The News and Information Publication of The Society of Rheology
Volume 81 Number 2 July 2012

Rheology Bulletin

Rheology meets in Lisbon this summer!

Inside:

Table of Contents

On the Cover:

Historical downtown Lisbon and the harbor (photo credit João Maia, ICR Lisbon organizer)

To the Left:

Wrinkles forming due to shape recovery of a new shape memory polymer coated with a thin layer of gold. The image is 50 microns × 50 microns and was obtained using tapping mode AFM by Ph.D. student, Pine Yang. The image is part of a study by Pine Yang, Richard M. Baker, James H. Henderson, and Patrick T. Mather, all of Syracuse University, where they are investigating "Active Cell Culture" wherein cell-material interactions are studied for future applications in tissue engineering.

Standing Committees

Membership Committee (2011-2013)
Christopher White, chair
Saad Khan
Jason Maxey
Lisa Mondy
Florian Nettesheim

Education Committee (2011-2013)
Anne M. Grillet, chair
Marie-Claude Heuzey
Jonathan P. Rothstein
Maryam Sepehr
Patrick Spicer

Bingham Award Committee
Jeffrey F. Morris, chair (2009-2012)
Patrick Doyle (2010-2013)
Jae Chun Hyun (2009-2012)
Michael Graham (2011-2014)
Lisa Mondy (2010-2013)
Savvas Hatzikiriakos (2011-2014)
Jan Vermant (2011-2014)

Metzner Award Committee
Gareth McKinley, chair (2009-2012)
Suzanne Fielding (2010-2013)
Peter Fischer (2009-2012)
Ole Hassager (2011-2014)
Eric Shaqfeh (2010-2013)

Meetings Policy Committee
Andrew M. Kraynik, co-chair
Greg McKenna, co-chair (VP)
Albert Co (Secretary)
John Brady (2013W Local)
Shelley Anna (2013W Program)
Carlos Rinaldi (2013W Program)
Marie-Claude Heuzey (2013 Local)
Wes Burghardt (2013 Program)
Dan Klingenberg (2013 Program)
Michael Mackay (2014 Local)
Kalman Migler (2015 Local)

Webmaster	Albert Co
Editor, Rheology Bulletin	Faith A. Morrison
Associate Editor for Business, Journal of Rheology	A. Jeffrey Giacomin
Director, International Outreach Program	Gerald G. Fuller
Designee to AIP Governing Board	A. Jeffrey Giacomin
Society of Rheology Representatives to External Committees/Organizations:	
AIP Committee on Publishing; also Chair	A. Jeffrey Giacomin
AIP Advisory Committee on Physics Today (2013)	Gerald G. Fuller
U.S. National Committee on Theoretical and Applied Mechanics	Eric Shaqfeh
International Committee on Rheology	Andrew M. Kraynik

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. Letters to the editor: *rheology@aip.org*.

Serial Key Title: Rheology Bulletin
LC Control No.: 48011534
Published for The Society of Rheology
by the American Institute of Physics
ISSN: 0035-4538 CODEN: RHBUAV
CALL NUMBER: QC1 .R45

The *Rheology Bulletin* is archived at *www.rheology.org/sor/publications/rheology_b/issues.htm*
and is also available through the *iRheology* app.

Profile by Dimitris Vlassopoulos, IESL-FORTH, Heraklion, Crete, Greece

Bingham medalist 2012: Ralph H. Colby

Ralph H. Colby received his B.S in Materials Science and Engineering from Cornell University in 1979. He worked for 2 years at the General Electric Company in rheology and process development before enrolling as a graduate student at Northwestern University's Chemical Engineering Department. He received a M.S in 1983 and a Ph.D. in 1985 under the guidance of William W. Graessley. Ralph's thesis work involved a detailed study of the rheology of linear polybutadiene melts and was carried out in part at the Corporate Research & Science Laboratories of Exxon Research and Engineering Company, where he spent 15 months as a visiting student. Ralph's thesis papers are considered to be classic. He still holds the record for having measured the viscosity of the monodisperse polymer melt with the largest number of entanglements (more than 8000). After graduating from Northwestern, Ralph moved to Rochester, NY and worked for ten years at the Kodak Research Laboratories where he developed a highly successful research program on experimental rheology of soft matter. Colby's areas of interest over these ten years included linear polymer melts and solutions, miscible polymer blends, block copolymers, randomly branched polymers, polymer gels, liquid crystalline polymers, polyelectrolytes, proteins, surfactants, and colloidal suspensions. He initiated collaboration with world-class theorist Michael Rubinstein. This is one of the most successful and productive collaborations in our field, which still continues today. One of the most important outcomes of this collaboration is the outstanding Polymer Physics textbook (Oxford, 2003), probably the best of its kind; it is a masterpiece of clarity and profoundness, and includes an amazing collection of problems of varying difficulty. In 1995 Colby moved to academia joining the faculty of the Pennsylvania State University, where he has been Professor of Materials Science and Engineering since 2000. Ralph received the C. E. K. Mees Award of Eastman Kodak Company (1987) and the Wilson Research Award of Penn State (2004). He served as co-chair of the Technical Program of the XVth International Congress on Rheology and co-editor of its proceedings (AIP, 2008). He is a fellow of the American Physical Society and the editor of the *Journal of Rheology*.

From the beginning of his research career Ralph followed the legacy of Bill Graessley and recognized that the synergy of synthesis, properly designed and carefully executed experiment, and deep understanding of theory is necessary for advancing the field of molecular rheology. This synergy of expertise remains the cornerstone of Ralph's approach to research in a wide range of topics in soft matter, and is behind his huge success. In fact, Ralph has a well-deserved reputation as one of the best

rheological experimentalists in the world. At the same time, he has an extraordinarily deep grasp of theory and his integrated approach combining experiments and theory results in contributions with the broadest possible impact.

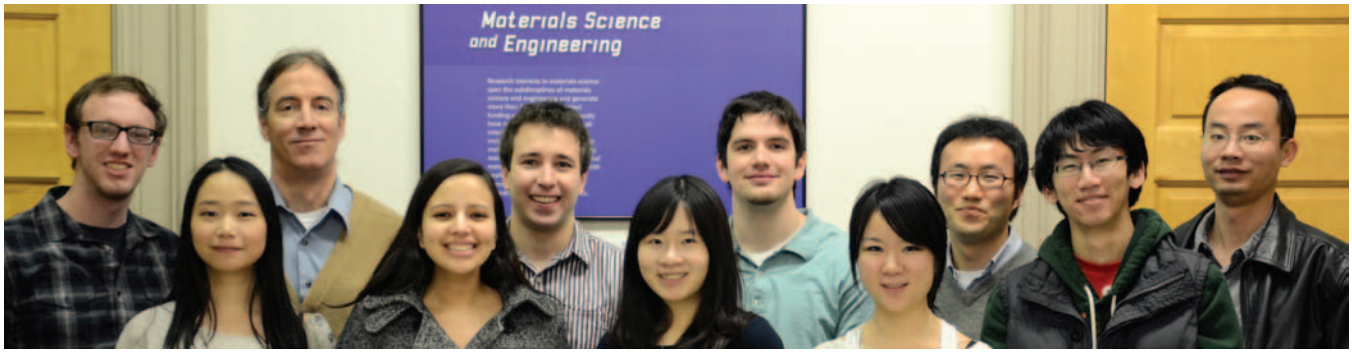
In 1988, Ralph discovered a remarkable property of miscible polymer blends: the contributions of individual components to viscoelastic response have temperature dependences relative to the glass transition temperature (T_g) for the blend that closely match those of the pure components relative to their own individual T_g's. Thus, the dynamics of miscible blends follow fundamentally different temperature dependencies from those of polymer solutions and can exhibit thermorheological complexity. Colby's observations attracted many groups to examine different blends in order to test the generality and to search for molecular explanations of this phenomenon. Ralph's subsequent work in collaboration first with Gerry Fuller and later with his long-time colleague, Sanat Kumar, has brought to the subject a variety of new spectroscopic probes and molecular simulations.

Colby has laid the groundwork for our current understanding of constraint-release effects in entangled polymers in a series of classic works including his papers with Rubinstein and later with Viovy explaining the interplay of reptation, contour length fluctuations and constraint release in bidisperse polymers. These works are still the state of the art in the field today, providing the ingredients in most modern tube models of polymer relaxation. Moreover, the "Colby-Rubinstein" theory for semi-dilute solutions of polymers in theta solvents established the "4/3 exponent" for entanglement spacing as a function of concentration, and is commonly used not only for predictions of solution rheology, but also for the state of the art theories of "dynamic dilution" for the rheology of branched polymer melts.

Ralph has made several experimental and theoretical (with Dobrynin and Rubinstein) breakthroughs that shaped the field of polyelectrolyte rheology. These breakthroughs include the increased relaxation time and the appearance of shear thinning at lower shear rates as the solution concentration is lowered, the observation and the explanation of the fact that the semidulute unentangled regime spans 3 decades in concentration, whereas the entangled regime is qualitatively different from that of uncharged polymers. He has also extended his work to ionomers. The sticky reptation model with Leibler and Rubinstein and the association of loss modulus peak in the rubbery plateau region of ionomers to ionic domain relaxation, brought new life to the field. Currently, Colby's group is revisiting outstanding fundamental problems such as ionic mobility, ion aggregate structure at different length scales and glassy and chain dynamics by combining rheology with dielectric spectroscopy, SAXS, and scaling theory. This poorly understood class of materials is expected to become very important for many applications including actuators, sensors, separators between the electrodes of advanced batteries, and fuel cell membranes.

Using their landmark classification of gelation, based on the overlap parameter and related number of entanglements between crosslinks, Colby and co-workers developed models for the rheology of randomly branched polymers near the gel point and showed their universality. This discovery has implications to the design and synthesis of different types of branched polymers. Ralph applied his expertise on gelation of simple flexible polymers to more complex systems, such as denaturated collagen in order to understand the kinetics of helix formation. Using rheo-optics he showed that optical rotation is proportional to the number density of helices. The latter were measured simultaneously with viscosity and shear modulus. Rheological and scattering investigations of the two main constituents of synovial fluid, hyaluronic acid

(Continues page 26)



Colby Group January 2012: from left Josh Bartels, Shushan Gong, RHC, Maria Monica Castellanos Mantilla, Greg Tudryn, Helen Wang, Fawzi Hamad, Yuedan Dong, U Hyeok Choi, Huai-Suen Shiau and Siwei Liang.

Anton Paar

The New MCR Series: Modular Rheometers Ready for Everything

Whatever your rheological requirements are and will be in the future – MCR rheometers are always efficiently and comfortably adapted to meet your needs.

Find out more about the MCR rheometer series at www.anton-paar.com.

Anton Paar® GmbH
info@anton-paar.com
www.anton-paar.com

2012 Metzner Early Career Award: Charles M. Schroeder III

Charles Schroeder, Assistant Professor of Chemical & Biomolecular Engineering and Materials Science and Engineering at the University of Illinois at Urbana-Champaign (UIUC), has been awarded the 2012 *Arthur B. Metzner Early Career Award* of the Society of Rheology. This award singles out a Society member younger than 35 who has distinguished him/herself in rheological research, rheological practice, or service to rheology.

Schroeder received his B.S. in Chemical Engineering from Carnegie Mellon University and his M.S. and Ph.D. in Chemical Engineering from Stanford University. During his graduate research with Eric Shaqfeh (2011 Bingham Medalist), Schroeder studied polymer conformation hysteresis and the role of intramolecular hydrodynamic interactions on polymer dynamics using Brownian dynamics simulations. At Stanford, he also used single polymer experiments to study the dynamics of DNA molecules in non-equilibrium fluid flows working with Steven Chu. Schroeder spent a postdoctoral year at Harvard working with X. Sunney Xie; at Harvard, Schroeder developed a hydrodynamic flow-based assay to study DNA-protein interactions. Since 2008 Schroeder has been on the faculty of the University of Illinois at Urbana-Champaign.

At the University of Illinois, Schroeder recently extended the field of molecular rheology to a new class of polymeric materials, truly flexible polymers. Previously, single polymer studies were limited to double stranded DNA, which is a semiflexible polymer. Synthetic polymers of commercial relevance are much more flexible than these models, and Schroeder and his group have developed a versatile chemical platform to synthesize chemically-modified single-stranded DNA of any "designer" sequence with concomitant labeling of the polymer backbone with a fluorescent dye. The dyed segments allow the group to observe relaxation dynamics of single flexible chains, and Schroeder and his group have demonstrated that relaxation processes follow a fundamentally different route than has been assumed previously. "The results of his studies will transform our understanding of polymer chain dynamics and rheology," according to his nominator, Charles Zukoski of the University of Illinois.

Schroeder's group recently developed a new theoretical framework that allows for determination of materials properties (e.g. polymer elasticity) from far-from-equilibrium measurements (e.g. polymer dynamics). This theoretical development is a first-of-its-kind tool in the field of complex fluids/soft materials and offers a powerful new approach to extract materials properties.

Finally, Schroeder's group recently developed a new method to confine and manipulate single nanoparticles in free solution using the sole action of hydrodynamic forces in a microfluidic device. The "microfluidic trap" is based on active flow field control at a fluid stagnation point, which enables particle confinement of small nanoparticles for long times.

Taken together, Schroeder's work combines elegant experimental work with rigorous analysis — just the tools needed to advance rheology. Charles Schroeder thus exemplifies the excellence that has been come to be expected from those singled out for the Metzner Award. Charles Schroeder is the fourth recipient of the *SOR Early Career Award*; the plaque and prize associated with the Metzner Award will be presented to Schroeder in Pasadena in February 2013.

The *SOR Early Career Award*, established in 2009, is named for Art Metzner, distinguished rheologist, university professor, editor of the *Journal of Rheology*, and Bingham medalist.

Profile by Faith Morrison and Charles Zukoski

JOURNAL OF RHEOLOGY

A New Editor for the *Journal of Rheology*

There have only been eight editors of the *Journal of Rheology* (including the editors of its predecessor publication, the *Transactions of the Society of Rheology*) since its inception. In late 2011, Ralph Colby became the 9th. Colby, Professor of Materials Science and Engineering and Chemical Engineering at Pennsylvania State University, USA, is one of the top theoretical rheologists, as well as one of the top experimental polymer rheologists in the world. In 2012, Colby was selected to receive the Bingham Medal of the Society of Rheology (see profile, page 4).

When the 8th *JOR* Editor John Brady indicated that he was interested in stepping down as Editor, the SOR Executive Committee pulled together a team of three eminent rheologists to do a thorough search for a new Editor. Several candidates were interviewed and carefully vetted to be sure that the candidate had the proper skill set and demeanor to be *JOR* Editor. The job of *JOR* Editor involves a great deal of classic publishing work, but, thankfully, computer software has taken care of much of the old, hands-on work. Remaining to the job is the task of reading all submissions, finding appropriate reviewers, corresponding with authors, deciding go/no-go, and following up on all the details of the process. The *JOR* Editor is also a voting member of the SOR Executive Committee, and thus, an additional charge is the stewardship of all things publishing for the Society. The Editor is also responsible for the process for selecting the recipients of the *JOR Publication Award*.

New Editor Colby has hit the ground running, and with the help and cooperation of outgoing Editor Brady, the transition has been seamless. The *Bulletin* sat down with the Ralph Colby (well, had an email exchange and a few chats, in any case), and here we bring you some insights from the new Editor.

Rheology Bulletin: What do you think is the role of the *Journal of Rheology*?

JOR Editor Colby: I see *JOR* as the top journal in the rheology field. In less than a year as Editor it is already clear that all the top people in the field are submitting there.

RB: What is the impact of electronic publishing on the *JOR*?

JOR: If you elaborate on this question I might answer - what are you driving at?

RB: Well, all around us books are under assault—Amazon sold more e-books than physical books last year. Schools are asking students to buy tablet PCs or iPads to use instead of carrying text books. We have both a physical journal and an electronic journal. Do you see that continuing? Do you see the paper going away? Do you see any other issues that the *Journal* may face due to the current trends in electronic publishing?

JOR: We certainly live in changing times and you are correct that publications are going to shift format in the near future. The Society of Rheology was very astute in choosing AIP as its publisher, as they keep production costs low, enabling us to mail each issue of *JOR* to the SOR membership. Since those costs are so low compared with competing journals, I do not forsee any changes on the horizon regarding printing and mailing of *JOR*. However, all AIP journals shall change format later this year, with graphics in the Table of Contents being one of the changes. We also plan to have a full color graphic on the cover of each issue in the not-so-distant future.

RB: What is the Editor's role at the *Journal*?

JOR: The Editor's role is to ensure that the submitted paper gets serious review, with multiple experts giving insights that make the published paper far stronger. Sometimes this process is slow but hopefully always worth waiting for.

RB: What feedback do you want from JOR readers and/or SOR members?

JOR: Good question - I guess I welcome any feedback, but so far I mostly get feedback when the review is slow or my decision is not popular...

Malvern

www.malvern.com/kinexus

THE BIG IDEA IN RHEOLOGY

We haven't just redesigned a rheometer.

We've redefined the way it interacts with you.

kinexus®

More rheology, less effort

84th Annual Meeting of The Society of Rheology: 10-14 February 2013 Pasadena, CA USA

It is an International Congress year, and the Society of Rheology will therefore hold is 2012 meeting in February 2013. The 84th Annual Meeting of the Society of Rheology is scheduled for 10-14 February 2013 in Pasadena, California, and your hosts are John Brady, Andy Kraynik, Julie Kornfield and Maram Sepehr.

photo credit: Greg Asbury

The Technical Program for Pasadena is printed in this *Bulletin*. Abstracts may be submitted through the Society's web site from late July until 12 October 2012. Abstracts for poster presentations may be submitted through 7 December 2012.

Also in Pasadena, the Society will sponsor a two-day short course titled "Microfluidics and its Application" (Instructors: Anubhav Tripathi, Charles Schroeder, and Annie Colin). Details will be on the website.

All photos courtesy of the Pasadena Convention & Visitors Bureau. Clockwise from lower left, Caltech, Pasadena Library, a cafe in old Pasadena, and Van Gogh's "The Mulberry Tree" from the Norton Simon Museum.

All sessions will be held at the Pasadena Convention Center, which connects to the Paseo Colorado, Pasadena's three-block, open-air urban village. The 65 retail shops and restaurants of the Paseo Colorado have something for everyone. The banquet will be held on Tuesday night at the Athenaeum at Caltech. Also in Pasadena are the Huntington

PASADENA Convention & Visitors Bureau VisitPasadena.com

Library, Art Collections and Botanical Gardens, which include rare collections and an authentic Japanese Garden. Nearby is the Norton Simon Museum, home to a world-class art collection, and the Gamble House, a significant example of American Arts & Crafts architecture. Hotel room blocks for attendees have been arranged at five hotels within walking distance of the Convention Center.

The weather in Pasadena in February is an average high temperature of 70°F(21C) and an average low temperature of 45°F (7C) with average February rainfall of 3.9 inches. It will be a great place to get away to. Information about getting to Pasadena and other details of the meeting will appear on the Society's website later in the year.

John F. Brady
Local Arrangements Chair
Chemical Engineering, 210-41
California Institute of Technology
1200 E. California Blvd.
Pasadena, CA 91125 USA
Phone: 626-395-4183
email: jfbrady@caltech.edu

Technical Program 84th Annual SOR Meeting February 2013 Pasadena California USA

Program Co-Chairs

Shelley Anna
Carnegie Mellon University
Department of Chemical Engineering
Department of Mechanical Engineering
5000 Forbes Avenue
Pittsburgh, PA 15217
(412) 268-6492
sanna@cmu.edu

Carlos Rinaldi
J. Crayton Pruitt Family Department of Biomedical Engineering
Department of Chemical Engineering
University of Florida
Gainesville, FL 32611
(352) 273-9222
carlos.rinaldi@bme.ufl.edu

Technical Sessions:

1) Suspensions and Colloids
2) Polymer Solutions and Melts
3) Blends and Composites
4) Solids and Glasses
5) Emulsions, Foams and Interfacial Rheology
6) Self-Assembling, Associating and Gel-Like Systems
7) Electric and Magnetic Field Effects in Rheology
8) Rheology in Biological Systems
9) Poster Session

Plenary Lectures:

Ralph H. Colby (2012 Bingham Medalist, Materials Science and Engineering, Penn State University)

Michael D. Graham (Dept. of Chemical and Biological Engineering, University of Wisconsin-Madison)

Charles F. Zukoski (Dept. of Chemical and Biological Engineering, University of Buffalo)

A list of session chairs will appear on the Society website, www.rheology.org, in late Summer 2012.

The deadline for submission of abstracts for oral presentations is Friday, 12 October 2012.

The deadline for submission of abstracts for posters is Friday, 7 December 2012.

To submit a presentation or poster abstract, please visit the Society website, www.rheology.org, after July 2012.

A report on "LAOS Rheology Day," held Friday the 13th at the Colburn Laboratory, University of Delaware

Contributing authors: R.H. Ewoldt,[1] A.K. Gurnon,[2] C. López-Barrón,[2,3] G.H. McKinley,[4] J. Swan,[2] and N.J. Wagner[2*]

[*]Corresponding author: wagnernj@udel.edu

Author Affiliations:
[1]Department of Mechanical Science and Engineering, University of Illinois Urbana-Champaign, Urbana, IL 61801, USA
[2]Center for Molecular and Engineering Thermodynamics, Center for Neutron Science, Department of Chemical and Biomolecular Engineering, University of Delaware, Newark, DE 19716
[3]ExxonMobil Chemical Company, 5200 Bayway Drive, Baytown, Texas, 77520, USA
[4]Mechanical Engineering, Massachusetts Institute of Technology, Cambridge, MA 021309, USA

Participants in the *LAOS* (large amplitude oscillatory shear) *Rheology Day* gathered in Colburn Laboratory at the University of Delaware from around the U.S. to discuss recent advances in the use of large amplitude oscillatory shear to interrogate material properties. The participants included many industrial scientists from DOW, DuPont, ExxonMobil and TA Instruments as well as students and faculty from four institutions. Talks focused on three broad classes of materials — shear thickening colloidal dispersions, shear ordering and melting of block copolymer micelles, and shear banding wormlike micelles — as well as new advances in LAOS rheometry, including: large amplitude microrheology, time resolved SANS (small angle neutron scattering) measurements of microstructure during LAOS, flow velocimetry during LAOS, and stress- versus strain-controlled LAOS measurements. New theoretical predictions for shear banding wormlike micelles, yield stress fluids, and active microrheology of colloidal dispersions were also presented and discussed. The talks were followed by lively discussion, and the following summarizes some of the key outcomes of these discussions that may be of value to the community. Support for this activity from the Department of Chemical and

Figure 1a. Speakers (S) and Organizers (O). From left to right: Jim Swan (S, UD), Gareth McKinley (O, MIT), Chris Dimitriou (S, MIT), Carlos López-Barrón (S, ExxonMobil), Randy Ewoldt (S, UIUC), Kate Gurnon (S, UD), Thomas Ober (S, MIT), Lin Zhou (S, CUNY), Pam Cook (O, UD), Norm Wagner (O, UD).

Figure 1b. A composite view of the participates in the seminar room.

Discover
the
New

HYBRID RHEOMETER

TA has combined powerful technology from the ARES-G2 with the core of our best selling AR products. Add in patented and patent-pending new technologies, and we've created the world's most powerful rheometer platform.

TA

www.tainstruments.com

Biomolecular Engineering and the Center for Molecular and Engineering Thermodynamics at the University of Delaware is gratefully acknowledged.

Summary of Presentations

Three speakers from the University of Delaware: James Swan, Kate Gurnon and Carlos López-Barrón, presented work focused on the development of unsteady, non-equilibrium microstructure in materials deformed under LAOS. Swan described a micro-mechanical model solution of the Smoluchowski equation for a dilute colloidal dispersion deformed by an oscillating micro-rheological probe. The key result of the modeling is that, in contrast to entangled polymer solutions and melts, for colloidal dispersions the hydrodynamic interactions play an important role in determining both the suspension microstructure and the stress response of the dispersion during LAOS. Gurnon and López-Barrón presented results of time resolved oscillatory rheology and small angle neutron scattering (*tOrSANS*) experiments conducted on concentrated colloidal dispersions and solutions of worm-like micelles, respectively. This new technique and a versatile apparatus available for use are explained briefly in the sidebar (p17, top). In Gurnon's case, the resulting flow curves were compared to an analytical solution of the Giesekus model for the stress response of a non-linear viscoelastic material. From this comparison, she concluded that stress resulting from the hydrodynamic interactions among the particles (neglected in the Giesekus model) play a crucial role in the LAOS response. Shear thickening was also evident in the LAOS stress response and in the corresponding microstructure. Thus, both theory and experiment elucidate an important and fundamental difference between the LAOS response of viscoelastic solutions and colloidal dispersions, a topic to be further discussed at the ICR in August. Continuing this theme, López-Barrón observed the intra-cycle organization and melting of structures in block copolymer micellar solutions in ionic liquids. This is evident in the neutron scattering spectra, which enable the creation of "Structure-Lissajous plots" showing the degree of order as a function of the applied strain and strain rate (see second side bar, p17 bottom). When fluidized by shearing well beyond the yield strain, the complex viscosity of the solutions matched that measured in steady shear, confirming the so-called *Delaware-Rutgers* rule [López-Barrón *et al.*, *2012*]. For the case of worm-like micellar solutions, López-Barrón observed cyclic alignment and disordering of the micelles within a cycle of oscillation. The maximum alignment occurs at the peak in strain rate.

Advances in constitutive equation modeling of shear-banding fluids under steady shear and LAOS were presented by Lin Zhou from the New York City College of Technology, CUNY working with Pam Cook of the University of Delaware. In particular, she compared several modern microstructurally-motivated constitutive models for entangled, worm-like micellar solutions (VCM, PEC, PEC+M, *etc*.) and their sensitivity to various flow conditions in the Couette geometry. Zhou observed the formation of two and three shear bands depending on the constitutive model as well as pronounced elastic recoil in many cases.

Shear banding solutions under LAOS deformation have both time and spatially dependent velocity fields, requiring the development of advanced experimental methods for properly determining the deformation field. This was addressed by Thomas Ober and Chris Dimitriou from the McKinley group at the Massachusetts Institute of Technology. Ober presented a new apparatus for performing flow velocimetry studies of non-linear viscoelastic materials. A laser light sheet is directed into the gap of a cone and plate rheometer through a window at its edge. Scattering from tracer particles, which are dispersed in the material, is collected by imaging a thin focal region illuminated by the laser. This enabled study of the development and evolution of the shear bands formed in worm-like micellar fluids deformed by LAOS. Dimitriou presented a rheological study of Carbopol microgel, a model yielding, elasto-viscoplatic material. He determined that imposing large amplitude, oscillatory stress (which may be termed *LAOStress*) rather than the corresponding strain-controlled protocol (*LAOStrain*) provided the most revealing probe of such materials.

Randy Ewoldt from the University of Illinois, Urbana-Champaign, gave the final presentation of the session in which he discussed the differences between stress and strain control in the context of large amplitude oscillatory deformation. He posed a number of intriguing questions. Which is better, stress or strain control, for characterizing particular materials? What measures of non-linearity analogous to those in "New measures for characterizing nonlinear viscoelasticity in large amplitude oscillatory shear," [Ewoldt *et al.*, 2008] might be obtained from a large, imposed oscillatory stress? What additional material properties may be inferred by comparison of stress- and strain-controlled deformation?

Summary of Discussion

The discussions following the presentations were animated. Two significant topics of discussion are summarized here: (1) the definition of the material coefficients in a stress-controlled LAOS experiment, (2) the definition and organization of the rheological space probed by LAOS.

(1) "To stress or to strain?" - that is the question.

During his presentation, Ewoldt raised the issue that the definitions of higher harmonic Fourier coefficients in LAOS are currently ambiguous. Specifically, the signs of the 3rd, 7th, 11th, etc. harmonics change depending on the seemingly arbitrary choice of representing an oscillatory input as either a sine or cosine in the time

domain. While this arbitrary choice does *not* affect the definitions of first-harmonic coefficients, e.g. J_1' and J_1'' (and therefore linear viscoelastic measures are not affected), it does affect the definitions of the third-harmonic measures such as J_3' and J_3''. This current ambiguity therefore obfuscates any attempt to interpret the meaning of the signs of higher-harmonic *Fourier* coefficients. This has consequences for the theoretical underpinnings and definitions of material measures for both strain-control and stress-control LAOS. Work on strain-control LAOS seems to follow a typical convention, representing the shear strain input as a sine wave, $\gamma(t)=\gamma_0 \sin\omega t$. However in stress-controlled LAOS there is not yet a standard convention.

A resolution was proposed, in two parts. First, although the time-domain *Fourier* coefficients are ambiguous, the deformation-domain *Chebyshev* coefficients are clearly defined and immune to this ambiguity. Chebyshev coefficients are based on orthogonal polynomials in the deformation-domain (i.e. the stress is expressed as a direct function of strain and strain-rate) [Ewoldt *et al.*, 2008], and as a consequence, the coefficients are independent of the time-domain representation of the input as sine or cosine. Second, it was proposed that the current convention for strain-controlled LAOS should be maintained as $\gamma(t)=\gamma_0 \sin\omega t$, and for stress-control LAOS the cosine basis should be used, $\sigma(t)=\sigma_0 \cos\omega t$. Although a sine representation for stress may be more natural experimentally (in order to start with zero imposed stress at time $t = 0$), it was noted that this zero-time reference is arbitrary when analyzing steady-state periodic oscillations in LAOS. The main advantage to the cosine representation is to keep the notation clean and more intuitive and to eliminate the need to include several negative signs within the definitions. Immediate discussion ensued with other participants at the symposium, and after thoughtful exchanges, a consensus formed around these suggested conventions. The mathematical details behind the Fourier coefficient ambiguity have important consequences for data processing of LAOS signals, as well as for the fundamental definitions of higher-harmonic material functions in LAOS.

(2) The mountains flowed -- Deborah, Péclet, Weissenberg, *et al.*

LAOS is a unique rheological probe because of the ability to impose a simple shear deformation with two independent time scales derived from the peak rate of strain of the flow, $t_s \sim \dot{\gamma}_0^{-1}$, and the frequency of oscillation, $t_0 \sim \omega^{-1}$ [Dealy, *Rheol. Bull.*, July 2010]. The ratio of the two time scales defines the maximum strain amplitude in a cycle: $\gamma_0 = t_0/t_s$. These time scales, in conjunction with a material's own spectrum of internal relaxation times, define a number of dimensionless groups. What are those numbers, in which limits do they relate to familiar flow regimes, and what insight is gained through their interpretation? This was a topic of a lively discussion that is summarized as follows.

The linear response regime is delineated by the region of phase space (t_s, t_0) in which the rheological properties of a material are insensitive to changes in t_s. The shear stress is linear in the rate of strain, and variation in the flow curves is driven by competition between material relaxation processes and the oscillation of the imposed flow. When, for instance, the stress response can be described as that of a single-mode Maxwell material (a spring of stiffness G in series with a dashpot of viscosity η), the material's internal relaxation mechanism is characterized by the time scale $\lambda=\eta/G$. The ratio of this time scale to the period of oscillation defines the Deborah number,

$$De=\lambda/t_0=\eta\omega/G$$

The period of oscillation takes on the role, "time of observation," which is classically used to define the Deborah number. Fittingly, the transition from principally elastic to principally viscous behavior is given by De approximately equal to 1.

For polymeric materials, the modes of internal relaxation (of which there may be many) may not be known *a priori*. Comparison and fitting of viscoelastic models is typically used to determine the appropriate time scale (or scales), t_i. In colloidal dispersions, stress relaxation is affected by diffusion of the colloids themselves. The characteristic internal relaxation time is taken to be a length scale squared divided by a characteristic colloidal diffusivity: $\lambda=a^2/D$. In this case a dimensionless group is defined:

$$\alpha=\lambda/t_0=a^2\omega/D$$

While homologous to the Deborah number, α depends on the choice of the length scale (particle size, inter-particle spacing, *etc*.) and diffusivity (short-time, long-time, self, collective, *etc*.). A particular choice is appropriate when $\alpha \sim 1$ corresponds to a key feature in frequency response of the suspension. This is the mechanical spectroscopic nature of linear response theory.

The steadily imposed deformation of materials is probed when the period of oscillation exceeds all other time scales $t_0 >> t_s, \lambda$. The flow is at most *slowly* varying in time. Here, flow curves are characterized by the ratio,

$$Wi=Pe=\lambda/t_s$$

The same distinction between polymeric and colloidal materials holds here. This ratio is called the Weissenberg number, Wi, in the polymer rheology community and the Péclet number, Pe, among colloid scientists.

The linear response regime is defined by the limit $Wi, Pe \rightarrow 0$, while the steady flow regime is one in which $De, \alpha \rightarrow 0$. Under LAOS then, there are three characteristic dimensionless groups: the maximum

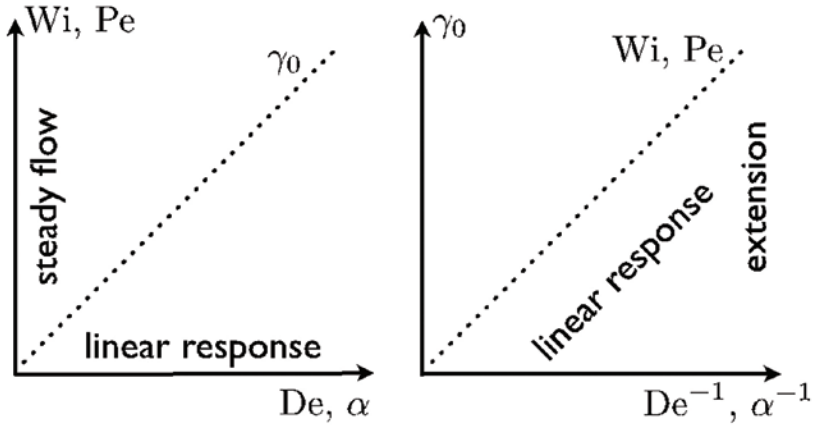


Figure 2: Two projections of the three dependent dimensionless groups: maximum strain amplitude, γ_0; Weissenberg, Wi, or Péclet, Pe numbers; and Deborah number, De, or α. The dotted lines along the diagonals indicate a path along which the denoted dimensionless group is constant. In the first projection, appropriate for viscous materials, regions corresponding to steady flow and linear response run parallel to axes with zero frequency and varying peak rate of strain, or zero peak rate of strain and varying frequency, respectively. In the second, appropriate for elastic materials, the region corresponding to rate-independent extension resides at small frequencies. The region of linear response lies below a diagonal denoting a peak rate of strain well below the characteristic relaxation frequency of the material.

strain amplitude, γ_0; De or α; and Wi or Pe. However, because there are only two independently imposed time scales, one of these dimensionless groups is auxiliary, for example

$$\gamma_0 = \mathrm{Wi}/\mathrm{De} = \mathrm{Pe}/\alpha$$

Therefore, the optimally designed LAOS experiment requires careful consideration of the relevant physics governing the stress response of the material. For instance, should we vary Wi and De independently in a material most sensitive to the maximum strain amplitude? Two revealing projections onto this three parameter domain are depicted in Figure 2. Here equivalent linear variation in the peak rate of strain and oscillation frequency leads to experiments with fixed maximum strain amplitude. Similarly, linear variation in the maximum strain amplitude and inverse oscillation frequency leads to experiments with fixed peak rate of strain. For rheologically-complex materials that are primarily viscous in nature (*e.g.* colloidal dispersions below the glass transition), the former projection may be preferable as the coordinate axes (vertical: $\dot{\gamma}_0$ or Wi or Pe, horizontal: ω or De or α) represent the realms of steady flow and linear response respectively. For materials with a prominent elastic response, the latter projection (vertical: γ_0, horizontal: ω^{-1} or De^{-1} or α^{-1}) represents defined, rate independent, extension on the far right and at low frequencies. Linear response is a region bounded by the diagonal along which the peak rate of strain is faster than the characteristic relaxation time of the material. Note that these phase spaces complement the traditional Pipkin phase space, (γ_0 vs. ω). However, unlike these projections, lines through the origin do not denote simple boundaries in Pipkin space. Figure 2 was developed as a succinct expression of the rheological space probed by LAOS that can aid in designing and interpreting LAOS experiments as well as facilitate comparison to theory.

Attendees enthusiastically supported the LAOS symposium and the lively discussion and debates during and following the presentations and discussions highlighted the excitement surrounding the LAOS technique. The value of bringing together experimentalists and theorists to identify and address the most pressing issues was most apparent, and there will be significant follow-up to this at the International Congress of Rheology in Portugal in August.

References

Anton Paar, "RheoOptics- Rheo-SANS/SAXS Small-Angle Neutron or X-ray Scattering". www.anton-paar.com/RheoOptics-Rheo-SANS-SAXS-Small-Angle-Neutron-or-X-ray-Scattering/Rheometer/60_Corporate_en?product_id=286. - Downloads,Manuals (2012).

Berret, J.F., Porte, G., and Decruppe, J.P., "Inhomogeneous shear rows of wormlike micelles: A master dynamic phase diagram". **Physical Review E**. 55(2): p. 1668-1676 (1997).

Butera, R.J., Wolfe, M.S., Bender, J., and Wagner, N.J., "Formation of a highly ordered colloidal microstructure upon flow cessation from high shear rates". **Physical Review Letters**. 77(10): p. 2117-2120 (1996).

Eberle, A.P.R. and Porcar, L., "Flow-SANS and Rheo-SANS applied to soft matter". **Current Opinion in Colloid and Interface Science**. 17(1): p. 33-43 (2012).

Ewoldt, R.H., Hosoi, A.E., and McKinley, G.H., "New measures for characterizing nonlinear viscoelasticity in large amplitude oscillatory shear". **Journal of Rheology**. 52(6): p. 1427-1458 (2008).

Ewoldt, R.H. and McKinley, G.H., "On secondary loops in LAOS via self-intersection of Lissajous-Bowditch curves". **Rheologica Acta**. 49(2): p. 213-219 (2010).

Giacomin, A.J., Bird, R.B., Johnson, L.M., and Mix, A.W., "Large-amplitude oscillatory shear flow from the corotational Maxwell model". **Journal of Non-Newtonian Fluid Mechanics**. 166(19-20): p. 1081-1099 (2011).

Liberatore, M.W., Nettesheim, F., Wagner, N.J., and Porcar, L., "Spatially resolved small-angle neutron scattering in the 1-2 plane: A study of shear-induced phase-separating wormlike micelles". **Physical Review E**. 73(2): p. 020504 (2006).

López-Barrón, C.R., Porcar, L., Eberle, A.P.R., and Wagner, N.J.,

(Continues page 25)

tOrSANS: Measurement of atomic to mesoscopic microstructure simultaneous with rheology under LAOS

Rheologists are constantly challenged to elucidate the microstructural origins of the nonlinearities inherent in viscoelastic materials. Of specific interest here are the time-dependent microstructural changes for materials undergoing large amplitude oscillatory shear (LAOS). During the recent LAOS Symposium at UD, we introduced a novel technique to measure those microstructural changes of a material undergoing LAOS using small angle neutron scattering (SANS). Highlighted in this *Bulletin* are the first measurements using the time-resolved oscillatory rheo-Small Angle Neutron Scattering technique (*tOrSANS*), an instrument constructed for the SANS diffractometer D22 at the Institute Laue-Langevin (Grenoble, France) in conjunction with Lionel Porcar (ILL) and Aaron Eberle (NIST, now ExxonMobil). These geometries are currently available for use at the National Center for Neutron Research at NIST as well as at the Institute Laue Langevin, Grenoble. More information can be found at the Center for Neutron Research at UD (www.cns.che.udel.edu) or the Neutron Scattering Society of America's web site (www.neutronscattering.org).

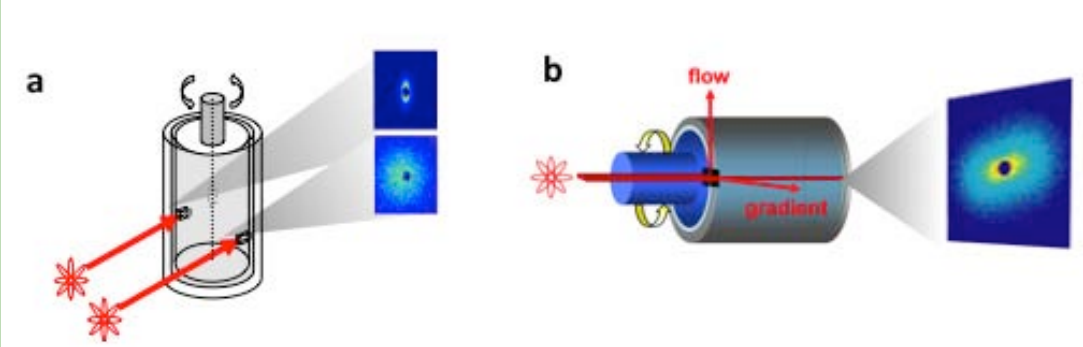


Figure 3. a) Geometry for *tOr-SANS* experiments in the 1,3 and 2,3 planes of flow and b) new geometry that directly probes the shear plane (1,2 plane of flow) (adapted from Helgeson et al. "Neutron transmission measurements of concentration profiles in non-homogeneous shear flows," 2010 Annual Report, NIST Center for Neutron Research, Gaithersburg, MD. p. 38-39, 2010).

The shear rheology is measured via a stress-controlled rheometer (Anton Paar MCR 501) outfitted with a custom-made quartz Couette geometry enabling simultaneous probing by neutrons (quartz is nearly invisible to neutrons) [Anton Paar, 2012]. Two planes of shear may be investigated using the Couette geometry configuration (Figure 3a).

(Continues page 18)

Viewing rheological data from LAOS experiments

There are thus a number of complementary and inter-connected ways to view the rheological information extracted from a LAOS experiment. These can be summarized graphically as shown in Figure 5. One may represent the sinusoidal input and associated linear (or nonlinear) output as time series (as shown in Figure 5(a). Alternatively by choosing a set of orthogonal basis functions (e.g. such as the Fourier series or Chebyshev polynomials T_n) one can quantify the spectral content of the nonlinear output signal as shown in Figure 5(b). When the output stress is decomposed into elastic and viscous components,

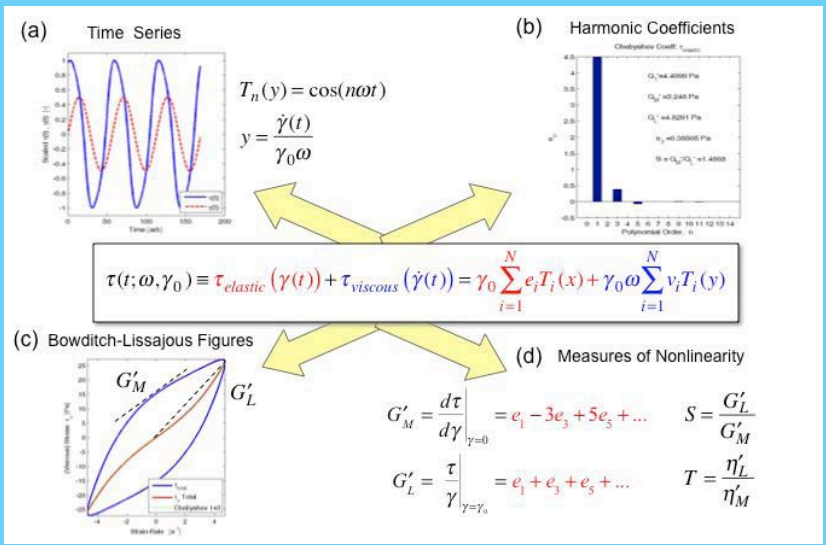


Figure 5. Various methods for plotting LAOS rheometry data.

(Continues page 27)

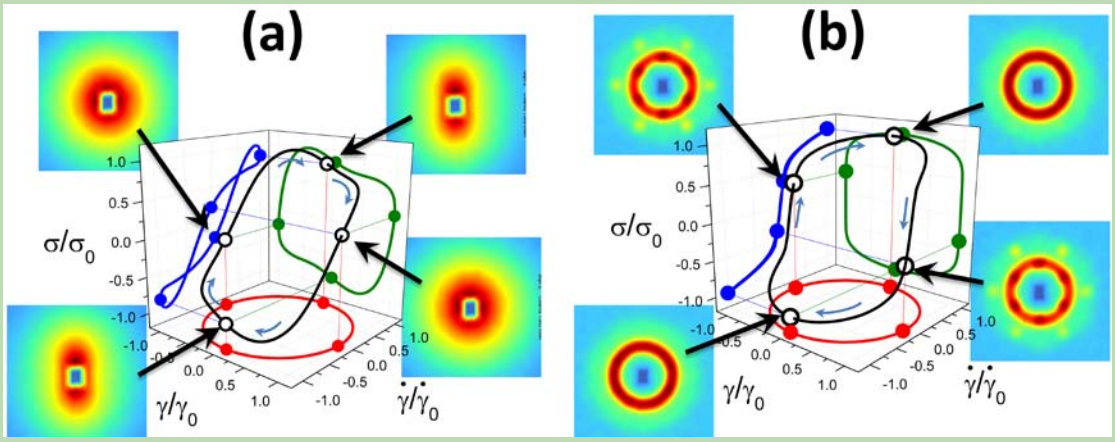


Figure 4. Stress response and SANS profiles during LAOS of (a) a 6 wt% aqueous solution of CPCl/NaSal, with molar ratio [NaSal]/[CPCl]= 0.5 at 25 °C ($\omega = 0.56$ rad/s and $\gamma_0 = 10$) and (b) a 24 wt% Pluronic F127/EAN solution at 40 °C ($\omega = 1$ rad/s and $\gamma_0 = 100$). The arrows indicate the direction of oscillation.

The neutron beam may be configured to travel along the velocity-gradient direction, thereby interrogating the flow-vorticity (1-3) plane of shear (this orientation is also known as "normal" or "radial"). Alternatively, the neutron beam is collimated into a thin slit and aligned parallel to the flow direction (also known as "tangential") thereby investigating the gradient-vorticity (2-3) plane. This instrument for examining complex fluids under steady shear has been recently documented by Porcar *et al.* [2011]. The recent review by [Eberle and Porcar, 2012] describes the use of this and related devices for structure-property determination across a broad range of materials and applications. What is new here? The *tOrSANS* technique allows one to interrogate materials while making dynamic oscillatory measurements. It requires the synchronization of the time-resolved mechanical deformation of the oscillation cycle and the time-resolved neutron detection, thus enabling real-time measurements of structure and rheology.

Time-resolved scattering methods rely on time binning the detector output into several memory modules [Butera *et al.*, 1996; Porcar *et al.*, 2004]. For LAOS this binning is done over an oscillation cycle. The technique can track microstructure changes occurring at frequencies ≤ 10Hz with time bins on the order of tens of milliseconds in length. This corresponds to 30-60+ bins per cycle. The measurement is repeated over many oscillation cycles (100-1000+ cycles) to achieve adequate statistics for SANS analysis. A prerequisite for choosing a material to interrogate with this technique is that it behaves the same for each subsequent oscillation cycle — in other words, the oscillatory stress response achieves an *alternance* state [Giacomin *et al.*, 2011]. Successful implementation of this technique to capture the changes in microstructure of a material during LAOS relies on careful synchronization of the oscillation period, binning time length and the number of repeated cycles, all of which depend upon the material under investigation.

Two samples were interrogated in the 1-3 plane using *tOr-SANS*: a wormlike micellar solution (WLM) and a polymeric micellar crystal. Figure 4a shows the three-dimensional representation of the Lissajous curves depicting the stress response during LAOS as a function of strain and strain rate for an aqueous solution of 6% cetylpyridinium chloride (CPCl)/sodium salicylate (NaSal) in 0.5M NaCl/D_2O. This model WLM has been extensively studied during steady shear by [Berret *et al.*, 1997; Rehage and Hoffmann, 1988; Rehage and Hoffmann, 1991] and many others. Also shown at indicated points are the SANS spectra obtained in the 1-3 plane (normal orientation). An isotropic pattern indicates no flow-induced orientation, such as would be observed at rest, whereas a highly oriented pattern indicates strong flow orientation. As observed, the points of highest shear rate correspond to highest orientation during the oscillation cycle, whereas the points of zero shear (and nearly zero stress) correspond to nearly un-oriented WLMs. The degree of orientation can be quantified from the pattern, structure-property relationships created, and this can be used to test constitutive models derived from microstructure.

Of particular interest are the secondary loops in the stress-strain rate projection of the Lissajous curves for WLM during LAOS. Ewoldt and McKinley [2010] attributed these secondary loops to a stress overshoot, a phenomenon commonly observed during the startup of flow of polymer solutions. Using *tOrSANS* in the 1-3 plane of shear, the microstructure is shown to transition from a highly entangled state of micelles (isotropic scattering profile) to an aligned state of the WLM (anisotropic profile). A further adaption of the *tOrSANS* method to flow start up was also performed (not shown here) to further investigate the relationship between these curious secondary loops in the Lissajous stress curve as a result of the transition between the highly

(Continues page 27)

Why did the mountains do anything at all?

To the Editor:

In the January 2011 Bulletin[1], Morton Denn offered a complete, and informative, discussion of the translation of Judges 5:5, but the issue to me is not whether the mountains quaked or flowed or melted; rather, why did the mountains do anything at all? Markus Reiner wrote[2]

> "*[Deborah knew] that the mountains flow, as everything flows. But, secondly, that they flowed before the Lord, and not before man, for the simple reason that man in his short lifetime cannot see them flowing, while the time of observation of God is infinite.*"

Reiner suggests that mountains, i.e. solids, flow not on a mortal time scale but on a divine time scale. Though it is correct to say solids have (astronomically) large viscosity, Judges 5:4-5 is talking about mountains flowing or quaking in real time, that is, on a mortal time scale:

> "*O Lord, when You came forth from Seir,*
> *Advanced from the country of Edom,*
> *The earth trembled;*
> *The heavens dripped,*
> *Yea, the clouds dripped water,*
> *The mountains quaked—*
> *Before the Lord…*"[4]

The references to Seir and Edom recall the Israelites' passage through those regions as they were escaping Egypt (see Numbers 19-24 or Deuteronomy and [5]). The references also recall the giving of Torah to many nations before the Israelites accepted it at Mt. Sinai[6, 7]. Be it references to the Israelites' travels or references to the moment the Israelites accepted God's word, that is, the commandments, the mountains flowed or quaked or melted in real time, mortal time; the mountains were not intended, in Judges 5:4-5, to flow in God's time. Thus, Reiner's original statement in [2] was an incorrect interpretation.

I think this example of misinterpretation can offer some insight to our field. The aim of rheology is to understand the molecular and micro-/macroscale structures inherent to materials and the functions those structures serve. As our standard tool, we have the humble rheometer: a machine that exists on the macroscale but allows an investigator to make claims about the micro-/nanoscale[8,9]. Unfortunately, and in spite of the work of many talented and intelligent people, the noble aim of rheology is one that puts its purveyors in a precarious position.

There are perils of misinterpretation for those using rheological techniques as nothing more than a tool, a means to an end. For instance, looking through food-related journals one will find researchers using machines like the Texture Analyzer to investigate the rheological properties of non-Newtonian fluids and then making conclusions based on their, indiscriminate, use of viscosity. There are also papers detailing the use of a cone-and-plate (CP) system for highly structured fluids and suspensions. Yes, the CP is a preferred tool in rheology because it provides a single (instead of variable) shear rate across the gap. However, highly structured fluids and suspensions will show confinement effects at the gap necessary for CP. Errors of interpretation creep into reports of rheological measurements due to insufficient attention to the context of the measurement.

I have the impression that the problem identified above results from too little attention being given to the historical development of the field; brevity seems to have been chosen over a more thorough discussion of how current techniques and tools were built from prior knowledge. Reiner (and H.A. Barnes) had (have) great respect for the historical perspective. Reiner's book[10] is filled with examples where he re-examines the historical knowledge underpinning current knowledge. What Reiner did well was to start at the beginning and work forward. This same approach will best serve the entire field of rheology given the fever pace of advancements.

Michael W. Boehm
The University of Queensland

References:

[1] M. Denn, "Just what did Deborah say?," *Rheology Bulletin*, vol. 80, January 2011.
[2] M. Reiner, "The Deborah Number," *Physics Today*, vol. 17, 1964.
[3] C. W. Macosko, *Rheology: Principles, Measurements, and Applications*. New York: VCH, 1994.
[4] D. L. Lieber, J. Harlow, Rabbinical Assembly, and United Synagogue of Conservative Judaism., Etz Hayim = [Ets *Hayim]: *Torah and Commentary*, Travel-size ed. Philadelphia: Jewish Publication Society, 2004.
[5] T. F. McDaniel. (2003, *The Song of Deborah: Poetry in Dialect*. Available: tmcdaniel.palmerseminary.edu/Deborah.pdf
[6] R. S. Yerushalmi, *The Torah Anthology The Book of Shoftim*. Jerusalem: Moznaim Publishing Corporation, 1991.
[7] R. M. Weissman, *The Midrash says on The Weekly Haftaros* vol. 2. Brooklyn: Benei Yakov Publications, 1993.
[8] C. Clasen, H. P. Kavehpour, and G. H. McKinley, "Bridging tribology and microrheology of thin films," *Applied Rheology*, vol. 20, 2010.
[9] G. A. Davies and J. R. Stokes, "Thin film and high shear rheology of multiphase complex fluids," *Journal of Non-Newtonian Fluid Mechanics*, vol. 148, pp. 73-87, Jan 2008.
[10] M. Reiner, Deformation, Strain and Flow: an *Elementary Introduction to Rheology*, 3rd ed. London,: H. K. Lewis, 1969.

Society Business

NEWS

ICR2012 Lisbon this Summer

The 16th International Congress on Rheology takes place in Lisbon, Portugal 5-10 August 2012. Details and registration materials for ICR2012 may be found on the conference website www.rheology-esr.net/ICR2012/. The co-chairs of ICR2012 are João Maia (shown here), Igor Emri, and Crispulo Gallegos.

ICR2012 Lisbon Travel Grants Awarded

The SOR is supporting student travel to the ICR through its *Student Meeting Travel Grant Program*, administered this year by SOR ExCom member-at-large Norm Wagner. A total of 36 students received grants in 2012 paying for six nights in a conference hotel for students. These students and their advisors are members of the SOR in order to qualify for the awards. The award recipients are predominantly from the U.S., but there are also recipients from Canada, Brazil, the E.U. and India. In addition to helping students attend the International Congress, this program also attract students to join the Society. The SOR's *Student Meeting Travel Grant Program* continues to grow in popularity and helps ensure continued interest in the rheological sciences among young scientists and engineers.

TA Instruments Introduces Distinguished Young Rheologist Award

In 2012 TA Instruments introduced a new award to honor an academic rheologist early in his/her career. The first recipient of this award is Matthew E. Helgeson, Assistant Professor in the Chemical Engineering Department of the University of California, Santa Barbara USA. Recipients of the *TA Distinguished Young Rheologist Award* are peer nominated by a group of established and respected academic researchers in the field of rheology.

The TA Award is designed to help accelerate the research of new academics through equipment grants. "TA recognizes academia as a source of product innovation," comments Terry Kelly, President of TA Instruments. "The *Distinguished Young Rheologist Award* is our newest program in support of our vision to maintain our leading market position through strong partnerships with the academic community."

Nominations Invited for 2013 Awards

Nominations for the Society's highest honor, the *E. C. Bingham Medal*, should be submitted in January 2013 (final date to be announced in the January *Bulletin*). The Bingham Medal is awarded to a member of The Society who has made outstanding contributions to the field of rheology. Rules and guidelines governing the Award are on the web at www.rheology.org/sor/awards/bingham/.

Nominations for the *Arthur B. Metzner Early Career Award* should be submitted also in January 2013 (check the website for the exact date, when announced). The Metzner Award is given to a member of the Society who is younger than 35 (on January 15th of the year the award is to be given) and has distinguished him/herself in rheological research, rheological practice, or service

to rheology. The award consists of a plaque and a $7,500 honorarium. Rules and guidelines governing the Metzner Award are on the web at http://www.rheology.org/sor/awards/Metzner/.

Official Nomenclature Being Revised: Input Solicited

A committee has been appointed to revise and update the Official Nomenclature of the Society of Rheology. The members are John Dealy (Chair), Jeff Morris, Faith Morrison, and Dimitris Vlassopoulos. Members are invited to submit their suggestions for amendments and additions to the nomenclature. You can see the present nomenclature from the Society's web page. Please send your input to john.dealy@mcgill.ca or to another member of the committee. Your help is vitally needed.

Franklin D. Dexter (1918-2011)

Franklin D. Dexter, a former president of the Society of Rheology, passed away on 14 October 2011 at the age of 93. Dexter was born in 1918 in Omaha, Nebraska. He graduated from the University of Maine with a degree in Engineering Physics in 1941 and served as a Lieutenant in the U.S. Army during World War II, spending much of the war in New Guinea and the Philippines. After the war Dexter worked at Bakelite in Bound Brook, NJ (part of Union Carbide - later acquired by Dow Chemical) in the development lab. It was during that time that he was president of the Society of Rheology (1956-57). Dexter had various other positions with Union Carbide including serving as Managing Director of Union Carbide's British operations during the 1970's. He retired from Union Carbide in 1978 and was active in various professional and community activities for quite a few years after retirement. He is survived by his three sons, two daughter-in-laws, and three grandchildren.

2013 Nominating Committee to be Formed

The SOR will hold officer elections in 2013, and the Nominating Committee for those elections will be formed in late Fall 2012. The SOR Constitution provides for a three-member Nominating Committee to report its recommendations at least 145 days prior to the Annual Meeting, approximately 22 May 2013. Members interested in serving on the Nominating Committee should indicate their interest to a member of the SOR Executive Committee. International and industrial members are particularly encouraged to serve.

Benny D. Freeman Named Winner of Roy W. Tess Award in Coatings

Benny D. Freeman will receive the *Roy W. Tess Award in Coatings* for 2012. The announcement was made by the Officers and the Award Committee of the Division of Polymeric Materials: Science and Engineering (PMSE) of the American Chemical Society (ACS).

Freeman earned his Ph.D. in Chemical Engineering from the University of California, Berkeley. He was a NATO Postdoctoral Fellow for 2 years at the Ecole Supérieure de Physique et de Chimie Industrielles de la Ville de Paris (ESPCI). Freeman began his academic career at North Carolina State University in 1989. In 2002, Freeman moved to The University of Texas at Austin and is currently the Kenneth A. Kobe and Paul D. and Betty Robertson Meek and American Petrofina Foundation Centennial Professor of Chemical Engineering.

Freeman's research focuses on mass transport of small molecules in polymer coatings. He and his students and colleagues have studied structure/property relations for polymer based desalination as well as gas and vapor separation membrane coating materials, new polymer membrane materials for hydrogen separation and natural gas purification, polymer based barrier packaging materials and new polymer coatings for improving fouling resistance of liquid separation membranes.

Freeman will receive the *Tess Award* during the 244th National Meeting of the ACS in Philadelphia, PA.

The Tess Award is presented annually by PMSE in recognition of outstanding contributions to coatings science and technology.

From the Blogs

Sticky fingers (The Economist 1Nov2011, online)
www.economist.com/blogs/babbage/2011/11/rheology

"IF YOU have ever given a bottle of tomato ketchup a good shake to make it pour more easily, then you have experimented with rheology." So begins a blog posting at *The Economist* that announces a new rheometer developed by Julia Rees, Will Zimmerman and Hemaka Bandulasena of the University of Sheffield, U.K. The device interprets the flow through a microchannel with a corner and deduces the rheological properties. More information may be found at the website.

Minutes of the ExCom Meeting

Sunday, 22 April 2012
Rosemont, Illinois

Attending: Jeffrey Giacomin, Greg McKenna, Albert Co, Monty Shaw, Ralph Colby, Shelley Anna, Gareth McKinley, Norm Wagner, John Dealy, Anne M. Grillet, Chris White, Jeffrey Morris (via Skype), Robert Harrington (AIP), Bridget D'Amelio (AIP), Gerry Fuller, Andy Kraynik, John Brady (via phone), Wesley Burghardt, Don Baird, Marie-Claude Heuzey, Jason Maxey, Matthew Liberatore (via phone), Saad Khan.

President Jeffrey Giacomin called the meeting to order at 9:00 a.m. in Sky Harbor Room, Hyatt Regency O'Hare, Rosemont, Illinois.

The minutes of October 9, 2011 were read electronically by Secretary Albert Co. A motion to approve the minutes was passed.

Monty Shaw reported on the financial status of the Society and *JOR*. Shaw showed examples of documentations needed for expense reimbursement. Expenses of the Cleveland meeting were discussed. The meeting had a net loss of about $9,000. Subscription and usage of *JOR* were discussed. A motion to approve the treasurer report was passed.

Ralph Colby gave the *JOR* Editor report. Colby also reported for the Journal Publication Award Committee and their recommendation. The special issue on foam rheology with Andy Kraynik was doing well. Colby discussed his plans to improve review time and to revamp the editorial board. A new graphical cover and table of contents were suggested. A motion to approve the Editor report was passed.

John Dealy reported on the progress of the ad hoc Nomenclature Committee. A draft of the official symbols and nomenclature was distributed. A motion to approve the report was passed.

Anne Grillet reported for the Education Committee. In conjunction with the Pasadena (February 2013) meeting, a two-day short course titled "Microfluidics and Its Application" (Instructors: Anubhav Tripathi, Charles Schroeder, and Annie Colin) will be offered. For the Montreal (October 2013) meeting, the committee is considering a two-day short course on "Computational Rheology using LAMMPS" (Instructors: Jeremy Lechman, Matt Lane and Steve Plimpton) or a Saturday-only short course on "Using Large Amplitude Oscillatory Shear (LAOS)" (Instructors: Randy Ewoldt and Jeffrey Giacomin) and a complementary experimental offering on Sunday. A motion to approve the report was passed.

Chris White reported for the Membership Committee. As of April 2012, there were 1260 members. Gifts to graduating Ph.D. students were sent. A motion to approve the report was passed.

Jeffrey Morris reported via Skype for the Bingham Award Committee. There were several good candidates and the committee recommended a candidate. A motion to approve the report was passed.

Gareth McKinley reported for the Metzner Award Committee. There were several very good applications. The committee recommended an awardee. A motion to approve the report was passed.

Robert Harrington of AIP discussed publishing changes and matters at AIP. Bridget D'Amelio of AIP reported on statistics of *JOR*. D'Amelio also illustrated DeepDyve, a platform for article rental, and discussed an app for author experience.

Albert Co reported on plans for the websites. The SOR website and the members' website will be redesigned and be mobile friendly. A motion to approve the report was passed.

Gerry Fuller reported on international outreach activities. The Indian Society of Rheology has re-established. Brazil has created their society. Outreach support through short course teaching was recently offered in South Africa. Columbia has a growing rheology community. There are activities in Thailand and Morocco. Fuller also showed a graphic he designed

for ICR2012; the graphic depicted the logos of rheological societies worldwide. A motion to approve the report was passed.

Andy Kraynik reviewed trends of past meetings and reported on the Cleveland meeting. Norm Wagner reported on the Student Travel Grant Program for the ICR Lisbon meeting.

Shelley Anna reported on the plan of the technical program for the Pasadena (February 2013) meeting. A motion to approve the report was passed.

John Brady reported via phone on the local arrangement of the Pasadena meeting. All arrangements are in good shape.

Wes Burghardt reported on the plan of the technical program for the Montreal (October 2013) meeting. A motion to approve the report, with provision that the final version of the program be circulated to the members of the Executive Committee, was passed.

Don Baird presented a proposal for the February 2017 meeting in Tampa, Florida. Possible venues were discussed.

Marie-Claude Heuzey reported on the local arrangement of the Montreal meeting. Possibilities for a Monday evening reception were discussed. A motion to approve the Monday evening reception, if the local arrangement desired and the budget were reasonable, was passed. Heuzey will consult with Kraynik.

Jason Maxey presented a proposal for the February 2017 meeting in Houston, Texas. Possible venues were discussed.

Matt Liberatore presented a proposal for the October 2017 meeting in Denver, Colorado. Possible venues were discussed. Kraynik provided his impressions of the sites from his visit.

Saad Khan presented a proposal for the October 2018 meeting in Raleigh, North Carolina. Possible venues were discussed.

Minutes of Executive Session

The meeting entered into executive session at 3:40 p.m.

Present: Jeffrey Giacomin, Greg McKenna, Monty Shaw, Ralph Colby, Shelley Anna, Gareth McKinley, Norm Wagner. Gareth McKinley recorded the session as Albert Co had to leave for flight.

After Ralph Colby recused himself, all three award committee recommendations (Bingham, Metzner, Publications) were approved unanimously and enthusiastically.

Meetings Policy Co-Chair Andy Kraynik entered the Executive Session by invitation.

Don Baird's proposal for the February 2017 meeting in Tampa Bay and Matt Liberatore's proposal for the October 2017 meeting in Denver were approved unanimously and enthusiastically.

Jason Maxey entered the Executive Session by invitation. Jason Maxey's proposal for the February 2017 meeting in Houston was deferred. He has been asked to retool this for an October meeting in 2018.

Saad Khan entered the Executive Session by invitation. Saad Khan was encouraged to retool his proposal for an October 2019 meeting in Chapel Hill, North Carolina (new location).

Monty Shaw led a discussion on *JOR* editorial matters. Discussion of AIP governance was tabled.

The meeting was adjourned at 4:10 p.m.

Submitted by Albert Co, Secretary, with assistance from Gareth McKinley

Treasurer's Report

To the Membership:

The tables on pages 24-5 of this *Bulletin* provide information concerning the 2011 financial transactions of the Society, the financial position at the end of 2011, and the proposed budget for 2013. As can be seen from the net in the table labeled "Receipts and Disbursements," the financial picture for 2011 was quite rosy thanks largely to an unexpected, one-time increase in copy royalty income. As explained at the meeting, the budget for 2012 was originally near break-even, but went negative with the creation of a $30,000 travel fund for students attending the ICR in Lisbon. The budget for 2013 looks even bleaker because of two meetings with attendant expenses for student travel and awards. In response to increasing recurring expenses, I will propose at our annual meeting in February, 2013, a balanced-budget amendment for the constitution, along with plan on how a balanced budget can be achieved.

Respectfully submitted,
Montgomery T. Shaw, Treasurer

The Society of Rheology, Inc.
Balance Sheet

(all amounts, USD)	2011 Year End	2010 Year End	2009 Year End	2008 Year End	2007 Year End
Assets					
Cash in checking account(s)	41,084	13,257	18,330	10,859	24,466
Securities	0	0	0	0	0
Balance in AIP account	1,545,020	1,435,019	1,425,005	1,342,819	1,292,672
Total Assets	1,586,104	1,448,276	1,443,335	1,353,678	1,317,138
Liabilities and Net Assets					
Liabilities					
Deferred subscription revenue					
Deferred member dues					
Deferred revenue	111,633	89,283	125,501	87,675	111,995
Total Liabilities	111,633	89,283	125,501	87,675	111,995
Net Assets					
Publication reserve	450,000	450,000	450,000	450,000	450,000
Student travel grant reserve	30,000	30,000	30,000	10,000	10,000
Annual Meeting reserve	300,000	300,000	300,000	300,000	300,000
Operating reserve	150,000	150,000	150,000	100,000	100,000
Unrestricted	544,471	428,994	387,834	406,003	345,143
Total Net Assets	1,474,471	1,358,994	1,317,834	1,266,003	1,205,143
Total liabilities and net assets	1,586,104	1,448,276	1,443,335	1,353,678	1,317,138

Journal of Rheology
Receipts and Disbursements

(all amounts, USD)	2013 Budget	2012 Budget	2011 Year End	2011 Budget	2010 Year End
RECEIPTS					
Subscriptions	145,000	150,000	150,980	165,000	159,285
Royalties & Reprint Sales	6,300	5,500	88,162	4,000	5,337
Ad Sales	49,000	45,000	51,856	43,000	49,814
JORO revenue	75,000	65,000	94,242	61,000	70,946
Miscellaneous	2,000	2,100	2,000	2,000	2,105
TOTAL RECEIPTS	277,300	267,600	387,240	275,000	287,488
DISBURSEMENTS					
Ads	14,000	12,000	13,033	10,000	13,180
Reprints, Single Copy	1,200	1,800	630	2,200	1,382
Paper, Printing	29,000	29,000	26,267	27,000	28,605
SOR Editorial	45,000	45,000	40,914	36,000	46,217
Production	38,000	35,000	38,250	39,000	36,322
Fulfillment	5,550	5,925	5,350	5,725	5,882
Distribution	19,900	22,650	20,026	22,700	20,855
Electronic publishing	50,000	41,000	47,830	41,000	55,765
Miscellaneous	8,200	7,000	8,849	8,500	6,431
TOTAL DISBURSEMENTS	210,850	199,375	201,148	192,125	214,638
Net	**66,450**	**68,225**	**186,091**	**82,875**	**72,850**

The Society of Rheology
Receipts and Disbursements

(all amounts, USD)	2013 Budget	2012 Budget	2011 Year End	2011 Budget	2010 Year End
RECEIPTS					
Dues	44,500	46,000	46,619	49,000	47,969
Interest	3,000	3,000	2,460	5,000	2,744
Journal of Rheology	277,300	267,600	387,240	275,000	287,488
Mailing List Sales	0	100	-15	300	80
Donations	0	0	0	0	0
Bulletin Advertising	10,000	10,000	11,500	10,000	10,800
Annual Meeting (net)	0	0	-6,874	0	13,106
Short Course (net)	0	0	2,929	0	16,247
TOTAL RECEIPTS	334,800	326,700	443,860	339,300	378,433
DISBURSEMENTS					
AIP Dues Bill & Collect.	11,500	11,500	11,104	11,000	11,386
AIP Adm. Services	10,000	8,000	9,218	8,000	7,568
AIP Mem. Soc. Dues	13,000	7,500	13,069	7,500	7,500
Contributions and Prizes	24,000	12,000	10,471	11,000	11,825
Journal of Rheology	210,850	199,375	201,148	192,125	214,638
Bulletin	18,000	22,000	13,406	19,000	22,127
Bingham Award	20,000	0	10,000	500	12,972
Executive Cmt. Meetings	20,000	13,000	20,370	13,000	16,695
Pres. Discretionary Fund	1,500	1,500	1,477	1,500	814
Treas. Discr. Fund	1,500	1,500	0	1,500	0
Bulletin Editor Discr. Fund	1,500	1,500	0	1,500	0
Progr. Chm. Discr. Fund	6,000	0	786	3,000	0
Webmaster Discr. Fund	3,000	3,000	2,246	3,000	1,030
International Activities Fund	5,000	5,000	2,000	5,000	2,000
Office Expenses	500	4,000	551	4,000	2,224
Banking Services	160	100	184	100	60
Liability Insurance	5,100	5,200	5,079	3,900	3,830
Membership Broch. & Appl.	0	2,000	0	1,500	2,193
Accountant	2,300	2,200	2,200	2,000	2,200
Student member travel	50,000	30,000	25,495	21,000	14,541
Annual meetings, future	6,000	6,000	0	8,000	2,299
Website	200	3,000	50	3,000	215
Miscellaneous	100	100	817	500	0
TOTAL DISBURSEMENTS	410,210	338,475	329,670	321,625	336,117
Net	**-75,410**	**-11,775**	**114,190**	**17,675**	**42,316**

end

(Continued from page 16)

"Dynamics of melting and recrystallization in polymeric micellar crystal subjected to large amplitude oscillatory shear flow". **Physical Review Letters**. 108, 258301 (2012).

Porcar, L., Hamilton, W.A., Butler, P.D., and Warr, G.G., "Topological Relaxation of a Shear-Induced Lamellar Phase to Sponge Equilibrium and the Energetics of Membrane Fusion". **Physical Review Letters**. 93(19): p. 198301 (2004).

Porcar, L., Pozzo, D., Langenbucher, G., Moyer, J., and Butler, P.D., "Rheo-small-angle neutron scattering at the National Institute of Standards and Technology Center for Neutron Research". **Review of Scientific Instrument**s. 82(8) (2011).

Rehage, H. and Hoffmann, H., "Rheological Properties of Viscoelastic Surfactant Systems". **Journal of Physical Chemistry**. 92(16): p. 4712-4719 (1988).

Rehage, H. and Hoffmann, H., "Viscoelastic surfactant solutions: model systems for rheological research". **Molecular Physics: An International Journal at the Interface Between Chemistry and Physics**. 74(5): p. 933 - 973 (1991).

(Continued from page 5)

and the globular plasma proteins (that consist primarily of serum albumin and gamma-globulins) showed why synovial fluid is such a great lubricant for mammalian joints. This key discovery lead to understanding the lubricating action of this fluid, with implications to medicine, pharmaceutical science, and bioengineering.

Perhaps the single most important outstanding issue in the field of glass formation is whether there is a length scale associated with dynamic heterogeneities and how it depends on temperature. Here again, the contribution of Colby has had a huge impact. Using a dynamic scaling model, he has demonstrated that the length scale of cooperative motion of all glass-forming liquids follows universal temperature dependence. In the same context, the relaxation times of a particular glass former are expressed as the product of the universal cooperative length scale raised to the sixth power and a function related to non-universal thermally activated process. Well above glass transition temperature, a crossover to Arrhenius temperature dependence is recovered and provides an estimate of the caging temperature. This very important discovery offers ways of critically testing universalities in the behavior of glass-formers, which represents one of the most important challenges.

Colby Group Winter 2009: from left Wenjuan Liu, Yan-jie Wang, Greg Tudryn, Laura Mely Ramirez, U Hyeok Choi, RHC, Libby Asteak, Dan king, Siwei Liang, Shih-wa Wang and Ruebner Bushnell.

Copolymers, liquid crystalline polymers and surfactant micelles are three popular classes of structured polymeric materials. Ralph realized early on that in order to understand these complex fluids one needs to study their structure and dynamics on scales much larger than their molecular dimensions. Achieving this understanding required careful and patient measurements of rheology down to extremely low rates in combination with application of structure probing techniques. Colby's classic paper on a block copolymer with shear viscosity measurements down to unprecedented shear rates of 10^{-7} s^{-1} proves his dedication, determination to tackle, and ability to solve challenging problems. His collaboration with Bates and Tirrell has opened the route for a large body of works on shear-alignment of block copolymer micelles.

Ralph's current projects include studies of ionomers, branched polymers, and nanocomposites. We are anxiously awaiting the new discoveries from Colby's lab.

The above brief description is a testimony to Ralph's remarkable instinct for important and timely problems that attract the attention of both scientific and industrial communities. Colby is also one of the pioneers responsible for the transformation of rheology into a molecular and structural science, drawing in complementary experimental techniques such as scattering (X-ray, neutron, and light), dielectric spectroscopy, polarimetry, NMR, and microscopy, as well as molecular simulations, in order to cover all the essential structural timescales and lengthscales in complex fluids. In addition, he has a rare talent in selecting strategic and long-lasting collaborations with top-notch scientists.

The great success of the International Congress on Rheology in Monterey is, to a large extent, due to Ralph who, along with Gary Leal, put together a memorable program. Ralph is always encouraging, helpful, and generous with his time. He is constantly demonstrating scholarship and leadership in taking rheology into new territories, where it can play a crucial role in solving major scientific and technological problems.

Ralph is a devoted father of Melissa, Edwin and Graham. He enjoys playing ice hockey and is a passionate fan of the Boston Red Sox. If you cannot go with Ralph to a football game of the Nittany Lions at State College, make sure that you dine with him. You will enjoy his unique humor, but do not compete with him on after-dinner drinks! Cordial congratulations to Ralph on receiving the 2012 Bingham medal!

(Continued from page 18)

entangled and disentangled states of WLM occurring over a single oscillation cycle. *tOrSANS* results provide a direct microstructural interpretation of this curious behavior and can be used to test constitutive models as the scattering patterns can be directly related to the stress [Helgeson *et al.* 2009].

Another interesting phenomena investigated with *tOrSANS* is flow-induced order and disorder in soft particle dispersions. Figure 4b shows a sample of the rheological measurements and corresponding micro-structures for a Pluronic block copolymer (F127) in ethylammonium nitrate (EAN, a room temperature ionic liquid). F127/EAN solutions form spherical micelles that, at concentrations above 22 wt%, self-assemble into cubic lattices. Under shear they form layers with hexagonal symmetry (evidenced by scattering spots with six-fold symmetry, see Fig. 4b). By applying a sufficient shear rate, the crystalline order is lost and the sample shear melts. We studied shear melting of these structures when subjected to LAOS [López-Barrón *et al.*, *2012*]. Fig. 4b shows the Lissajous plots along with SANS profiles at different points in the cycle. Clearly melting (formation of isotropic SANS spectra) and recrystallization (appearance of scattering spots) occurs reversibly during a LAOS cycle. The square shape of the Lissajous curve indicates shear thinning during two quarters of the cycle. The molten state coincides with the onset of the shear thinning, and the reordering is more evident at the point of minimum shear rate. The analysis of the relative intensities of the scattering peaks provides important new insight on the physics of melting and recrystallization of soft colloids.

As interesting and valuable as this new technique is, often the most important structure deformation takes place in the flow-gradient (1-2) plane. This time-resolved method has been extended to include a custom shear cell [Liberatore *et al.*, 2006] which projects the neutron beam along the vorticity direction. Additional investigations were made in the (1-2) plane of shear for the WLM and a shear-thickening fluid by Gurnon as reported at the conference and these results will be presented at the ICR.

(Continued from page 17)

the resulting coefficients in the expansion (here denoted e_i and v_i) correspond to higher order elastic and viscous coefficients that have clear physical interpretations (see Ewoldt *et al*., 2008). A striking visual way of representing the nonlinear material response is through elimination of the time variable and cross plotting the (time varying) stress against the (time-varying) strain as shown in Figure 5(c). This Bowditch-Lissajous curve helps rapidly identify phenomena such as strain-hardening or shear-thinning in the material response. Viscoelastic energy dissipation corresponds to the area enclosed by such trajectories. A series of such curves can be constructed to probe the entire Pipkin diagram. It is also possible to quantify the gradients of stress vs. strain at certain points in these hysteresis loops (e.g. at the points of infinitesimal strain or maximum strain) and define appropriate material moduli such as the minimum strain modulus (here denoted G'_M) and the large strain modulus (here denoted G'_L). These moduli can also be computed analytically from the coefficients of the Chebyshev series (as shown in (d)) thus interconnecting these different methods of analysis. Naturally in the limit of linear viscoelasticity these measures all reduce to the familiar moduli of linear viscoelasticity.

(Calendar, continued from page 28)

2016

1-5 August 2016
XVIIth International Congress on Rheology, Kyoto, Japan, Hiroshi Watanabe (every four years).

2017

February 2017
88th Annual Meeting of The Society of Rheology, Tampa Bay, FL USA, Don Baird

October 2017
89th Annual Meeting of The Society of Rheology, Denver, CO USA, Matt Liberatore

2018

October 2018
90th Annual Meeting of The Society of Rheology, location TBA

2019

October 2019
91st Annual Meeting of The Society of Rheology, location TBA

For other meeting notices, see also
www.rheology.org/sor/info/Other_Meetings.htm
http://www.rheology-esr.org/Meetings.php
www.appliedrheology.org/(click on conferences)

The Society of Rheology
American Institute of Physics
Suite 1NO1
2 Huntington Quadrangle
Melville, NY 11747-4502 USA

CALENDAR OF RHEOLOGY CONFERENCES AND COURSES

2012

5-10 August 2012
XVI[th] International Congress on Rheology, Lisbon, Portugal, João M. Lopes Maia (every four years)

4-5 August 2012
Short Course on Colloidal Suspension Rheology, Lisbon, Portugal; Norman Wagner and Jan Mewis

4-5 August 2012
Short Course "IRIS: Synergy of Rheological Data Analysis and Modeling," Lisbon, Portugal; Henning Winter and Manfred Wagner

19-24 August 2012
XXIII[rd] International Congress of Theoretical and Applied Mechanics ICTAM 2012; Beijing, China (every four years)

10-11 September 2012
Conference on Suspension Processing & Suspension Engineering Rheology; Cambridge, U.K., Richard Buscall and Alex Routh (www.constable-andsmith.com/suspensionrheology)

2013

9-10 February 2013
SOR Short Course "Microfluidics and Its Application," Pasadena, California, USA; Anubhav Tripathi, Charles Schroeder, and Annie Colin,

10-14 February 2013
84[th] Annual Meeting of The Society of Rheology, Pasadena, California, USA, John Brady

12-13 October 2013
SOR Short Course on Rheology (topic TBA), Montreal, Quebec, Canada.

13-17 October 2013
85[th] Annual Meeting of The Society of Rheology, Montreal Quebec Canada, Marie-Claude Heuzey, Paula Wood-Adams.

2014

4-5 October 2014
SOR Short Course on Rheology (topic TBA), Philadelphia, Pennsylvania USA

5-9 October 2014

86[th] Annual Meeting of The Society of Rheology, Philadelphia, PA USA, Michael Mackay

2015

October 2015
SOR Short Course on Rheology (topic TBA), Baltimore, Maryland USA

October 2015
87[th] Annual Meeting of The Society of Rheology, Baltimore, Maryland USA, Kalman Migler and Jai Pathak.

(Continues, page 27)