be an integral part of the analysis.

3. Experiments and results

The fluid used was Liquid Isoprene Rubber (LIR50), a linear monodisperse 1,4-polyisoprene (high cis content) supplied by Kuraray Corp. This polymer was made by anionic polymerization and had a molecular weight of ~45000 kg/mol and polydispersity of less than 1.1. All tests were performed using the AR2000 rheometer with a 40 mm or 25 mm parallel plate geometry with gaps ranging from 0.5 to 2 mm, at a temperature of 25°C maintained with a Peltier plate. The rheometer was mounted on a vibration-isolated platform and leveled. Samples were loaded without air bubbles and excess sample was "trimmed" from the edges when the gap was 10% larger than the desired gap. All tests were performed using the default settings for oscillatory testing ("Continuous oscillation", conditioning time and sampling time both being 3 s or 1 cycle, whichever is longer).

3.1. Validation of phase angles : Constant-strain frequency sweep experiments

A common oscillatory test sequence involves conducting a single oscillatory measurement at each frequency in a specified frequency range, with the strain amplitude being kept constant throughout the frequency range. This test

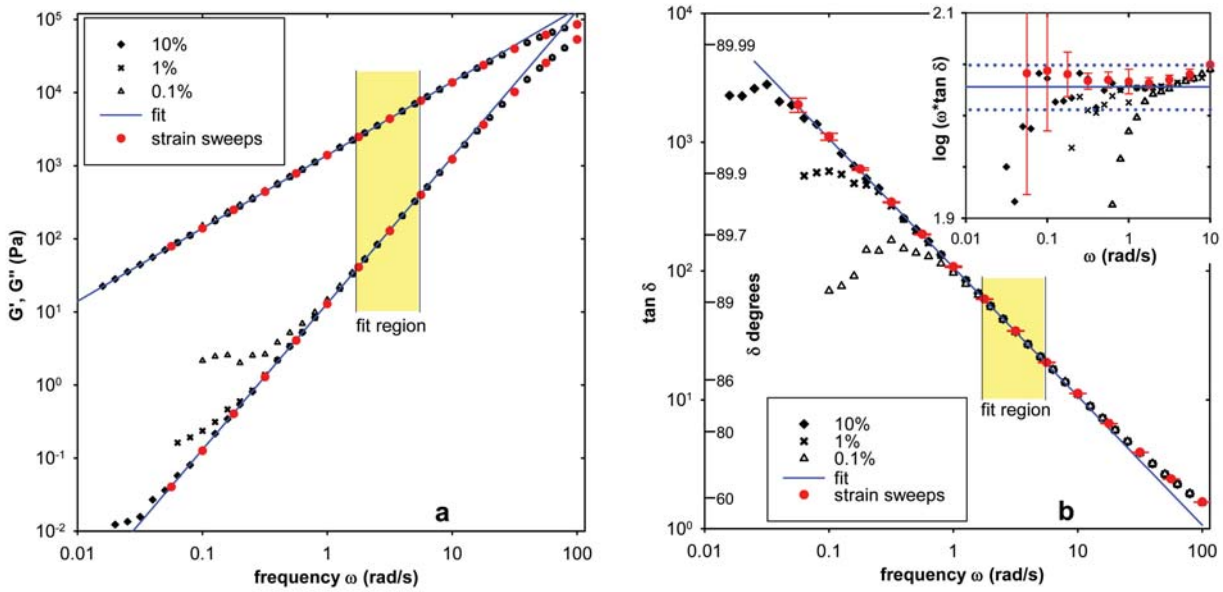


Fig. 2: Black symbols are a. oscillatory moduli from frequency sweep experiments at three different strain amplitudes. b. tanδ from the same experiment. Red symbols are data from strain sweep experiments of Fig. 3. Thin blue lines are terminal behavior (Eqs. 13) fitted to the 0% strain data within the shaded yellow rectangles. Inset to b. shows the tanδ results in a form more suitable to identifying deviation from terminal behavior. In the inset, solid blue line shows the terminal behavior (Eqs. 13), and dotted blue lines show 5% deviation from the terminal behavior.

sequence is often called a "frequency sweep" test in the software associated with many rheometers. The black diamonds in Figs. 2 a&b show the results of a frequency sweep test performed at a strain amplitude of 10%, which is within the linear viscoelastic limit. As expected, this linear, monodisperse, entangled polymer shows terminal behavior down to fairly small $\tan\delta$ values of about 10. There is therefore a range of frequencies (illustrated by the yellow region in Figs. 2 a&b) in which two conditions are satisfied: the material is in the terminal regime, *and* the instrument can be expected to measure $\tan\delta$ reliably. We can therefore establish the terminal behavior of this material:

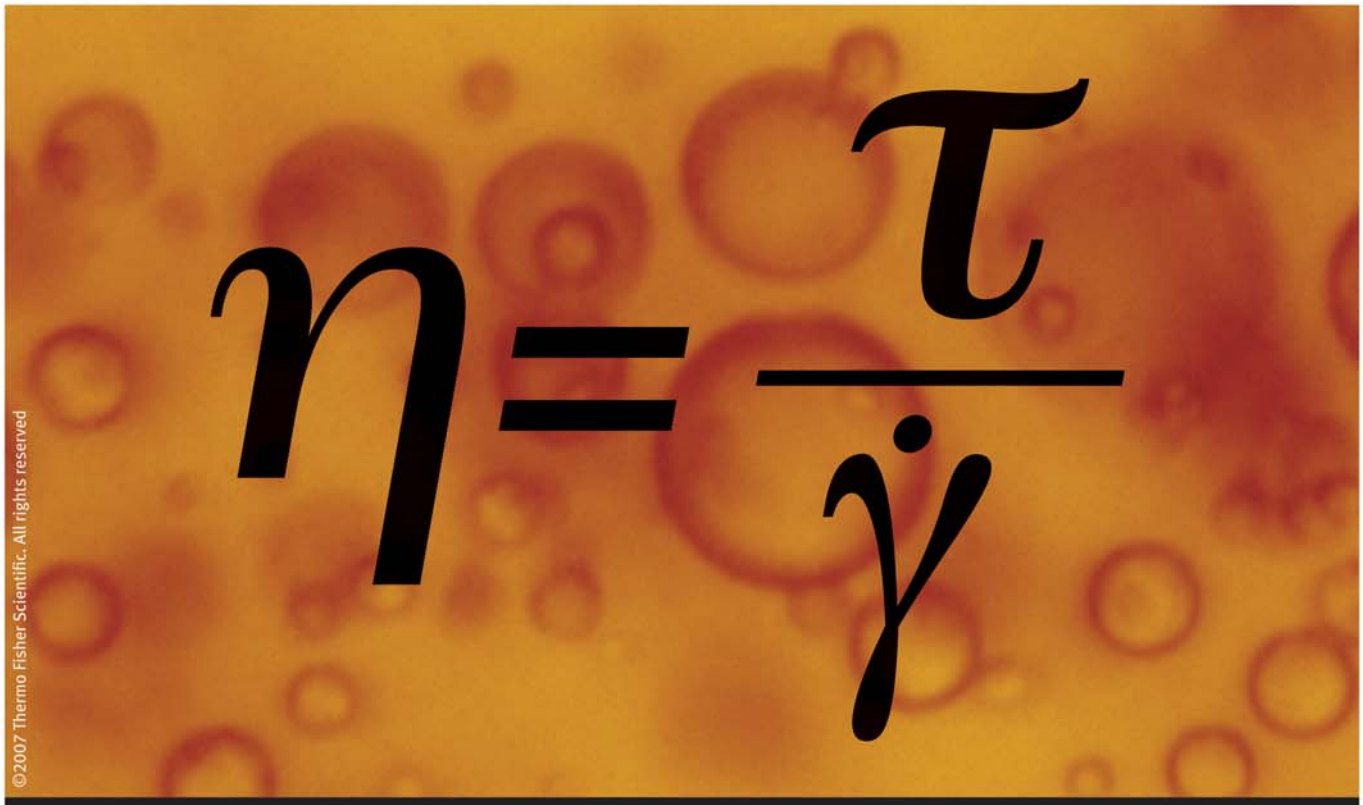
$$G' = 13.13\omega^2 \;\; ; \;\; G'' = 140\omega \; ; \;\; \tan\delta = \frac{106.7}{\omega} \qquad (13)$$

The accuracy of oscillatory measurements as δ approaches 90 degrees can now be tested by examining deviations from this behavior at lower frequencies. Indeed the data do deviate from the expected terminal behavior. Such deviations are more clearly evident when the product of $\tan\delta$ and frequency – which is expected to be constant in the terminal region – is plotted *vs.* frequency (see inset to Fig. 2b). If we regard a 5% error on $\tan\delta$ as acceptable, at 10% strain it appears that oscillatory measurements are accurate up to $\tan\delta$ on the order of 1000 ($\delta \approx 89.94$ degrees). This simple test to validate phase angle measurements can be performed *only* because the fluid is monodisperse and well-entangled, i.e. the phase angle validation is crucially dependent on the assumption that the correct terminal behavior can be captured from phase angle data far from $\delta = 90$ degrees.

Upon repeating the frequency sweep tests at lower strains, the rheometer makes significant errors at large $\tan\delta$, e.g. at 0.1% strain, it is not possible to measure a $\tan\delta$ of even 100 ($\delta = 89.4$ degrees) accurately. However, small values of $\tan\delta$ can still be measured accurately. In other words, as $\tan\delta$ increases (δ approaches 90 degrees), an increasingly larger strain amplitude is necessary for accurate measurements. This immediately suggests that the accuracy of frequency sweep tests can be improved by increasing the strain amplitude as $\tan\delta$ increases. This will be discussed in more detail below.

3.2. Instrumental limits for phase angle accuracy: A strain-sweep protocol

A key finding of Fig. 2 is that at small strain, there can be significant errors in measuring $\tan\delta$. It is therefore of immediate interest to find the minimum strain, γ_{min}, required for measuring $\tan\delta$ within a specified error, say 5%. To characterize this γ_{min} as a function of $\tan\delta$, we conducted strain sweep tests at several different frequencies. Fig. 3 shows a typical sample of the results. At each frequency, the measured values of $\tan\delta$ show a plateau at sufficiently high strain amplitude, and a deviation from the plateau at low strain amplitude. We will discuss these features in succession.



Get the Full Picture – Combine Rheology with Microscopy

Thermo Fisher introduces the new, easy-to-use Rheoscope module for the Thermo Scientific rheometer platform HAAKE MARS. The module allows you to simultaneously record rheological properties and changes to the microscopic structures of complex fluids.

Get the full picture and visualize the interaction between the rheological and structural changes – understand how your products work.

Advantages of the combined method:

- A sophisticated rheometer combined with a powerful visualization technique.
- Ease of use: Both the rheometer and camera are controlled via the HAAKE RheoWin software. Link the structural image to flow characterization.

Get the benefit of 2 instruments in 1
Shear rate, rheological results and visual structure at the same time and same place.

Visit www.thermo.com/mars to download a video of the product in action.

Thermo Fisher Scientific, Karlsruhe/Germany · www.thermo.com/mc
Tel. +49 (0) 721 4 09 44 44 · info.mc.de@thermofisher.com

Part of Thermo Fisher Scientific

Thermo SCIENTIFIC

The XVth International Congress on Rheology and 80th Annual Meeting of The Society of Rheology will take place *3-8 August 2008 in* Monterey, CA USA. The technical program is listed below and on page 14. Note that in 2008 there will be a closing lecture and a social event open to all participants.

ICR 2008

3-8 August 2008
Monterey

Opening Lecture: Paul Callaghan, Victoria University of Wellington New Zealand
From molecules to mechanics: nuclear magnetic resonance and rheological insight

Closing Lecture: Fred MacKintosh, Vrije Universiteit Amsterdam
Non-equilibrium mechanics of active gels and living cells

Invited Lecturers: (to be run in concurrent pairs)

Nitash Balsara – University of California Berkeley (USA)
Decoupling the electrical and mechanical properties of block copolymer electrolytes
Mike Cates – University of Edinburgh (UK)
Rheology of dense suspensions
Michel Cloitre – Ecole de Physique et de Chimie Industrielles (ESPCI), Paris (France)
Tailoring the rheological behavior of soft particle dispersions: ageing, yielding, slip and flow
Justin Cooper-White (bio-rheology) – University of Queensland (Australia)
title forthcoming
Michael Mackay – Michigan State University (USA)
Anomalous rheology of polymer - nanoparticle suspensions
Scott Milner (entanglement theory) – ExxonMobil (USA)
title forthcoming
Peter Olmsted – University of Leeds (UK)
Interface dynamics and boundary effects in shear banding
Alejandro D. Rey – McGill University (Canada)
Liquid crystal models of biological materials and processes
Michael Rubinstein – University of North Carolina (USA)
Dynamics of entangled polymers
Victor Steinberg – Weizmann Institute (Israel)
Elastic turbulence: a random flow without inertia
Howard Stone – Massachusetts Institute of Technology (USA)
Complex fluids and multiphase flows in small devices
Kenji Urayama – Kyoto University (Japan)
Characterization of nonlinear elasticity of elastomers and gels by multiaxial deformations
Jae Ryoun Youn (nanocomposite processing) Seoul National University (Korea)
title forthcoming

Mini Symposia Organizers

1. MATERIALS PROCESSING
K.H. Ahn (Seoul National University, Korea) <ahnnet@snu.ac.kr>
Paulo R. de Souza Mendes(Pontificia Universidade Catolica,Brazil)
<pmendes@rdc.puc-rio.br>

2. COMPLEX FLOWS (experimental and computational/theoretical studies)
Antony Beris (University of Delaware)<beris@che.udel.edu>
Jan Dhont (FZ Juelich) <J.K.G.Dhont@fz-juelich.de>

3. HOMOGENEOUS POLYMERIC SYSTEMS
Lynden Archer (Cornell University)<archer@cheme.cornell.edu>
Alexei Likhtman (University of Leeds) <A.Likhtman@leeds.ac.uk>

4. HETEROGENEOUS and SELF-ASSEMBLING POLYMERIC SYSTEMS
Hiroshe Watanabe (Kyoto University) <hiroshi@scl.kyoto-u.ac.jp>
Pier Luca Maffettone (University of Turin) <pier.luca.maffettone@polito.it>

5. BIO-RHEOLOGY
Jim Harden (University of Ottawa) <jharden@science.uottawa.ca>
Christoph F. Schmidt (Gottingen University) <C.F.Schmidt@DPI.Physik.Uni-Goettingen.de>

6. SUSPENSIONS and COLLOIDS
Norm Wagner (University of Delaware) <wagner@che.udel.edu>
Jeff F. Morris (City College of New York) <morris@che.ccny.cuny.edu>

7. SURFACTANTS, EMULSIONS and FOAMS
Denis Weaire (Trinity College, Dublin) <dweaire@tcd.ie>
Lynn Walker (Carnegie Mellon University) <lwalker@andrew.cmu.edu>

8. GRANULAR MATERIALS and AGEING
V. Kumaran (Indian Institute of Science, Bangalore, India) <kumaran@chemeng.iisc.ernet.in>
Melany Hunt (California Institute of Technology) hunt@caltech.edu

Please contact mini-symposia chairs if you have ideas for session topics within these areas.

more

ICR 2008

Please contact mini-symposia chairs if you have ideas for session topics within these areas.

Minisymposium Organizers, continued

9. MICROFLUIDICS
Todd Squires (University of California Santa Barbara) <squires@engineering.ucsb.edu>
Annie Colin (Rhodia, France) <Annie.Colin-exterieur@eu.rhodia.com>

10. SOLIDS/GELS and GLASSES from SOFT and COMPOSITE MATERIALS
Dimitris Vlassopoulos (University of Crete) <dvlasso@iesl.forth.gr>
Wilson Poon (University of Edinburgh) <w.poon@ed.ac.uk>

11. INTERFACIAL RHEOLOGY
Jan Vermant (Katholieke Universiteit Leuven) <jan.vermant@cit.kuleuven.be>
Kausik Sarkar (University of Delaware) <sarkar@me.udel.edu>

12. MICRO-RHEOLOGY
Eric M. Furst (University of Delaware) <furst@che.udel.edu>
David A. Weitz (Harvard University) <weitz@deas.harvard.edu>

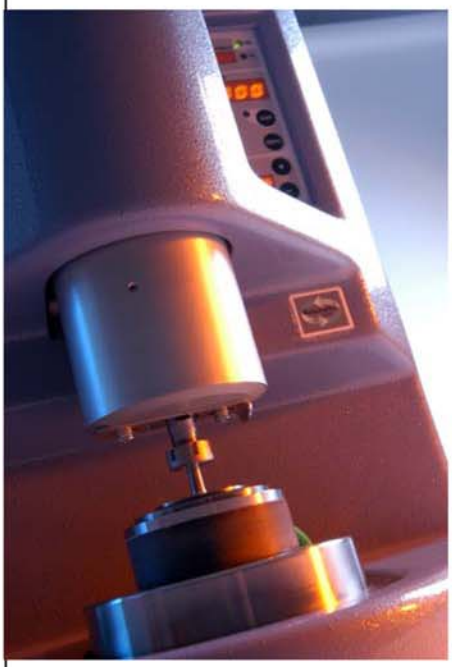
13. NEW EXPERIMENTAL METHODS
Gareth McKinley (Massachusetts Institute of Technology) <gareth@mit.edu>
Malcolm Mackley (Cambridge University) <mrm@cheng.cam.ac.uk>

14. FOOD RHEOLOGY
Erich J. Windhab (Eidgenössische Technische Hochschule Zürich ETH) < erich.windhab@ilw.agrl.ethz.ch>
Eric Dickinson (University of Leeds) <e.dickinson@food.leeds.ac.uk>

15. RHEOLOGY of SOLIDS and GLASSES
C. Michael Roland (Naval Research Laboratory NRL) <mike.roland@nrl.navy.mil>
Didier Long (Rhodia, France) <didier.long-exterieur@eu.rhodia.com>

16. GENERAL RHEOLOGY
Gary Leal (University of California Santa Barbara) <lgl20@engineering.ucsb.edu>
Ralph Colby(Pennsylvania State University) <rhc@plmsc.psu.edu>

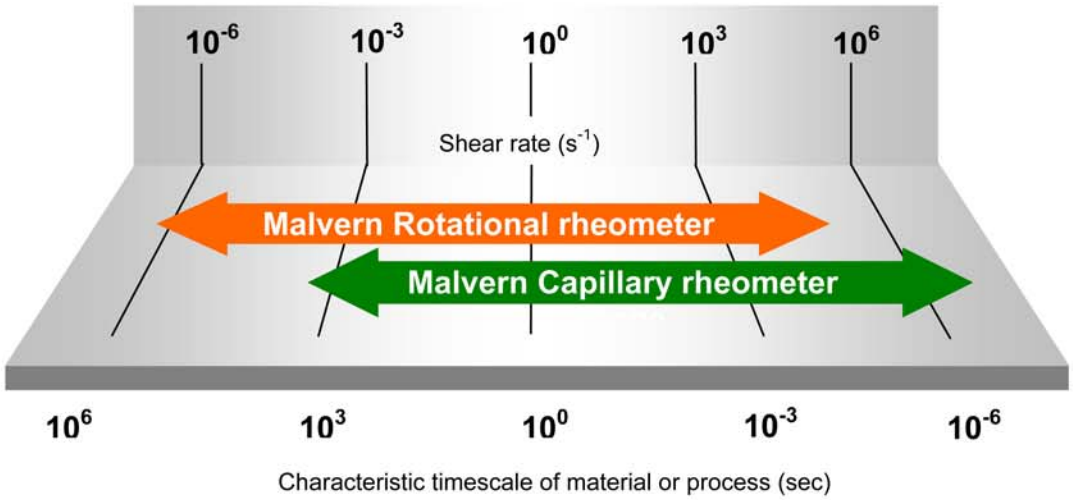
Innovations in rheological solutions



Malvern's rheological instruments have the unique ability to directly characterize material properties over 13 decades of shear rate. This means that physical material parameters can be measured, as well as their impact on process operation and end-use function.

These intelligent solutions apply to all industries where the rheological characteristics of a material determine its processability, performance and consumer acceptance.

Malvern is the only material characterization company with specialist resources in the measurement of particle size, shape, zeta potential, molecular weight and rheology. Malvern has the understanding and expertise to advise on how these microstructural parameters influence bulk rheological properties.



For more information, contact us on 508-480-0200 or e-mail to info@malvernusa.com

Visit our web site for "on demand" presentations, web seminars and application notes on rheology and light scattering

www.malvern.com

(Phase Angle, continued from page 12)

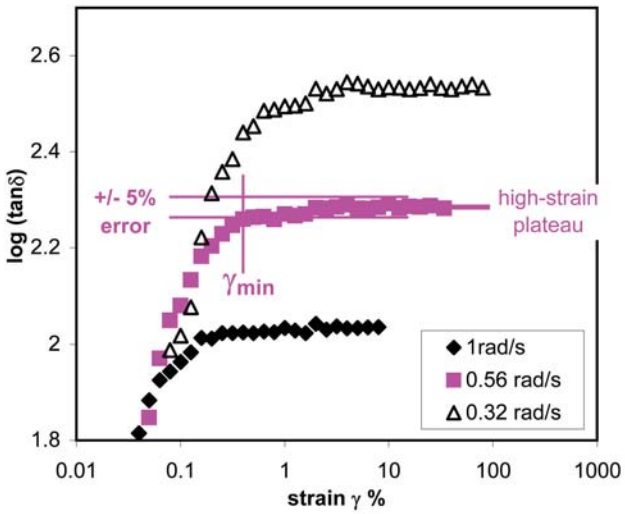


Fig. 3: Typical strain sweep measurements at three different frequencies. The horizontal lines show +/- 5% error limits for tanδ at 0.56 rad/s. The vertical line identifies γ_{min}, the minimum strain required for reliable phase angle measurement.

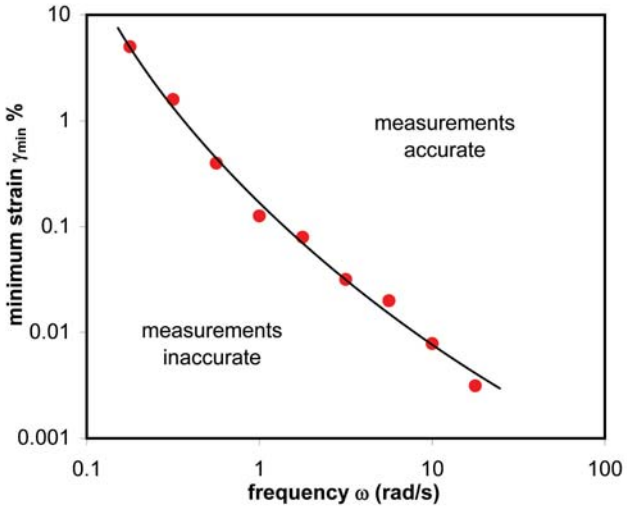


Fig. 4: Minimum strain amplitude, γ_{min}, as a function of frequency. Red circles are the γ_{min} values obtained from Fig. 3, and the line is a guide to the eye. For $\omega \geq$ 20 rad/s, the γ_{min} was smaller than the smallest strain that could be applied by the rheometer for the geometry used. Data at $\omega \leq 0.1$ have been excluded because the standard deviation on tanδ exceeded 5% (see inset to Fig. 2b).

The mean values of the high-strain plateau at each frequency have been added to Figs. 2a and b (red points). These mean values agree well with the previous frequency sweep data, and are all within 5% error of the expected terminal value. Thus, *on an average*, the AR2000 can measure large tanδ values – exceeding 1000 – accurately. However, the error bars in Fig. 2b show the standard deviation of the various points constituting the plateau. From these error bars it is clear that as tanδ approaches and exceeds about 1000 ($\omega \sim 0.1$ rad/s), the standard deviation on tanδ increases sharply and can exceed 5% of the mean value (this is more clearly visible in the inset to Fig. 2b), i.e. *a single measurement* of tanδ is not likely to be within 5% error.

Fig. 3 also shows that with decreasing strain, the measured values of tanδ deviate, and reduce systematically from the plateau value. We can immediately identify the strain, γ_{min}, below which most tanδ values are more than 5% in error; the procedure for doing so is illustrated at the frequency of 0.56 rad/s in Fig. 3. The values of γ_{min} thus obtained are plotted as a function of frequency in Fig. 4. This diagram is a map of instrumental limitations when measuring phase angles: the region below the solid line, labeled "measurements inaccurate" is to be avoided when conducting measurements.

This map quantifies the observation already made in Section 3.1, viz. accurate phase angle measurements require increasingly larger strain amplitudes at low frequencies. Thus, a simple strategy to improving the accuracy of oscillatory measurements is: don't conduct a frequency sweep test at *fixed* strain amplitude, instead, increase the strain amplitude at low-frequency. The same strategy was proposed previously for improving the reproducibility of $|G^*|^2$. One convenient way of doing so is to perform a frequency sweep at fixed stress amplitude, so that the strain increases as frequency reduces ($\gamma \sim \omega^{-1}$ for a material in its terminal region). Another convenient method is to use a "Minimum Torque" option available in some rheometers for strain-controlled frequency sweep tests. This option increases the strain amplitude beyond the specified value if the torque is less than a user-specified minimum value. It would be useful if the software also had provision to specify a maximum strain that should not be exceeded. In all such cases, when increasing the strain to improve the quality of oscillatory data, the rheologist must take care to remain in the linear viscoelastic region.

The form of Fig. 4, viz. the minimum strain vs. frequency, is not very practical because a different material may show a significantly different γ_{min} vs. ω behavior. For example, consider what would happen if the same test were repeated with a less elastic fluid for which tanδ at 1 rad/s is much higher, say 10,000. We certainly do not expect the rheometer to be able to measure accurately a tanδ of 10,000 – no matter how high the strain.

Therefore, we redraw Fig. 4 in a form that directly addresses the question: "What conditions should be met to measure any particular value of tanδ accurately?" In drawing such a map, we must avoid "derived" quantities such as strain, and instead use more basic parameters viz. the torque and the displacement. Accordingly, a better representation of the instrumental limits may be obtained

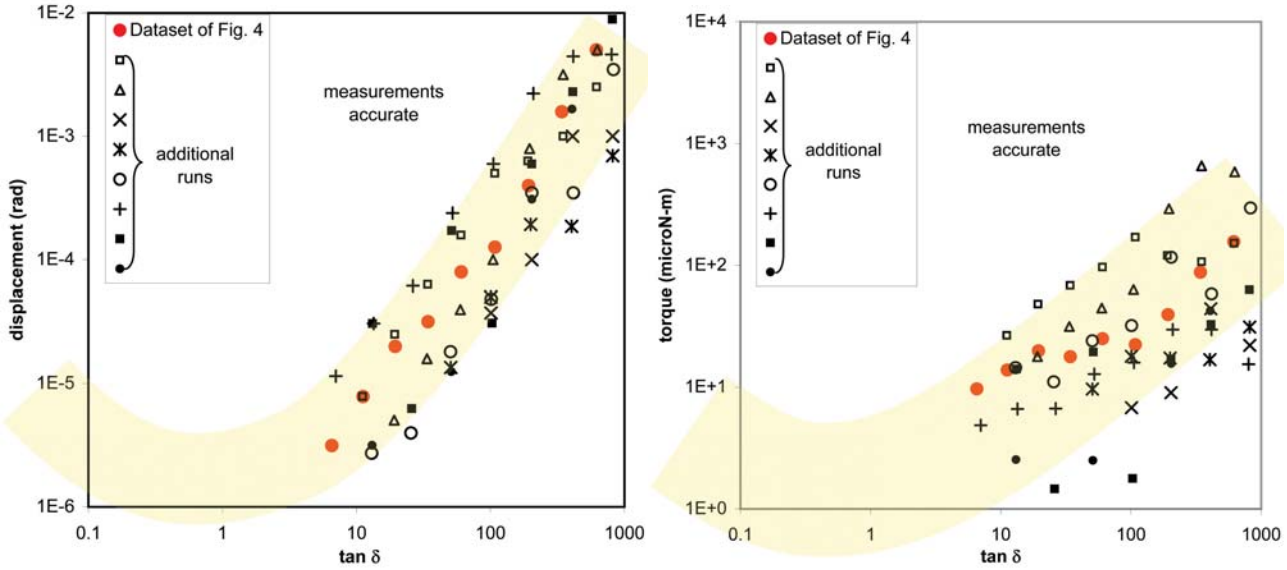


Fig. 5: Maps of instrument limits. Red circles are the torque and displacement corresponding to the same dataset as Fig. 4. Remaining symbols are various runs with different gaps and plate diameters.

by plotting the minimum torque T_{min} and minimum displacement θ_{min} corresponding to each γ_{min}, as a function of the $\tan\delta$ corresponding to each frequency. Such a representation is shown in Fig. 5, where the red points correspond to the same dataset in Fig. 4.

We repeated the analysis of Fig. 3 several times over a period of a few months using parallel plate geometry with gaps ranging from 2 mm to 0.5 mm, and plate diameters of 40 mm or 25 mm. These data are also shown in Fig. 5. The broad yellow lines through the scattered points show the general trend: measuring higher $\tan\delta$ requires increasingly higher amplitudes of the basic torque and displacement signals for the same (5%) error limits. There is substantial scatter in the minimum torque and displacement, i.e. in some runs, the specified level of performance (5% error on $\tan\delta$) can be achieved under more adverse conditions, whereas in other runs, the same performance required much larger displacement and torque values. We are not certain why the instrument limits are so inconsistent; it may be due to uncontrollable factors such as minor changes in air bearing pressure, incidental vibrations, possible electrical noise, etc. It is important to emphasize that it is only the *minimum torque and displacement limits* of the rheometer that are not reproducible from one run to another; the $\tan\delta$ values away from the limits (i.e. the plateaus in Fig. 3) were highly consistent. For accurate measurements, one must conduct experiments substantially above the minimum limits estimated in Fig. 5 so that irreproducibility of the limits does not affect the results.

In this article we have only been concerned with large values of $\tan\delta$. As mentioned in Section 2, at large $\tan\delta$, oscillatory measurements are limited by the error in G′ which grows proportionately to $\tan\delta$. In the other extreme of $\tan\delta$ approaching zero, oscillatory measurements are limited by the errors in G", which grow proportionately to $(\tan\delta)^{-1}$. Thus we anticipate that with decreasing $\tan\delta$, θ_{min} and T_{min} will rise again; this is the reason why the broad yellow curves in Fig. 5 have been shown to have minima. Experiments with other fluids for which G′ exceeds G" would be necessary to verify the upturn in the minimum torque or displacement for $\tan\delta < 1$.

Of these two parameters, θ_{min} or T_{min}, which one is the more fundamental limiting factor? Our results of Figure 5 show a great deal of scatter, both for small changes in geometry and even for repeat tests using the same geometry. Therefore we are unable to answer this question here except to note that the range of scatter is larger for the torque than for the displacement. This argues for a displacement limit that is fundamental. Repeating these experiments with fluids with substantially different viscosity would help determine whether torque or displacement is the fundamental limiting factor.

4. Closing comments

In summary, we have presented procedures to validate the accuracy of phase angle measurements as the phase angle approaches 90 degrees. They are easy to conduct and use readily available materials, viz. linear, monodisperse, well-entangled polymers, as calibration standards. Therefore

the test can be applied easily by any rheologist to test any specific rheometer.

In plotting the instrumental limits in the form of Fig. 5, we have presumed that the most important parameters that affect phase angle accuracy are the torque and the displacement. While this is eminently plausible, other factors may also play a role. For example, at high frequency, the accuracy of any inertial corrections, rather than limitations of torque or displacement, may dominate the performance limits. In the experiments in this paper, inertial effects were negligible over most of the frequency range.

We have used the polyisoprene LIR50, for phase angle validation because this is a linear, monodisperse, room temperature melt which was already available in a large quantity in our laboratory. Other rheologists may find it more convenient to select other model fluids, either polymer melts or solutions, that are more similar to their fluids of interest. As long as the fluid is monodisperse and well-entangled, the terminal region will extend over a wide range of $\tan\delta$ and the procedure outlined here can be applied. In fact, the strain sweep procedure of Fig. 3 does not even need a model fluid: it will yield the *limits of resolution* of $\tan\delta$ (Fig. 5) for any material and at any phase angle. However, without a model fluid, there will be no guarantee that the high-strain plateau values of Fig. 3 are correct; whereas with a linear monodisperse fluid such as LIR50, the same experiment will also validate the *accuracy* of $\tan\delta$ as δ approaches 90 degrees.

It is worth noting that in our strain-controlled experiments, while the AR2000 could measure phase angles quite close to 90 degrees, it never reported δ values exceeding 90 degrees (i.e. negative values of $\tan\delta$). This is somewhat surprising; the simple-minded expectation would be that the rheometer makes *random* errors in measuring phase angle, and hence as δ approaches close to 90 degrees, measured values of δ will fall on both sides of 90 degrees. We are not sure why the measured values of δ remain below 90 degrees, but this may also be the reason why there are systematically-negative deviations of $\tan\delta$ at low strain in Fig. 3.

The minimum torques and displacements required for accurate phase angle measurements (Fig. 5) are substantially larger than the minimum torque and displacement specifications quoted by the manufacturer. We suspect that specifications given for the AR2000, and perhaps for other rheometers, are only intended for G* or η^*, and not for phase angle measurements. If so, the given specifications are of only limited use since oscillatory measurements *must* include the phase angle to give any information about viscoelasticity.

Despite this criticism, we want to comment that the AR2000 rheometer, and perhaps other comparable instruments, can measure very high values of $\tan\delta$ – roughly on the order of 1000 – within 5% accuracy, provided signals are maintained above limits such as those of Fig. 5. This is remarkable performance, and better than we had expected prior to performing these tests. This level of performance was realized using the default test settings of the rheometer, and without taking any special precautions in sample loading, except to avoid bubbles: bubbles could give a large error in G' in the terminal region due to their surface tension elasticity.

Acknowledgement

We are grateful to Kuraray America Co. for donating the LIR 50 polyisoprene sample for this research. We are also grateful to experts from TA Instruments (notably Dr. Bernard Costello and Dr. Ron Garritano) and Paar-Physica (Dr. Joerg Lauger) for discussions and clarifications, and to Prof. John Dealy (McGill University) and Dr. Peter Saucier (Dow Chemicals) for providing references 1-5.

Bibliography

1. Saucier, P. C. & Obermiller, D. J. Precision in linear viscoelastic property measurement: Establishing a protocol for statistical quality control. *Annual Technical Conference - Society of Plastics Engineers* **53rd**, 1085-90 (1995).
2. Tchir, W. J. & Saucier, P. C. A statistical approach to curve fitting rheological data inclusive of experimental errors. *Annual Technical Conference - Society of Plastics Engineers* **49th**, 2321-5 (1991).
3. Saucier, P. C. & Tchir, W. J. Measurement and modeling of viscoelastic properties: estimation of parameters unbiased by property evolution. *Annual Technical Conference - Society of Plastics Engineers* **50th**, 2452-6 (1992).
4. Bafna, S. S. Precision of dynamic oscillatory measurements. *Polym. Eng. Sci.* **36**, 90-97 (1996).
5. Dealy, J. M. & Saucier, P. *Rheology in Plastics Quality Control* (Hanser Publishers, Munich, 2000).
6. Dealy, J. M. Questions about relaxation spectra submitted by a reader. *Rheology Bulletin* **76**, 14 (2006).
7. Fanconi, B. & Flynn, K. Non-newtonian polymer solution for rheology now available - Standard Reference Materials. *Journal of Research of the National Institute of Standards and Technology* **108**, 97-98 (2003).
8. Schultheisz, C. R. & Leigh, S. F. in *NIST Special Publication 260-143* (U.S. Department of Commerce, National Institute of Standards and Technology, 2002).
9. Laeuger, J., Heyer, P. & Snyder, C. R. in *77th Annual Meeting of the Society of Rheology* (Vancouver, 2005).
10. Macosko, C. W. *Rheology: Principles, Measurements, and Applications* (ed. Macosko, C. W.) (Wiley-VCH, New York, 1994).
11. Walters, K. *Rheometry* (Chapman and Hall, London, 1975).

Application for Membership in The Society of Rheology

Any student, scientist or engineer with an interest in the deformation or flow of matter is invited to join The Society of Rheology. Members receive the *Rheology Bulletin*, the *Journal of Rheology* and *Physics Today*. There are no academic or geographic requirements for membership. Complete and send a copy of this application form to the address below.

I wish to apply for membership in The Society of Rheology dating from January _____ (year)

last name:
first name:
department:
institution:
work address:
city:
state/province:
postal code: (work address appears in the directory)

mail address:
city:
state/province:
postal code: (publications sent to the mail address)

country:
phone:
fax:
e-mail:

affiliation: academia ☐ industry ☐ government ☐ (check most appropriate)

annual dues: regular member ($40) ☐ student member ($25) ☐ (include copy of student ID)

credit card: AMEX ☐ MasterCard ☐ Visa ☐ exp. date:

card number:

signature: _____ date: _____

Please enclose remittance in US dollars drawn on a US bank payable to "The Society of Rheology" and mail to Janis Bennett at AIP, Suite 1NO1, 2 Huntington Quadrangle, Melville, NY 11747-4502, 516-576-2403, 516-576-2223 (fax). A member subscription to the *Journal of Rheology* is only for your personal use. By your signature below, you agree not to loan or give any issues of this journal to a library or other lending institution without written permission from The Society of Rheology.

signature (required): _____ date: _____

Society Business

NEWS

SOR Officer Slate Announced

In accordance with Article V of the Rules of The Society of Rheology, SOR members received an email informing them of the list of nominees for the 2007 election, as reported by the Nominating Committee:

President: Robert Prud'homme, Princeton Univ
Vice President:
Ralph Colby, Pennsylvania State Univ
Faith Morrison, Michigan Technological Univ
Secretary: A. Jeffrey Giacomin, Univ of Wisconsin
Treasurer: Monty Shaw, University of Connecticut
Editor: John Brady, Caltech

Members at Large:
Dan Klingenberg, University of Wisconsin
Patrick Mather, Case Western Reserve University
Jeffrey Morris, Levich Institute
David Venerus, Illinois Institute of Technology
Norman Wagner, University of Delaware

For a period of forty-five (45) days following the date of that notification, additional nominees may be named by petition forwarded to the Secretary and signed by at least fifteen (15) members in good standing of The Society.

Members will cast their votes electronically at: www.rheology.org/sorvote/. This web site will be turned on about 19 July 2007. An email notification will be sent to all members when the web site is online.

AIP Names New Executive Director and CEO

(from AIP Press Office)

H. Frederick Dylla has been selected to be the next Executive Director and CEO of the American Institute of Physics (AIP). Dylla assumed these roles 1 April 2007. He replaces Marc H. Brodsky, who retired after more than 13 years at AIP's helm.

"Fred has already been an invaluable member of the AIP family," says AIP Governing Board Chair Dresselhaus. "His ideas and initiatives have enhanced AIP and its Member Societies for many years. As the next CEO and Executive Director, his experience, enthusiasm, and outward-looking nature will drive AIP in the right direction as we work with the rest of the scientific community to confront a future filled with challenges."

"I'm honored to be selected to be the next AIP Executive Director," says Dylla. "I am very optimistic for the outlook of the Institute to continue to grow in its role of supporting the value of physics for its Member Societies, the physics community and the world at large." *(continues page 27)*

AIP Establishes New Oral History Endowment

(from AIP press office)

A new endowment to be maintained at the American Institute of Physics (AIP) aims to bring the little-known behind-the-scenes history of industrial physics to light. The Marc H. Brodsky Fund for Oral History of Physicists in Industry will enable the AIP Center for History of Physics and Niels Bohr Library & Archives to interview several important industrial physicists each year, transcribe and preserve their oral histories, and make them available to researchers now and in the future. *(continues page 27)*

JOR Publication Award Winners Announced

The Journal of Rheology Publication Award for 2007 will be awarded to C. Clasen, J. P. Plog, W.-M. Kulicke, M. Owens, C. Macosko, L. E. Scriven, M. Verani, and G. H. McKinley for their paper "How dilute are dilute solutions in extensional flows?" JOR 50(6) 849 (2006). This team of investigators are from Institute of Technical and Macromolecular Chemistry, University of Hamburg, Germany, Department of Chemical Engineering and Material Science, University of Minnesota, Minnesota USA, and Hatsopoulos Microfluids Laboratory, Massachusetts Institute of Technology, Cambridge, Massachusetts USA.

The JOR Publication Award recognizes a paper published in the Journal in the two preceding years. The Award carries a cash prize of $1000 that is awarded publicly at the Awards banquet at the Society of Rheology Annual meeting. This year's meeting is in Salt Lake City, Utah, 6-11 October 2007; the awards banquet is Tuesday the 9th. All papers receiving JOR Publication Award are designated 'open access' and thus made available free to all.

Nominations Sought for 2008 Bingham Medalist

Members of The Society of Rheology are invited to nominate outstanding rheologists for The Society's highest honor, the Bingham Medal. The 2008 Bingham Medal will be awarded in Monterey at the International Congress on Rheology, which, because it is being held in North America, is also the 80th Annual Meeting of The Society of Rheology.

Nomination guidelines may be found on the web at www.rheology.org/sor/awards/bingham/default.htm. Nominations for 2008 are due 30 November 2007. This due date is earler than usual due to the timing of the ICR.

Minutes of the ExCom Meeting

Sunday 18 March 2007
Salt Lake City, Utah USA

Andy Kraynik Andy Kraynik called the meeting to order at 8:31 a.m. in the Executive Boardroom of the Hilton Salt Lake City Center. Attending committee members were Susan Muller, John Brady, Monty Shaw (teleconference), Jeffrey Giacomin, Bob Prud'homme, and Lynn Walker. Invited guests were Gerry Fuller (Chair, Local Arrangements, ICR2008), Faith Morrison (Editor, *Rheology Bulletin*), and Jaye Magda (Chair, Local Arrangements, Salt Lake City Meeting). The minutes of the previous meeting were read and approved.

Monty Shaw presented the Statement of Revenues and Expenses for The Society of Rheology and for its *Journal of Rheology*. The financial position of the Society is sound. The Portland meeting produced a surplus of roughly $2000. The Executive Committee passed a motion to accept these reports.

Andy Kraynik led a discussion on Treasurer succession, pointing out that an apprenticeship period for the Treasurer's position is normally undertaken before the Treasurer steps down.
Jaye Magda and Andy Kraynik (Local Arrangements Chairs) reported on the October 7-11, 2007 meeting in Salt Lake City, Utah. Careful budgeting for this meeting is underway. Everything is falling nicely into place for our next meeting.

John Brady, Editor, reported that the *Journal of Rheology* is healthy. Brady gave an online demonstration of the new AIP Author Resource Center (http://dx.aip.org/). This guides authors through technical details of electronic publishing including publishing in color.

Gerry Fuller (Co-Chair, Local Arrangements) reported on plans for the 2008 International Congress on Rheology in Monterey. Fuller led a discussion of the meeting budget.

Kraynik, on behalf of Gary Leal and Ralph Colby (Technical Program Chairs, ICR2008) presented a report on the Monterey program. The committee now consists of Kornfield, Brady, Kraynik, Pine, Hyun, James, Cooper-White, McLeish, Vermant, Vlassopoulos, Mendes, and Watanabe. Nearly every invited lecturer has been selected.
Kraynik, on behalf of the Chair of the Education Committee, Mike Solomon, led a discussion about future short courses. "Beginning Rheology" (an update of the 2004 Lubbock Meeting offering by Morrison and Giacomin, 2-day) will be offered in parallel with "Microfluidics for rheologists" (Squires, Anna and Doyle, 1-day) on the weekend preceding the Salt Lake meeting (October 6-7, 2007). For the weekend preceding the ICR (August 2-3, 2008), "Introduction to Rheology of Colloidal Suspensions" (Wagner and Mewis, 2-day) in parallel with "Surfactant rheology, self-assembly and microstructure dynamics" (Spicer, 1-day) are planned. The committee is actively soliciting proposals for future meetings.

For Pat Mather (Chair, Local Arrangements), Kraynik reported on the 2011 meeting (October 9-13) at the Intercontinental Hotel and Conference Center in Cleveland, Ohio. Everything is nicely falling into place.

Faith Morrison (Editor, *Rheology Bulletin*) reported that our latest *Bulletin* is our largest ever (32 pages). The previously tabled motion "that we allow advertising in the *Bulletin* to those not yet advertising in the *Journal of Rheology*, while still providing our discount to those who do advertise in the *Journal of Rheology*." was then discussed.

Giacomin, Editor for Business, reported on the *Journal of Rheology On-Line (JOROL)*. Usage remains strong. Giacomin reported that we now have 57 of the new individual member subscriptions to the *JOROL*. These, optionally, cost an extra $40 for regular members, and are free to retired members. This new form of subscription is popular. Giacomin also gave an on-line demonstration of journal usage statistics provided to the Society at www.scitation.org (password protection). AIP has made significant improvements.

On Pat Mather's (Chair of the Membership Committee) behalf, Kraynik reported that as of year-end 2006, we had 1584 members (including 1368 regular and 194 student). Mather is actively recruiting new student members.

At 2:30 p.m. Kraynik moved the meeting into Executive session. Brady left the room. The Bingham Committee recommendation to award the 2007 Bingham Medal to Professor John F. Brady of Caltech was then unanimously confirmed by the rest of the Executive Committee. Kraynik then moved the meeting back to regular session.
Kraynik led a discussion on the creation of new Society awards.

Giacomin reported that all papers having won the *Journal of Rheology* Publication Award have been made *open access*. So have all three papers outlining official nomenclature for rheology. *Open access* papers can be freely downloaded from the *JOROL*.

Giacomin reported that the insurance company that appeared to be misusing the SOR logo to market itself to SOR members, New York Life, is the designated insurance provider for the American Physical Society Insurance Trust (APSIT). As AIP members, SOR members are entitled to special life insurance rates from New York Life. Giacomin has been appointed to the APSIT Board.

At 4:07 p.m. Kraynik again moved the meeting into Executive session. The meeting was adjourned at 4:11 pm.

Treasurer's Report

To the membership:

Attached are tables describing the financial situation for The Society of Rheology at the end of calendar year 2006, along with a proposed budget for 2008. The latter will be presented for the approval of the Membership at our Annual Meeting in Salt Lake City in October. Due to a number of positive factors, including higher interest rates, the financial position The Society's continues to improve, although there remain the expected concerns about the International Congress on Rheology in 2008. Budget estimates for the ICR are around $500,000, which is roughly seven times a typical Annual Meeting. While we customarily budget for a break-even position for meetings and expect reasonable attendance in Monterey, the Executive Committee prudently voted to increase the

meeting reserves to $400,000. Were this modification made in 2006, the discretionary reserves would fall to $106,000. For the Journal of Rheology, proceeds from the licensing of library consortia continue to climb (see under JORO revenue). As a result, the electronic publishing venture, which started out with heavy expenses, is now showing a modest profit. For the Society in general, we are pleased to report that the Vancouver meeting was finally closed in 2006 with a small profit, after accounting for Student Travel and Executive Committee Expenses. The Portland Annual Meeting will be described at the Annual Meeting in Salt Lake City, along with a general discussion of meeting accounting issues.

Respectfully submitted,
Montgomery T. Shaw, Treasurer

Treasurer's Report

The Society of Rheology
Receipts and Disbursements
(all amounts, USD)

	2008 Budget	2007 Budget	2006 Year End	2006 Projection	2005 Year End
RECEIPTS					
Dues	56,000	55,000	55,040	55,408	56,780
Interest	54,000	53,000	52,862	57,105	29,823
Journal of Rheology	258,200	262,600	266,954	271,794	270,107
Mailing List Sales	0	0	-66	0	0
Bulletin Advertising	5,000	10,000	3,105	5,728	17,820
Annual Meeting (net)	-20,000	0	3,686	2,344	7,709
Short Course (net)	0	0	-2,384	623	-2,225
TOTAL RECEIPTS	353,200	380,600	379,198	393,002	380,014
DISBURSEMENTS					
AIP Dues Bill & Collect.	11,000	11,000	10,779	10,446	10,503
AIP Adm. Services	11,000	9,500	10,311	9,526	9,511
AIP Mem. Soc. Dues	8,000	7,700	7,936	7,936	7,706
Contributions and Prizes	1,900	1,900	329	1,731	2,033
Journal of Rheology	166,225	217,996	160,874	168,913	218,437
Bulletin	12,000	9,000	16,773	9,991	8,745
Bingham Award	7,000	7,000	5,000	5,000	10,000
Executive Cmt. Meetings	8,000	8,000	8,044	7,212	6,326
Pres. Discretionary Fund	1,500	1,500	159	0	0
Treas. Discr. Fund	1,500	1,500	0	400	556
Bulletin Editor Discr. Fund	1,500	1,500	0	0	0
Progr. Chm. Discr. Fund	2,000	3,000	0	4,000	2,637
Webmaster Discr. Fund	3,000	3,000	0	1,800	503
Office Expenses	3,000	4,000	2,234	4,103	2,880
Banking Services	100	100	20	40	39
Liability Insurance	7,500	7,500	3,823	5,654	4,349
Membership Broch. & Appl.	500	500	432	300	0
Accountant	2,100	2,200	1,925	1,925	1,925
Student member travel	16,000	12,000	11,771	12,754	3,566
Annual meetings, future	4,000	9,000	8,601	10,377	2,108
Website	1,000	1,000	282	300	637
Miscellaneous	500	500	0	0	0
TOTAL DISBURSEMENTS	269,325	319,396	249,295	262,408	292,459
Net	83,875	61,204	129,903	130,595	87,555

Journal of Rheology
Receipts and Disbursements

	2008 Budget	2007 Budget	2006 Year End	2006 Projection	2005 Year End
RECEIPTS					
Subscriptions	170,000	177,100	171,729	179,934	180,061
Reprint Sales	10,200	13,500	10,105	11,181	13,791
Ad Sales	36,000	35,000	35,650	31,057	35,107
JORO revenue	41,000	36,000	42,280	43,379	37,610
Miscellaneous	1,000	1,000	7,190	6,243	3,538
TOTAL RECEIPTS	258,200	262,600	266,954	271,794	270,107
DISBURSEMENTS					
Ads	7,000	9,500	7,199	6,581	9,454
Reprints, Single Copy	1,900	5,400	1,647	1,519	5,363
Paper, Printing	20,000	29,638	18,502	18,289	32,656
SOR Editorial	41,000	42,000	39,534	37,960	39,855
Production	30,000	55,000	29,841	29,242	54,985
Fulfillment	6,425	6,625	6,364	6,402	6,560
Distribution	20,100	20,833	18,724	19,825	19,094
Electronic publishing	35,000	43,000	33,570	43,103	42,239
Miscellaneous	4,800	6,000	5,494	5,991	8,231
TOTAL DISBURSEMENTS	166,225	217,996	160,874	168,913	218,437
Net	91,975	44,604	106,080	102,881	51,670

The Society of Rheology, Inc.
Balance Sheet

(all amounts, USD)	2006 Year End	2005 Year End	2004 Year End	2003 Year End	2002 Year End
Assets					
Cash in checking account	9,777	12,721	29,012	2,047	466
Securities	0	0	0	0	0
Balance in AIP account	1,185,978	1,056,188	976,655	938,047	915,334
Total Assets	1,195,755	1,068,909	1,005,667	940,094	915,800
Liabilities and Net Assets					
Liabilities					
Deferred revenue	129,339	132,396	155,969	143,603	162,363
Total Liabilities	129,339	132,396	155,969	143,603	162,363
Net Assets					
Publication reserve	450,000	450,000	450,000	450,000	450,000
Student travel grant reserve	10,000	10,000	10,000	10,000	10,000
Annual Meeting reserve	200,000	200,000	100,000	100,000	70,000
Operating reserve	100,000	100,000	100,000	70,000	70,000
Unrestricted	306,416	176,513	189,698	166,491	153,437
Total Net Assets	1,066,416	936,513	849,698	796,491	753,437
Total liabilities and net assets	1,195,755	1,068,909	1,005,667	940,094	915,800

the end

(John Brady, continued from page 5)

suffer from a number of shortcomings. For example, it predicted that particles would migrate if the suspension was sheared in a parallel plate device but not in a cone and plate apparatus, whereas experiments showed that the reverse was the case. Also, it could not account for the normal stresses which Gadala-Maria had measured some years earlier. Finally, it was far from clear how the trajectory model could be extended beyond any but the simplest unidirectional flows. In contrast, John & Nott's suspension balance model is based on the principles of mechanics plus dimensional analysis and, as modified by Jeff Morris, not only avoids the shortcomings of the trajectory model referred to above, but can also serve as a proper constitutive equation for a large class of complicated, and even some three-dimensional, flows. Consequently, it is the suspension balance model which is currently used on a worldwide basis when studying the rheology of concentrated suspensions.

John has received numerous international awards of which the AIChE Professional Progress Award ('98) and his election to the National Academy of Engineering ('99) particularly stand out. In addition, he served as an Associate Editor of the Journal of Fluid Mechanics ('90-'04) and became the Editor of the Journal of Rheology in July '05. And last but not least, he has proven to be an outstanding mentor of PhD students some of whom, e.g. Don Koch at Cornell, Ron Phillips at the Univ of California at Davis, Louis Durlofsky at Stanford, Roger Bonnecaze at the Univ of Texas at Austin, and Jeff Morris at the Levich Institute CCNY, are rapidly developing international reputations of their own. A more stellar list of accomplishments would be difficult to imagine.

(AIP CEO continued from page 22)

Dylla has been with the U.S. Department of Energy's Thomas Jefferson National Accelerator Facility since 1990. He has concurrently held an Adjunct Professorship in Physics and Applied Science at the College of William and Mary. The author of over 190 publications, he received his B.S., M.S. and Ph.D. in physics from MIT. He is a Fellow of the American Physical Society.

Outgoing CEO and Executive Director Marc Brodsky served AIP for thirteen and a half years. During his tenure, Brodsky oversaw dramatic changes in AIP publishing, as nearly all processes were changed to deal with electronic publishing.

(Meetings, continued from back cover)

9-13 October 2011
83rd Annual Meeting of The Society of Rheology, Cleveland, Ohio USA, Pat Mather

2012

Summer 2012
XVIth International Congress on Rheology, location TBA (every four years; in 2012 in Europe)

See also:
www.rheology.org/sor/info/Other_Meetings.htm
www.rheology-esr.org/Meetings.php
www.appliedrheology.org/ (click on conferences)

(Brodsky Fund continued from page 22)

The fund honors Marc H. Brodsky*s distinguished career as AIP*s Executive Director and CEO from 1993-2007, as well as his innovative work as an industrial physicist.

"In 1991 a fire at my company destroyed our records, and in recreating them, we conducted several oral histories of key personnel," says Julian A. Brodsky, co-founder, Director and Vice Chairman of Comcast Corporation. Julian, Marc's brother, is one of the lead contributors to the fund.

"Recognizing Marc through this fund is very appropriate because of his stellar reputation in the industrial physics world as well as his work at AIP," he says. "The fund honors both aspects of Marc*s career."

The fund was established on March 29, 2007 by lead gifts from the Lois and Julian Brodsky Family, John and Elizabeth Armstrong, and from many others. Currently, over $84,000 has been pledged to the Fund, which will remain open over the next four years for future contributions. For more information: www.aip.org/history/newsletter/spring2007/brodsky.html

CALENDAR OF RHEOLOGY CONFERENCES AND COURSES

2007

6-8 September 2007
IUTAM Symposium on Advances in Micro- and Nanofluidics, Dresden, Germany, N.A. (Nikolaus) Adams

6-7 October 2007
SOR Short Course on *Beginning Rheology* by Faith A. Morrison and A. Jeff Giacomin, Salt Lake City, UT USA; may be taken as a one-day course followed by the *Microfluidics for Rheologists* course, below, on the second day.

7 October 2007
SOR Short Course on *Microfluidics for Rheologists* by Todd Squires, Shelley Anna, and Patrick Doyle, Salt Lake City, UT USA

7-11 October 2007
79th Annual Meeting of The Society of Rheology, Salt Lake City, UT USA, Jaye Magda

2008

15-19 June 2008
2008 Annual Meeting of the Polymer Processing Society, Salerno, Italy, G. Titomanlio, www.pps-24.com

2-3 August 2008
SOR Short Course on Rheology (topic TBA), Monterey, CA USA

3-8 August 2008
XVth International Congress on Rheology and 80th Annual Meeting of The Society of Rheology, Monterey, CA USA, Gerry Fuller and Bob Powell, www.rheology.org/ICR2008/

24-30 August 2008
XXII International Congress of Theoretical and Applied Mechanics ICTAM 2008, Adelaide, Australia, prandtl.maths.adelaide.edu.au/ictam2008/

Summer 2008
13th International Congress of Biorheology, location TBA (held every three years, www.coe.ou.edu/isb).

2009

February 2009
5th International Symposium on Food Rheology and Structure - ISFRS 2009, Zurich Switzerland (every 3 years; www.isfrs.ethz.ch)

Spring 2009
5th Annual European Rheology Conference AERC 2009, location TBA

Summer 2009
5th Pacific Rim Conference on Rheology, location tentatively Hokkaido, Japan, Hiroshi Watanabe (every 4 years)

17-18 October 2009
SOR Short Course on Rheology (topic TBA), Madison, WI USA

18-22 October 2009
81st Annual Meeting of The Society of Rheology, Madison, WI USA, Jeff Giacomin

2010

Spring 2010
6th Annual European Rheology Conference AERC 2010, location TBA

23-24 October 2010
SOR Short Course on Rheology (topic TBA), Santa Fe, NM USA

24-28 October 2010
82nd Annual Meeting of The Society of Rheology, Santa Fe, New Mexico USA, Andy Kraynik

2011

Spring 2011
7th Annual European Rheology Conference AERC 2011, location TBA

8-9 October 2011
SOR Short Course on Rheology (topic TBA), Cleveland, Ohio USA