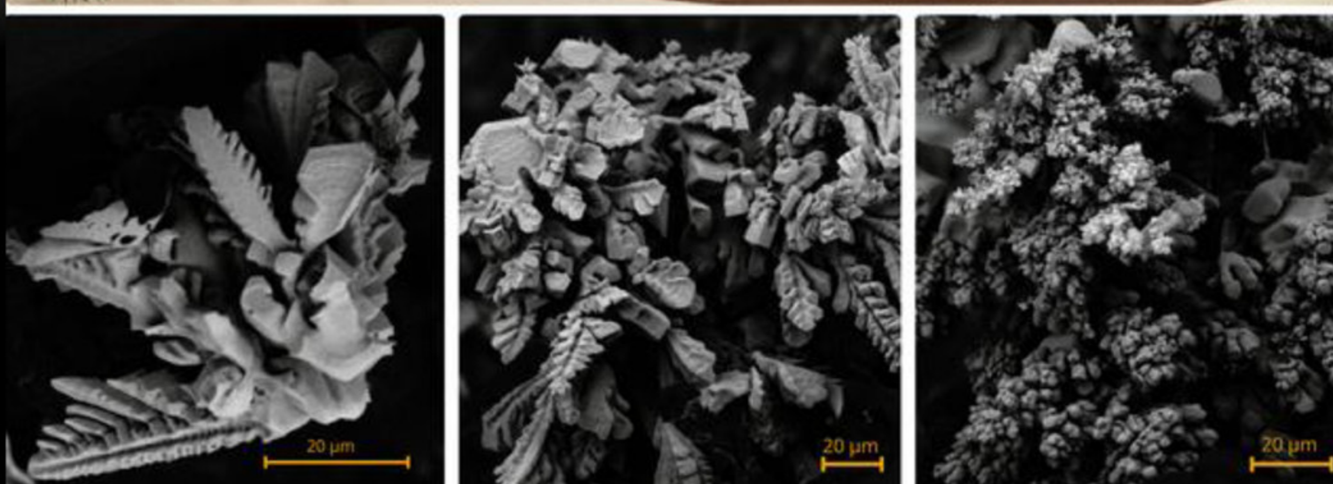
The News and Information Publication of The Society of Rheology
Volume 94 Number 1, August 2025

Rheology Bulletin



Inside:

- Computational Rheology of Complex Fluids
- In Memoriam: Andreas Acrivos
- Come to Santa Fe in October 2025
- SOR Awards 2025

Executive Committee

(Jan 1 2024–Dec 31 2025)

Table of Contents

On the Cover: Hydrates are crystalline compounds formed when water molecules encapsulate gas molecules under specific pressure and temperature conditions, creating ice-like structures. In the context of Carbon Capture and Storage (CCS), understanding the rheology of these hydrates is essential for predicting and managing their behavior in pipelines and storage facilities. These images depict the formation of synthetic hydrates using cyclopentane and water at 4°C, observed in the Double Wall Ring (DWR) geometry of a rotational rheometer. Due to the directional nature of crystal growth, hydrates formed under these controlled conditions resemble miniature trees, showcasing the intricate and delicate structures that emerge. Nucleation begins at the interface, emphasizing the importance of measuring interfacial rheology in these systems. The micrographs, captured with a scanning electron microscope (SEM) using a cryogenic system, provide a detailed view of these formations, offering valuable insights into hydrate growth mechanisms. These observations are particularly relevant for flow assurance strategies in industrial applications, helping to mitigate risks associated with hydrate formation in CCS and energy transport systems. Image provided by Paulo R. de Souza Mendes (Pontifícia Universidade Católica, Rio de Janeiro, Brazil).

The *Rheology Bulletin* is the news and information publication of The Society of Rheology (SoR) and is published yearly in August (in non-pandemic years). Subscription is free with membership in The Society of Rheology. Letters to the editor may be sent to Carlos R. López-Barrón at *carlos.r.lopez-barron@exxonmobil.com*

Serial Key Title: Rheology Bulletin
LC Control No.: 48011534
Published for The Society of Rheology by AIP Publishing LLC (AIPP) a subsidiary of 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/rheobulletin/*.

SoR Committees (2025)

Membership Committee
- Stacey Elliott
- Safa Jamali, chair
- Mazi Jalaal
- Carina Martinez
- Antonio Perazzo
- Sara Reynaud
- Travis Walker
- Chuqiao (Elise) Chen (student)

Education Committee
- Matt Armstrong
- Sumana Chakrabarti
- Kendra Erk
- Reza Foudazi
- Jim Gilchrist, chair
- Matthew Helgeson
- Thomas O'Connor, co-chair outreach
- Maggie Qi
- Abhinendra Singh

Bingham Medal Committee
- Ralph Colby
- Randy Ewoldt
- Sara Hashmi
- Saad Khan
- Denis Rodrigue, chair
- Michael Rubinstein
- Jan Vermant

Metzner Award Committee
- Xiang Cheng
- Sujit Datta
- Julie Kornfield
- Charles Schroeder, chair
- Sachin Velankar

SoR Fellowship Committee
- Will Hartt
- Steve Hudson
- Srinivas Raghavan
- Maryam Sepehr, chair
- Paulo de Souza Mendes

Journal Publication Award Committee
- Dimitris Vlassopoulos (Editor)
- Emanuela Del Gado (Associate Editor)
- Evelyne van Ruymbeke (MAL)
- Simon Rogers (MAL)
- Norbert Willenbacher (previous winner)

Meeting Policy Committee
- Jeff Morris, co-chair (VP)
- Andrew M. Kraynik, co-chair
- Kalman Migler (Secretary)
- Albert Co (Webmaster)
- Rae Anderson (Webmaster in Training)

Audit Committee
- Brian Edwards
- Jeffrey Martin (chair)
- Paul Salipante
- Lisa Biswal (ex officio)

Financial Advisement Committee
- Ryan Murphy
- Rekha Rao (chair)
- Jonathan Seppala
- Lisa Biswal (ex officio)

Diversity, Equity, and Inclusion Committee (—-)

Nominating Committee
- Christian Clasen
- Marie-Claude Heuzey (chair)
- Rajesh Khare

SOR Ad-Hoc Centennial Celebration Committee
- Mike Graham, chair
- Anne Grillet
- Safa Jamali
- Gareth McKinley
- Jeff Morris
- Peter Olmsted
- Vivek Sharma

SOR Ad-Hoc Future of Meetings Committee
- Albert Co
- Members at Large (Ex Officio)

Community Development Committee
- Jesse Gadley
- Peter Gilbert
- Ali Mohraz
- Jae Park
- Kelly Schultz
- Maryam Sepehr
- Katie Weigandt, chair
- Arshiya Bhadu (student)

Journal of Rheology Editorial Office

Editor-in-Chief	*Dimitris Vlassopoulos*
Associate Editor	*Emanuela Del Gado*
Editorial Assistant	*Ania Bukowski*

Society Service Appointments

Webmaster	*Albert Co and Rae Anderson*
Editor of Rheology Bulletin and Communication Coordinator (2024-2025)	*Carlos R. López-Barrón*
Social Media Director	*Christine Roberts*
Director, International Outreach Program (2024-2025)	*Gerald G. Fuller*
SoR Historian (2022-2023)	*Gareth McKinley*

External Committees/Organizations for 2025

American Institute of Physics (AIP)	
SoR Designee to AIP Governing Board	*Eric Furst (Mar 2023 – Mar 2026)*
SoR Member Representative to AIP	*Jonathan Rothstein (2024-2025)*
SoR Liaison on AIP History Committee	*Gareth McKinley (2023-2025)*
Soft Matter Association of the Americas (IUPAP)	
SoR Representative	*Jaci Conrad (2023 – 2026)*

AIP Publishing (AIPP)

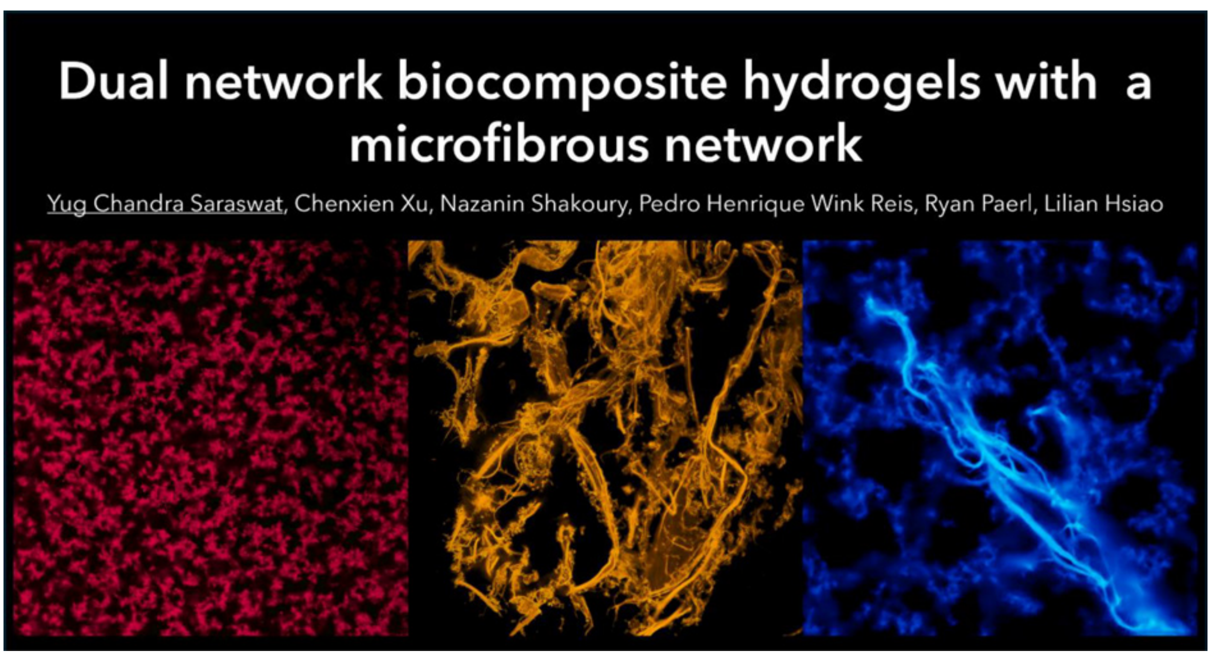
SoR Designee to AIPP Board of Managers	*TBA*
SoR Representatives on AIPP Publishing Partners Committee	*Peter Olmsted (2025)* *Simon Rogers (2022-2025)*

International Committee on Rheology

SoR Delegate to ICR — *Mike Graham (2024-2025)*
Secretary to the ICR — *Gerald G. Fuller*

US National Committee on Theoretical and Applied Mechanics

SoR Representative to NCTAM — *Anne M. Grillet (2023-2027)*



Viscoelastic properties of an extracellular matrix, such as increased stiffness, viscous dissipation, stress relaxation, and plasticity, can affect cell spreading, proliferation, and differentiation. Here, we study the strain stiffening and softening in a dual network hydrogel composed of agarose (left) and fluorescent dendritic chitosan microfibers (middle) dispersed in an aqueous solvent. A sol-gel transition occurs when the agarose is cooled below the gel point, during which the dendritic chitosan fibers self-assemble into a complex interpenetrating architecture (right). Image provided by Yug Saraswat (NC State University).

Dear Society of Rheology Members

I am happy to report that this has been an exciting and extremely productive year for the Society. As we quickly approach our centennial anniversary in 2029, we have begun a number of important projects designed to modernize our society, to increase and improve our visibility, and to provide new valuable resources to our members. These projects include: teaming up with APS to help plan our annual meetings starting with Boston in 2026; the introduction of a redesigned logo; the creation of an online education platform called the Rheology Academy; and the development of a new website with the help of AIP. The website will be hosted on AIP's new digital experience platform (DXP). The process has been spearheaded by our new webmaster, Rae Robertson-Anderson, in collaboration with Albert Co. I would like to express my deep appreciation to Rae for stepping into this role and thank them for all their hard work. We are really excited for the launch of the new website which is set to go live in October after the Santa Fe meeting. With these new initiatives, the Society of Rheology is positioning itself for another 100 years as the nexus of rheological research and practice.

Over the course of the last year, we have continued to execute on our mission to expand the knowledge and practice of rheology through hosting of our annual meetings, the publication of the Journal of Rheology, our education, outreach and mentoring activities, and through the fresh ideas that you submit to the Rheology Venture Fund. In addition to several ongoing projects, this year's RVF winners include: a project by Ben Yavitt and Aashish Priye entitled "A platform for community-driven DIY rheology projects" designed to develop plans for 3D printed DIY rheometer tools; a project by Monica Naccache and Priscilla Vargas entitled "Rheo4Kids: Outreach to bring the science of rheology to children and teenagers in Brazil" designed to develop a new outreach activities around materials used in our daily lives; and a mini symposium at the 2025 Santa Fe meeting dedicated to "Geology-Rheology" organized by Christine Roberts and Sujit Datta.

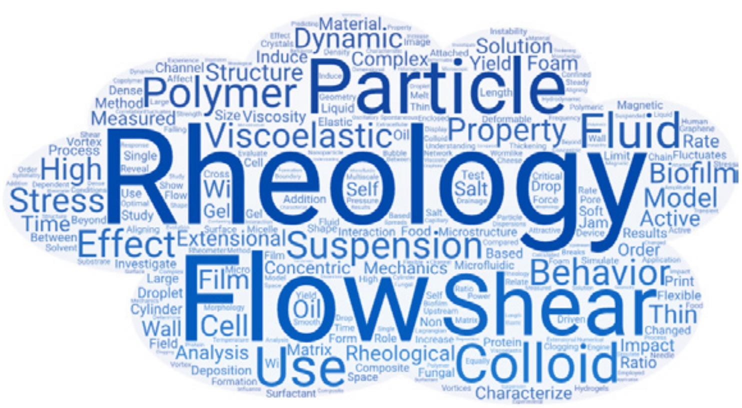
Last year's Society of Rheology Annual Meeting in Austin, Texas was a great success. With over 500 oral presentations and posters, it was one of the biggest SoR meetings we have ever held. It is clear that the science of rheology remains vibrant and strong. Special to thanks Kendra Erk and Safa Jamali for organizing the technical program and to local organizer Roger Bonnecaze and his great staff at UT Austin for putting together an amazing meeting.

This year's meeting will be in Santa Fe. Christine Roberts has done an amazing job as the local organizer of the meeting with the help of Lilian Hsiao and Reza Foudazi who have developed a great technical program for us. I hope you will join me there to celebrate our 2025 Bingham Medalist, Antony Beris, our Metzner Awardee, Safa Jamali, and our new class of Fellows. With a robust abstract submission, the technical program promises to be exciting, capturing both the depth and breadth of our Society. There will be two short courses, "Fundamentals of powder/granular rheology and flow" on Saturday and "Applied Powder Rheology" on Sunday. We also look forward to active member and community engagement with an outreach event at a local children's museum, the student-industry forum, the Rheology Research Symposium (RRS) and the student trivia night.

Over the last year, we have begun planning our centennial celebration to be held in the Washington D.C. area in 2029. Mike Graham is heading up a centennial committee to make the celebration special. We have lots of great ideas and projects moving forward focusing both on our society's storied history and the future of rheology.

With all that is happening in the country and in the world, I am acutely aware of how difficult these last few months have been for some of our members. Know that the Society of Rheology stands with you. As a society, we will continue to hold fast to our vision, values and mission. We will continue to support and promote the science and practice of rheology and science in general. Together we can make a difference.

Regards,
Jonathan P. Rothstein,
President of The Society of Rheology



Report from Austin: 95th SoR Annual Meeting

The 95th Annual Meeting of The Society of Rheology was held from October 12 to 17, 2024, in the heart of Texas, at the Austin Marriott Downtown. The technical program was curated by Technical Program Chairs **Kendra Erk** and **Safa Jamali**, and local arrangements were coordinated by Organizing Chair **Roger Bonnecaze**, with valuable support from **Susie Winfield** and **Andy Kraynik**.

Set against the vibrant city of Austin—renowned for its music, food, tech, and welcoming atmosphere—the meeting attracted over **450 attendees from 21 countries**, with the farthest travelers joining from Singapore.

The meeting was an overwhelming success, offering a dynamic forum to share the latest advancements in rheology, recognize the achievements of outstanding members, and mentor the next generation of scholars and practitioners. This success was made possible through the dedicated efforts of all organizers and enthusiastic participation by the community. Some of the highlights of the meeting include:

- **Short Courses.** Two well-attended short courses organized by **Matt Helgeson:** *LAOS Rheology - a start-to-finish guide* (Instructor: **Simon Rogers**) and *Automated Rheology and Application to Multi-methods Measurements* (Instructors: **Jeff Richards**, **Thibaut Divoux**).
- **Rheology Research Symposium** led by **Katie Weigandt**. This symposium brought together students and professionals for insightful discussions on career development in the field of rheology.
- **Community Engagement.** Our dedicated student members, under the guidance of **Jim Gilchrist**, introduced rheology to children at the *Austin Thinkery*, inspiring curiosity in the next generation.
- **Student Trivia Night.** A rheology-themed trivia night at *Central District Brewing* provided a setting for networking and camaraderie among graduate students and postdocs. The event was organized by **Arshiya Bhadu** and **Elise Chen**.
- **Plenary Talks. Karen Daniels** and **Douglas Jerolmack** gave an exciting talk on the *Rheology of granular matter on Earth and in the solar system*. **Matteo Pasquali** delivered a compelling talk on *The nexus of materials, energy, and carbon dioxide—and how rheology is impacting it.*
- **Named Lectures. Michael Graham** delivered an inspiring Bingham Lecture on *Data-driven and physics-aware microstructural modeling of flowing complex fluids.* **Lilian Hsiao** gave an engaging Metzner Lecture titled *Seeing is believing: Confocal rheometry of colloidal gels and suspensions*.
- **Technical Program**. Spanning three and a half days, the technical program featured over 400 talks covering the breadth of rheology organized by an outstanding team of session chairs.
- **Special Symposia**. Space Applications and Low-Gravity Research organized by **Norman Wagner**, **Thomas Voigtmann**, and **Olfa D'Angelo** and The Future of Rheology organized by **Matt Helgeson, Chunzi Liu,** and **Arman Ghaffarzadeh.**
- **Social and Networking Events.** An authentic Texas barbecue at *Banger's Sausage House & Beer Garden*, generously sponsored by **TA Instruments**, kicked off the meeting with a delicious and relaxed gathering. The following day the *Bingham Medal Reception and Banquet*, emceed by SoR President **Jonathan Rothstein**, was a celebratory highlight. **Bingham Medalist Michael Graham** and **Metzner Awardee Lilian Hsiao** were honored in memorable fashion. Several esteemed members were inducted as SoR Fellows, including: **Eric Furst, Christian Clasen, Albert Co, Norman Wagner, Michael Rubinstein, Brian Edwards, Michel Cloitre, Carlos López-Barrón,**

SoR President Jonathan Rothstein presenting Lilian Hsiao with Metzner Award.

Michael Graham, Marie-Claude Heuzey, Julia Kornfield, and **Gareth McKinley**

- The **2024 Journal of Rheology Publication Award** was presented to **Norbert Willenbacher, Claude Oelschlaeger, Jonas Marten**, and **Florian Péridont** for their article *Imaging of the microstructure of Carbopol dispersions and correlation with their macroelasticity: A micro- and macrorheological study* by JoR editor **Dimitris Vlassopoulos**.
- The **2023 Walters Prize** from the *Journal of Non-Newtonian Fluid Mechanics* was presented to **Fenghui Lin, Jiaxing Song, Zhiye Zhao, Nansheng Liu, Xi-Yun Lu, Bamin Khomami** (*Journal of Non-Newtonian Fluid Mechanics* **312**, 2023, 104968) by the journal editors-in-chief **Robert Poole** and **Ian Frigaard**
- The **Poster Session and Gallery of Rheology Reception**, generously sponsored by **Anton Paar**, was one of the most vibrant and well-attended in SoR history, fostering dynamic exchange and collaboration.

President of SoR Jonathan Rothstein presents Bingham Medal to Michael Graham.

Closing Reflections

Participants left the meeting energized—with new research ideas, collaborations, and friendships old and new. Many departed with the sense of belonging to a thriving, supportive community, and perhaps a few with plans to return to Austin to catch what they missed the first time.

By Roger Bonnecaze

SoR Fellows at the 2024 Austin Annual Meeting

Space Application and Low-Gravity Research Symposium at the Austin SoR Meeting (2024)

By Olfa D'Angelo

Space-science and rheology have a lot to learn from each other. Rheology plays a crucial role in the planning and success of research conducted in low-gravity environments, which also offers novel avenues for rheological experiments, some of which are simply not feasible on Earth. Conversely, rheology plays a crucial role in forthcoming space missions: from the behavior of granular flows on extraterrestrial planets, fuel viscosity under different gravity, and 3D printing of Lunar infrastructure to contribute to astronauts' well-being, rheological questions abound. Conversely, low-gravity environments offer novel avenues for rheological research, enabling experiments in parameter regimes relevant for building better models, but unattainable on Earth. A special symposium was organized by **Olfa D'Angelo** (ISAE-SUPAERO, University of Toulouse), **Thomas Voigtmann** (German Aerospace Center) and **Norman Wagner** (University of Delaware) to provide SoR members with information for opportunities in this growing area. This initiative was supported by the SoR Venture Fund.

The program started Monday morning with a plenary by **Karen Daniels** (North Carolina State University) and **Doug Jerolmack** (University of Pennsylvania), highlighting the critical role of granular rheology for both Earth and space science. This was followed by an invited session featuring a range of presenters discussing the impact of low gravity on rheological materials and systems, with each talk highlighting a unique aspect of space-based rheology research to a packed, overflowing room:

- **Phillip Irace**, Science Program Director for the International Space Station (ISS) National Lab, presented insights into microgravity rheology on the ISS, where gravity-induced forces are decoupled from other drivers. This allows for precise rheological measurements in complex fluids, particularly in systems like colloidal suspensions that tend to sediment under Earth's gravity. He emphasized how microgravity enables studies on transport phenomena, including flame propagation, otherwise impossible in terrestrial labs.

- **Katie Koube,** Senior Materials Engineer at ICON 3D, discussed lunar regolith simulants and their role in additive manufacturing for lunar infrastructure. Her focus was on the kinematic viscosity of lunar regolith melts, which are essential for the in-situ resource utilization (ISRU) process. She highlighted the challenges of replicating the properties of actual lunar regolith on Earth and how understanding these differences is critical for future lunar construction.

- **James Mantovani**, Senior Physicist at NASA Swamp Works KSC, described his work on plume-surface interactions (PSI) during lunar landings. His work focused on gas permeability in lunar regolith and its effect on high-speed regolith ejecta, which poses a risk to surface and orbital assets. Mantovani presented data from permeability measurements of regolith simulants to improve PSI models for lander safety.

- **Eric Furst**, Professor at the University of Delaware and recipient of the NASA Exceptional Achievement Medal, presented experiments on paramagnetic colloidal suspensions in microgravity. He described how the absence of sedimentation on the ISS led to unexpected anisotropic domain structures in these suspensions, providing new insights into phase separation and the kinetic dynamics of colloidal gels under toggled magnetic fields.

- **Thomas Voigtmann**, Professor at the German Aerospace Center, stepping in for Laura Alvarez (University of Bordeaux), discussed the fluidity of biological membranes in microgravity. Using the sounding rocket program MAPHEUS, they found that giant unilamellar vesicles exhibited reduced fluidity in the absence of gravity, which could have implications for drug delivery systems during space missions.

- **Mazi Jalaal**, Assistant Professor at the University of Amsterdam, focused on plastocapillarity in microgravity, where droplets of yield-stress fluids can remain in the low Bond number regime – the regime of interest for technological applications like 3D printing. His work discussed theory, simulation and experiments conducted in space and how surface tension plays a dominant role in material behavior in low-gravity environments.

A Space Rheology Luncheon, with over 50 participants, immediately followed the symposium and gave a chance for lively discussions between speakers and audience members. After a welcome by SoR president Jonathan Rothstein, Professor Sachin Velankar (NSF Program Director for CBET) described funding opportunities for performing experiments on the ISS in conjunction with CASIS. This was followed by Philip Irace providing further technical information about conducting experiments on the ISS and the application process.

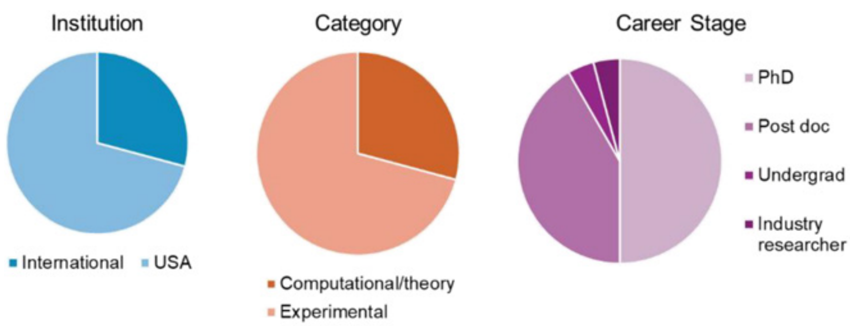
The final event of the Symposia was a poster competition during the Wednesday evening poster session, where two outstanding posters were identified: 1st place went to *Sean Farrington* for work on blood rheology, with application to astronauts' health, and 2nd place went to Ted Egnaczyk for geopolymer rheology for lunar construction.

The organizers were thrilled by the symposium's success and the enthusiastic participation from the rheology community. Stay tuned for the next exciting developments!

Student Affairs

Future of Rheology Seminar Series

This monthly virtual seminar series showcases the work of outstanding students, postdocs, and early-career industrial researchers. All are welcome to attend. Top speakers may be invited to present at the special "Future of Rheology" mini-session at the annual meeting. Abstract submissions are open from January to February each year. Stay tuned for seminar schedules by becoming a member and following our social media channels.



Statistics on the abstract submission for virtual seminars

Seminar announcement

Student Trivia Night

All students, post-docs, and early-career industry researchers are invited to the Student Trivia Night at the annual meetings. Enjoy drinks, rheo-nerdy trivia and fun time with friends!

Prize Winners!!!

Trivia Night at Central Brewing, Austin 2024

Your Opinion Matters

If you have fun ideas or suggestions, please let us know by emailing us:
futureofrheology@rheology.org

SoRStudent
Future flows

← **Join the Slack Channel to Stay Connected**

SoR 96TH ANNUAL MEETING

October 19 – 23, 2025 in Santa Fe, New Mexico
Technical Co-Chairs: Reza Foudazi (OU) and Lilian Hsiao (NCSU)
Local Chair: Christine Roberts (Sandia National Laboratories

Award Lectures:
Bingham Award: Antony N. Beris (Delaware)
Metzner Award: Safa Jamali (Northeastern)


Plenary Lectures:
L. Mahadevan (Harvard)
Amy Q. Shen and Simon J. Haward (OIST)



A strong **technical program** is expected, with a wide range of fundamental and applied topics, including Colloidal Suspensions and Granular Materials, Polymer Solutions, Melts and Blends, Interfacial Rheology, Surfactants, Foams and Emulsions, Self-assemblies, Gels and Networks, Techniques & Methods: Reometry, Tribometry, Spectroscopy & Microscopy, Biomaterials, Bio-fluid Dynamics and Biorheology, Flow-Induced Instabilities and Non-Newtonian Fluids, AI and ML in Rheology, Additive and Advanced Manufacturing, Rheology and Sustainability for Energy and Production, Applied Rheology for Pharmaceuticals, Food and Consumer Products, and Rheology for Soft Robotics

Educational Short Courses:

(1) Fundamentals of Powder/Granular Rheology and Flow (A. Sauret, U. Maryland, A. Singh, Case Western Reserve University, T. O'Connor, Carnegie Mellon U., & J. Gilchrist, Lehigh U.)
(2) Applied Powder Rheology (A. Shetty & J. Eickhoff, Anton Paar)

A special track on the intersection between geology and rheology will bring topics such as granular flow, ice flows, and lava to the meeting. The 2025 Future of Rheology speakers, early-career rheologists, will reprise their talks in a special mini-session and will have an opportunity to win a prize for the best speaker. Postdocs and graduate students may participate in the Rheology Research Symposium and a student trivia night, and the Student-Industrial Forum for connection and mentoring opportunities.

As always, the social program will provide venues for **networking, fellowship, and good food**. On Sunday, a Welcome Reception will be held at the Convention Center. Monday we will explore the New Mexico History Museum, and Tuesday's Bingham Medal Banquet will be held at the Santa Fe Railyards and Farmer's Market Pavilion. The social program will close on Wednesday with the poster session and reception.

Santa Fe Mural. Credit: TOURISM Santa Fe

And don't forget: Abstracts for the poster session, Gallery of Rheology, and Videos of Rheology are due on August 15th!

Congress Announcement

2025 PHYSICS & ASTRONOMY CONGRESS

October 30–November 1 | Denver, CO

Engage with the Next Generation of Rheologists at #SPSCon 2025

The 2025 Physics and Astronomy Congress (#SPSCon) is the largest gathering of undergraduate physics and astronomy students in the country—an ideal opportunity for graduate programs, research groups, and industry partners in rheology to connect with rising talent. Held in Denver, CO, from November 6–8, 2025, this year's Congress will highlight the diverse career paths available to students, including those where rheology plays a critical role in areas like materials science, fluid dynamics, energy systems, and industrial applications.

Why Participate?

In addition to staffing a booth at the Career & Grad Fair, rheology-focused institutions and professionals can plug into Congress programming in several meaningful ways:

- Tours of NREL, NIST, and NOAA: These site visits will appeal to students interested in energy systems, environmental monitoring, and precision measurement—areas where rheology is essential to sustainable material development and fluid characterization.
- Careers in Industry Panel: Showcases how rheology intersects with real-world applications in energy, materials science, and manufacturing through this engaging student-facing panel.
- Lunch with Scientists: Members of the rheology community are encouraged to participate in this popular event to share career insights directly with students. Sign-up will be available through the Congress registration portal when it launches.

Explore Sponsorship Opportunities

Sponsorships are available for workshops, plenary sessions, student experiences, and networking events. Supporting #SPSCon is a meaningful way to raise visibility for your program or organization and to help students discover how rheology can shape their futures.

Learn more and explore how your organization can get involved at #SPSCon 2025:

Antony N. Beris
2025 Bingham Medalist

by Norman Wagner

The Society of Rheology proudly announces Professor Antony N. Beris as the recipient of the 2025 Bingham Medal, honoring a career marked by exceptional theoretical and computational contributions to the field of complex fluid dynamics and rheology. The Arthur B. Metzner Professor at the University of Delaware, Antony has pioneered our modern understanding of how internal microstructure interacts with flow, across a wide spectrum of materials and applications. His higher education is a Diploma of Chemical Engineering from National Technical University of Athens and PhD in Chemical Engineering from MIT with Robert Armstrong (Bingham Medal 2006) and Robert Brown. He became a Fellow of the Society in 2016 and holds fellowships in APS (DFD, 2021) and AAAS (1999). Among other honors, he received the Willem Prins Award in 2015 from Delft University for his work in polymer rheology.

Professor Beris's research spans microscopic to macroscopic modeling and simulation, uniting theory and computation to resolve important scientific and technical problems in our discipline. At the core of his work is the development and application of a rigorous nonequilibrium thermodynamics framework that integrates both reversible (Hamiltonian) and irreversible (dissipative) dynamics. His seminal monograph, *Thermodynamics of Flowing Systems with Internal Microstructure* (Oxford University Press, 1994, co-authored with B.J. Edwards), introduced a unified formalism using generalized Poisson and dissipation brackets. This approach laid a consistent theoretical foundation for modeling complex fluids such as polymeric systems, liquid crystals, emulsions, and thixotropic suspensions, and continues to be a defining reference in the field, with over 1400 citations.

Beris's contributions to computational rheology are equally groundbreaking. In the 1990s, he and his collaborators pioneered direct numerical simulations (DNS) of viscoelastic turbulent flows using the FENE-P model, demonstrating polymer-induced drag reduction from first principles. These simulations tackled the formidable challenge of coupling three-dimensional unsteady Navier-Stokes equations with the evolution of a conformation tensor. The resulting insights helped elucidate the energy transfer mechanisms in polymer-laden turbulence and inspired a new generation of computational studies across the globe.

His early work on viscoplastic flows includes foundational contributions to the field. His 1985 *J. Fluid Mech.* paper, co-authored with Tsamopoulos, Armstrong, and Brown, provided the first detailed analysis of the creeping motion of a sphere through a Bingham plastic. The study introduced asymptotic approximations for drag and identified unyielded zones, setting a standard for future analyses of yield-stress fluids. Antony developed this further to make major contributions to the study of thixotropy and time-dependent rheological phenomena. His 2002 publication in *JNNFM* with Mujumdar and Metzner proposed a new structural model for thixotropic suspensions. Another hallmark of his work is the extension of the Cox-Merz rule to yield-stress and thixotropic systems, as described in his widely cited 1991 *JoR* paper. His more recent studies on blood rheology, such as his 2014 *JoR* paper and 2021 review in *Soft Matter* have advanced our fundamental understanding of red blood cell aggregation and dispersion in physiological flows, providing parameterized models that align closely with steady and transient experimental data, including new results for unidirectional LAOS (UD-LAOS) designed to mimic *in vivo* pulsatile flows.

Beyond classical systems, Antony has been at the forefront of modeling emerging materials. His work on "living polymers" in rodlike micellar systems brought the dynamics of micelle breakage and reformation into a thermodynamic context through stress-dependent reaction kinetics. His studies of liquid crystals culminated in the Beris-Edwards model, which reconciled and unified earlier theories into a consistent tensorial formulation. His exploration of emulsions, particularly with respect to micro-inertial effects, has offered foundationally new perspectives in this field. A hallmark of his research is the consistent comparison of new theory with leading experimental and simulation data, which has motivated him to also develop novel, powerful computational tools for optimization of parameter fitting by parallel tempering (*AIChE J.*) that find application in model reduction and simplification across a broad range of engineering science.

His scholarly output includes more than 150 refereed publications, a dozen of which have garnered over 150 citations each. He has delivered 188 invited lectures—including keynotes at international congresses—and 328 contributed presentations, primarily on rheology-related topics. His expertise has been widely sought in rheology-related short courses, delivered across the U.S., Europe, and Asia, including notable venues such as the University of Louvain, the Institute of Mathematics and its Applications, the Kavli Institute of the Chinese Academy of Sciences, and most recently, the University of Patras. His outreach to the community includes co-authoring English language translations of classical papers by Geisekus.

Antony Beris has played a central role in community leadership, including the organization of major rheological meetings. He was the program chair for the 66th Annual Meeting of the Society of Rheology (1994), co-chaired the 78th meeting (2006), and has taught numerous international workshops on nonequilibrium thermodynamics and numerical methods for viscoelastic flows. Since 2009, he has served on the editorial board of the *Journal of Non-Newtonian Fluid Mechanics* and has been an active reviewer for all major fluid mechanics and rheology journals.

Equally important is Professor Beris's legacy in education and mentorship. Over the years, he has inspired generations of undergraduate and graduate students through his teaching in fluid mechanics and applied mathematics. His former Ph.D. students have gone on to distinguished academic careers, including some leading academics well known to the rheology community: Lt Col. Matt J. Armstrong (ret. U.S. Military Academy), Brian J. Edwards, (Chem Eng. Univ. Tennessee); Kostas D. Housiadas, (Mathematics, University of the Aegean, Greece); Vlasis G. Mavrantzas, (Chem. Eng., University of Patras and ETH Zurich); R. (Suresh) Sureshkumar, Distinguished Professor (Syracuse), as well as postdocs including Univ.-Prof. Dr. Natalie German (Stuttgart) and Peter Wapperom (Mathematics, VPI), in addition to those who have impactful careers in industry, applying rheological and fluid dynamical insights to diverse sectors including advanced materials, polymers, and biomedical engineering.

Selective testimonials from his nominators underscore this impact, noting that Antony Beris "is a world leader in the fluid dynamics of complex fluids," while also praising his development of a nonequilibrium thermodynamic framework as a "monumental achievement that continues to be required reading for researchers." "Antony is so good and his work is so thorough," citing "his originality, independence and deep thinking, which characterizes his research style." Importantly, "Antony is an excellent teacher. He is able to communicate very difficult concepts to students in a way that they are able to understand them. Overall, he is committed to training the next generation of rheologists." Antony is indeed a keystone in the bridge between nonequilibrium thermodynamics, rheological science, and applied rheology and engineering.

On a personal note, I joined UD in 1991 excited for the opportunity to work with Prof. Arthur Metzner and then Associate Prof. Antony Beris. In the early 90s Antony was working intensely with then PhD student Brian Edwards on the aforementioned book, which was facilitated by teaching a graduate class that I and one of my first doctoral students, Lynn Walker (now Prof. of U. Minn.) boldly endeavored to learn. This seminar class often consisted of Brian and Antony developing the foundational principles of nonequilibrium thermodynamics and working out the bracket formulation for specific applications on the chalk board. We were privileged witnesses to the (sometimes contentious!) birth of a landmark piece of scholarship. Over the past decades at Delaware I have had the honor and pleasure to continue to grow and learn from Antony, including co-mentoring multiple doctoral students and taking deep dives into nonequilibrium thermodynamics and then exploring its practical manifestations. For the past decade, we have endeavored to develop a theoretical

A recent picture of Antony with his wife Sophia, son Nicholas and daughter Zoe.

and experimental understanding of the rich and complex thixotropic behavior of human blood by co-mentoring a cadre of exceptional students, which also facilitated developments in suspension rheology as detailed in a recent book chapter by Antony ("Hemorheology", in Theory and Applications of Colloidal Suspension Rheology, Cambridge Univ. Press, 2021). Always innovating his teaching and research, Antony is developing machine learning tools to advance rheological constitutive equations and more specifically, hemorheology.

With this award, the Society of Rheology honors not only Antony Beris's deep and sustained scientific excellence but also his lasting influence on the field's intellectual foundation and future direction. His scholarship exemplifies the depth, rigor and vision that the Bingham Medal is intended to celebrate. A proud father of Zoe (currently a UD physics student) and Nicholas, Antony and his wife Sophia (see photo accompanying this article) continue the Metznerian traditions of thoughtful and dedicated teaching and mentoring of the next generation of rheologists, as well as attracting international scholars that enrich our academic community and quickly become members of the international family of Delaware rheologists.

The Society of Rheology Mission Statement

Our Vision

An international community of rheologists working towards common goals as articulated in our founding Constitution.

Values

We are the nexus of excellence in the theory and practice of rheology. We are committed to advancement and promotion of the rheological sciences and practice of rheology broadly across diverse groups of individuals, disciplines and industries.

Mission

We aim to expand the knowledge and practice of rheology through education, partnership and collaboration with associated fields, industries, and organizations, as well as to disseminate to diverse communities what rheology is, and how it impacts humanity and the world.

– Adopted by the SoR Executive Committee, 10 June 2017

Safa Jamali
2025 Metzner Award

By Gareth H McKinley

Prof. Safa Jamali (Northeastern University) has made a wide range of multi-faceted and diverse contributions to the science and practice of rheology: from theoretical and fundamental contributions in suspension rheology, bringing advances in AI/ML technologies to rheology in a meaningful way, and to developing computational and data-driven tools that are of utility to a broad spectrum of rheologists. Safa was born in the city of Sari in northern Iran, the youngest of three brothers. He followed his older brother Sina into the area of polymers, and pursued an undergraduate degree in Polymer Engineering at Amirbakir University. Following his graduation in 2008 he applied to the inter-European *Erasmus* educational program in rheology and moved to U.C. Louvain where he studied in his first year with Prof Christian Bailly. Safa recalls doing a lot of extensional rheology measurements together with Florian Stadler who was a postdoc there at the same time, as well as extensive constitutive modeling conversations with Evelyn van Ruymbeke who was also then a postdoc in Louvain. For his second Erasmus year, Safa moved to Univ Minho in Portugal where he joined Jose Covas's polymer processing laboratory and completed a fully experimental masters' thesis project working with extensional and capillary rheometers. Having earned his master's degree in Engineering Rheology in 2010, Safa moved to the US to work with Joao Maia who had relocated from Minho to Case Western Reserve University just a year earlier. Safa was the very first graduate student to work with Joao in the general area of adapting Dissipative Particle Dynamics (DPD) techniques to simulate the nonlinear flow of rheologically-complex systems such as dense colloidal dispersions and he was awarded his Ph.D. in Macromolecular Science and Engineering in Spring 2015. His work at CWRU resulted in seven papers, including lead author contributions to articles in *Soft Matter, J. Chem. Phys.* and *J. Rheology.* DPD is an interesting tool for rheologists because it enables one to span much larger length scales and timescales than is possible with direct molecular dynamics techniques, but the challenge is to develop appropriate potential interaction functions between the rather nebulous 'dissipative particles' that can capture, in a quantitative way, the response of real materials. Safa worked on selecting appropriately soft and long-range potentials and this theoretical work was heavily guided by a (very well-cited) collaboration with Norm Wagner's group at U. Delaware who contributed their extensive experience in experimental colloid science and quantitative rheometry of such systems.

After graduating in May 2015, Safa came to MIT to work jointly with Prof. Bob Armstrong in ChE and me on an industrial-sponsored project funded by Chevron Technology Corporation in the broad area of "Flow Assurance" in the oil & gas sector. Our sponsors were interested in understanding the development of yield stresses, unyielded plug-like regions and other complex soft solid structures in waxy crude oils as they experience a complex thermal and flow history during extraction and pumping from the reservoir to the collection/refining facility. These materials exhibit a set of characteristics that are now commonly called 'elasto-viscoplastic' (EVP) in character and they are also strongly thixotropic (i.e., they show a strong dependence on the entire flow history). They thus present a serious challenge to fluid mechanicians and rheologists interested in trying to simulate the flow of such materials and at that time were not readily described by existing closed-form constitutive theories – which typically focused exclusively on the 'simpler' cases of inelastic/thixotropic materials or viscoelastic fluids such as polymer solutions and melts, or viscoplastic materials such as muds/clay dispersions (*but not all three at once*). EVP modeling has become a hot topic in the world of complex fluids in part because of the rapid and ongoing development of high-energy density flowable battery slurries as well as multiphase fracking fluids and drilling muds etc.

Safa was at MIT for approximately two years and made a number of important contributions that appeared in a series of three papers (two *PRLs* and a *Materials Today Advances* publication). He developed a modified DPD algorithm that allowed him to use soft/long-range Morse potentials to simulate dense clusters (of many 1000s) of hexagonal and weakly-attractive wax microcrystals, over a wide range of timescales, interaction strengths and imposed deformation conditions. His simulations were able to capture much of the complex rheophysics that these materials demonstrate experimentally; including fractal cluster formation and percolation (at very low volume fractions) to form a soft gel-like structure with a static yield stress; as well as elasto-viscoplastic (EVP) response characteristics in small and large deformations. His techniques enabled us to quantify the dynamical evolution in cluster size, shape and orientation under shear – which is manifested globally as the ubiquitous 'thixotropy' measured by experimentalists. The time-dependent simulations also show the onset and growth of spatial instabilities in local number density concentrations that nucleate, advect and grow to form the "shear-bands" that are of great interest to many complex fluid physicists studying materials as diverse as frictional granular flows, monodisperse polymer melts and even wormlike micellar systems. Subsequently Safa also adapted emergent ideas from the granular mechanics community such as computation of a "fabric tensor" which parameterizes and quantifies the particle-level connectivity of the complex sample-spanning ensemble structures that percolate and evolve in the system. His calculations showed that by following the evolution in magnitude and orientation of this fabric tensor we could connect microstructural measures to the simpler and empirical "structural thixotropy parameter" usually favored by experimentalists. While at MIT, Safa also interacted frequently with both Prof. Ken Kamrin in my department and also with the late, great Jim Swan in ChE, who were both interested in related topics in wet granular flows and in colloidal gels respectively.

He has continued to grow and develop these ideas after launching his own career in the Department of Mechanical Engineering at Northeastern University in 2017. In particular, Safa has pioneered a number of data science applications of Machine Learning to rheometry – through a large collection of papers including articles in *J. Rheol.*, a highlighted "young researcher" special feature issue of *Rheol. Acta* as well as several articles published in *Proc. Nat. Acad. Sci.* in 2023 and 2024 with his experimental collaborator, and previous Metzner Award winner, Simon Rogers (ChE, UIUC). These latter articles introduced the idea of a 'digital twin' of a complex fluid *in silico* with parameters that could be "learned" (or best fit) by regression against a wide range of input rheometric data. His body of work as a junior faculty member at Northeastern University has brought AI/ML to complex fluids and rheology, and developed AI tools as robust methods for complex fluid modeling. This work has taken several pathways: from construction and detection of unbiased constitutive models for different complex fluids, to developing multi-fidelity platforms for highly accurate predictions of the rheological behavior of a given system through a general platform called "rheology-informed machine learning". As a pioneer of data-driven techniques in rheology, Safa also wrote a perspective article in the 2023 *Rheology Bulletin*, co-edited a special issue of *Rheologica Acta* and also recently published a 2024 review in *Current Opinions in Colloids and Interface Science*. He continues to spearhead much of our community's efforts in this direction.

Finally, I think it is worth noting how much service time Safa devotes to the rheological community. He has been a staunch supporter and organizer of the *Rheology Research Symposium* since its inception and also serves as Chair of SOR's Membership Committee. He co-organized SOR's extremely successful Covid-era online workshop on the physics of dense suspensions in July 2020 with Emanuela del Gado and Jeff Morris, and was also the Technical Program Co-Chair (with Kendra Erk) last year in Austin, TX. In his spare time (such as it is!) Safa enjoys music and the arts. He plays the hang drum as well as a number of other musical instruments. Like me, he describes himself as a Scotch enthusiast (with a slowly, but steadily growing single malt collection), a decent poker player (unlike me!), and a half-decent cook (fusing different flavors of eastern and western cuisine together). Like many of us he notes that one of the biggest perks of this job is the chance to travel to so many different places, and interact with students and collaborators around the world. His enthusiasm for our field and for SOR is contagious as I hope you will discover during his 2025 award lecture.

Safa Jamali (center) at the ICR2016 in Kyoto with his postdoctoral advisor, Gareth McKinley (left) and PhD advisor, Joao Maia (right) – who were dressed as Samurai as part of the evening reception at Uzumasa.

Announcing the 2025 Elected Fellows of the Society of Rheology

Paulo E. Arratia

University of Pennsylvania

For innovative studies connecting out-of-equilibrium deformation in complex fluids to the resulting bulk transport, flow stability, and rheological properties across diverse systems including jammed suspensions, swimming microorganisms, biological fluids, and granular materials, and for outstanding service to The Society of Rheology as the editor of the Rheology Bulletin.

Randy H. Ewoldt

University of Illinois Urbana-Champaign

For pioneering new paradigms and resolving long-standing questions in the field of rheology, including design thinking for complex fluids, controlling the extensibility of yield-stress fluids, and elucidating the key experimental features and analytical underpinnings of protorheology. His overarching vision is that new engineering designs will result from a deeper fundamental understanding of rheologically-complex materials.

Anke Lindner

Ecole Supérieure de Physique et Chimie Industrielles

For advances in the understanding of the flow of dilute complex suspensions, such as flexible fibre or active suspensions, linking microscopic particle dynamics to macroscopic rheology using innovative microfluidic approaches.

Joao M. Maia

Case Western Reserve University

For excellence in advancing the processing of polymers and polymer blends to enable multifunctional materials and for developing innovative in-line measurement tools for polymer processing.

Matteo Pasquali

Rice University

For fundamental contribution to the rheology and phase behavior of soft phases of carbon nanotubes, graphene, and boron-nitride nanotubes, including the understanding of individual nanorod dynamics; for the development of new carbon materials and their solution processing methods, and for contributions to the rheology of emulsions, polymer solutions, and blood.

Fernando Pinho

Universidade do Porto

For contributions to the understanding of the turbulent flow of polymer solutions, developing the first rigorous turbulence models for dilute polymer solutions and for significant contributions to the study of microfluidic flows of complex fluids.

Patrick T. Spicer

University of New South Wales

"Dr. Patrick Spicer pioneers complex fluid research, designing smart fluids with unique flow behavior. At P&G, he developed processes to produce nanoparticles of bicontinuous cubic liquid crystalline phase, cubosomes, and advanced microrheology for stability. At UNSW, he studies complex fluid microstructures, enhancing commercial product design through rheology and applied engineering."

News from the Journal of Rheology

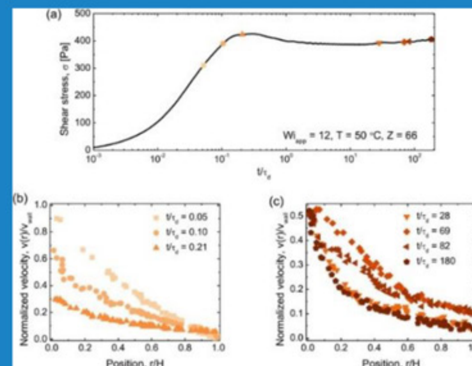
2025 Best Paper Award

"Flow-concentration coupling determines features of nonhomogeneous flow and shear banding in entangled polymer solutions"

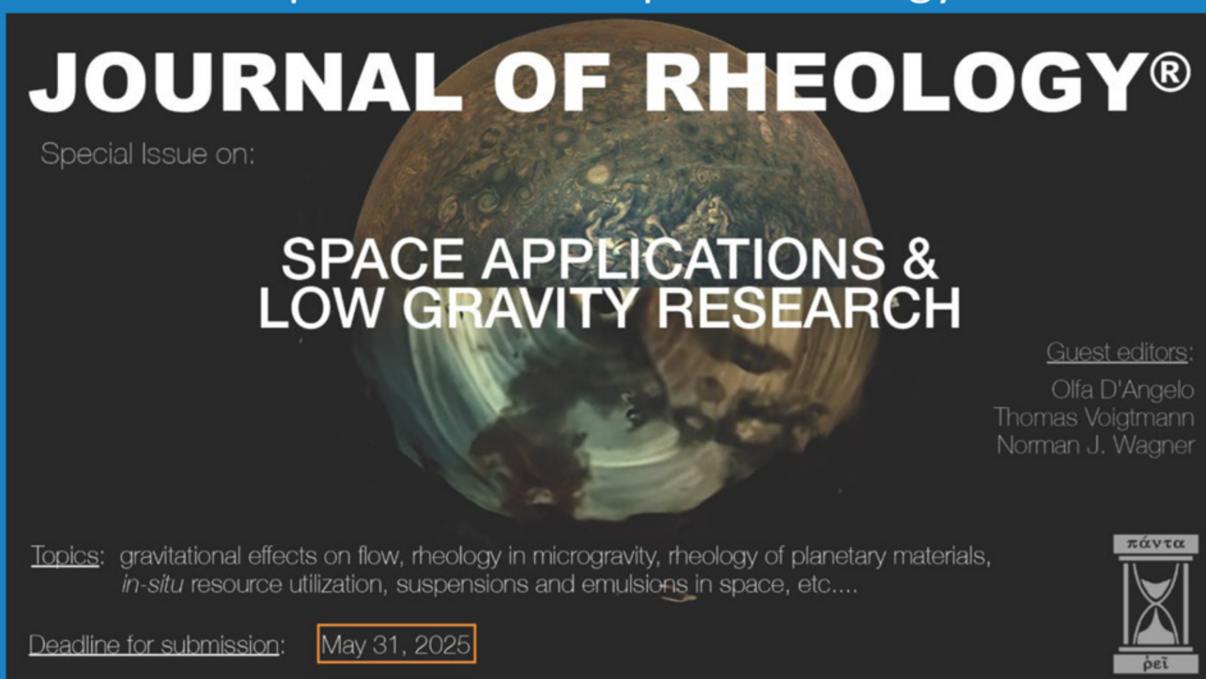
Michael C. Burroughs[1], Yuanyi Zhang[1], Abhishek Shetty[2], Christopher M. Bates[1,3], Matthew E. Helgeson[1], and L. Gary Leal[1]

[1]Department of Chemical Engineering, University of California, Santa Barbara, [2]Anton Paar USA, Inc., [3]Department of Materials, University of California, Santa Barbara

J. Rheol. **67**(1), 219–239 (2023)



Special Issue on Space Rheology



Computational Rheology of Complex Fluids: Polymeric & Wormlike Micellar Solution Cases

J. Esteban López-Aguilar

ABSTRACT

In this work, the essence of Non-Newtonian Fluid Mechanics and Computational Rheology is presented through three examples applied to the rheological characterisation of polymeric solutions using the SwanINNFM(q) family-of-fluids (1-5), and of worm-like micellar solutions using the BMP + _τ_p rheological equation-of-state (6-8), within the computational modelling of two benchmark flows in Non-Newtonian Fluid Mechanics: contraction-expansion flow geometries and flow past a sphere. The predictive capabilities of our computational tools are demonstrated, where mathematical models derived from conservation principles are solved (9-11) alongside the construction of constitutive equations from theoretical rheology (1-11). These mathematical models are solved using a computational algorithm based on a hybrid formulation of spatial discretisation in the form of finite elements for the mass and momentum balance equations, and finite volumes for the constitutive equation (1-8, 12-15). In contraction-expansion type benchmark flows, firstly for polymeric fluids, experimental pressure-drop measurements were reproduced quantitatively using the SwanINNFM family-of-fluids (1-5). We were able, for the first time, to predict quantitatively and explain long-standing augmented excess pressure-drops and highly-dynamic vortex structures observed in the flow of polymeric Boger fluids (16-21). Building upon contraction-expansion flows of thixo-viscoelastoplastic concentrated worm-like micellar solutions, the effects of considering extreme shear thinning and flow segregation through yield stress and shear banding were demonstrated (6-8, 22). Using the BMP + _τ_p constitutive model (8), shear bands are predicted in fully-developed flow zones away from the constriction, and their interaction with the complex deformation imposed by the contraction is reported. For the flow-past-sphere benchmark flow (7), numerical solutions obtained with the BMP + _τ_p model qualitatively reproduce features reported experimentally for the descent of spheres in worm-like micellar solutions, i.e., a flow instability associated with oscillations in the sphere settling velocity and negative wakes (22), and, for relatively concentrated micellar solutions, asymmetrical yield fronts.

INTRODUCTION

One of the fundamental contributions of rheology is the identification of diverse materials as Newtonian (those that follow Newton's Law of Viscosity, i.e., those which display a constant viscosity at constant temperature and pressure), and as non-Newtonian, i.e., those that do not comply with the Newtonian definition. The latter manifest non-linear flow properties through a variable apparent viscosity with deformation rate, time of an imposed flow, and even displaying simultaneous liquid and solid properties in the form of viscoelasticity and yield stress, to name a few typical rheological responses (9-11).

In its practice, rheology divides its study into four main areas (9-11): *(i) rheometry*, which spans over material-property measurement, e.g., fundamentally viscosity, elastic modulus, relaxation time; *(ii) constitutive modelling*, through which constitutive equations seek to reproduce and explain the material properties of complex fluids; *(iii) non-Newtonian fluid mechanics*, which studies the flow of non-Newtonian materials in complex geometries, whose essence lies in inhomogeneous deformations (deformations that combine shear and extension simultaneously in the flow field) and are reflected in physical arrangements with diverse geometric changes observed in nature and in technological applications, such as contractions and expansions, and flows around objects, among others; *and (iv) computational rheology*, which focuses its efforts in obtaining approximate numerical solutions to the flows studied in non-Newtonian fluid mechanics.

Complex fluids are materials with non-linear rheological characteristics derived from their microstructure, which may be classified as soft matter (9-11). Complex fluids are found in countless technological applications, e.g., cements, paints, toothpaste, foams, crude oil and its heavy fractions, drilling muds in oil extraction, foodstuff, mayonnaise, plastics, reactive mixtures, and cosmetics (9-11, 22-31). In addition, many biological fluids, such as blood, mucus, saliva and tissues, may display non-linear rheological properties (32-36).

The combination of: (i) the non-linear rheological properties of complex fluids, (ii) the conservation equations, i.e. of mass, momentum and thermal energy, and (iii) the simultaneous non-homogeneous shear and extensional deformations imposed in complex flows, result in mathematical problems of the highest complexity when attempting to describe, understand, and theoretically predict the experimental manifestations in non-Newtonian Fluid Mechanics (37-40). The interest of *Computational Rheology* is the prediction of complex flows of non-Newtonian materials. It bases its action on the development and application of advanced numerical techniques to the highly non-linear partial-differential-equation systems that represent flow problems whose solution is practically unattainable by exact methods (37-40).

There is a plethora of *numerical algorithms* for solving computational rheology problems (37-41). In general, their formulation has as a basis on Eulerian or Lagrangian frames of reference. The most popular Eulerian algorithms are based on finite-element and finite-volume methods (6-8, 37-40), devised to cover the mixed parabolic-hyperbolic nature of the mass-momentum-energy balance and constitutive equations. On the side of Lagrangian algorithms, particle dynamics methods (Smoothed Particle Hydrodynamics, Dissipative Particle Dynamics and lubrication dynamics methods), are among the most widely used (41), and represent a suitable option for the computational prediction of the rheology of suspensions and particulate systems (42).

Polymeric materials (melts and solutions) are made up of long-chain molecules, which interact closely through entanglement and reptation in molten and dissolved states. These interactions are the origin of their characteristic non-Newtonian features, in the form of marked shear thinning, and viscoelasticity through significantly-augmented normal-stress differences (10-11). The reflection of such rheological response in complex deformations has been a matter of extensive research (16-21). Studies on many benchmark flows have focused on their kinematic and dynamic response, for which augmented pressure drops and diverse vortex-enhancement mechanisms occupy a central role (16-21). In fact, the theoretical prediction and understanding of such features remain an open research topic to date, where efforts are still being concentrated in elucidating how polymeric materials respond under inhomogeneous deformations (1-6).

Wormlike micellar solutions (WLMs) are complex fluids composed of dispersions of elongated micelles that interact essentially through relatively weak entanglements; these physical interactions promote their thixotropic, viscoelastic and plastic properties (22, 25-31). WLMs are also known as *living polymers*, due to their ability to restructure when flowing by two mechanisms, i.e., (i) reptation, as polymers do, and (ii) construction and destruction of micellar structures (22, 25-31). For these reasons and their varied rheological properties, these complex thixo-viscoelastoplastic materials are used in a wide range of applications, such as in cleaning and home and health-care products (shampoos, soaps, detergents, drug carriers); in the petroleum industry, as drilling and well-stimulation fluids; in pumping systems, lubricants and emulsifiers (22, 25-31).

The diversity of rheological properties of polymers and WLMs is a challenge for the development of constitutive equations capable of describing their experimental manifestations in simple and complex flows (37-40). Polymers and WLMs generally display shear thinning, extensional hardening and softening, viscoelasticity, thixotropy (16-21, 22, 25-31) and, in the specific case of WLMs, flow segregation in the form of yield stress (27) and banding (35). All of these responses occur simultaneously and manifest across diverse spatial-temporal scales (22, 25-31, 35).

Constitutive equations for polymeric materials are diverse and numerous, some coming from microscopic arguments and others based on continuum approaches (11). Among the most widely-used constitutive-equation approaches of differential nature are those of the FENE type, where the Peterlin and the Chilcott-Rallison closures dominate (11, 43-44), and the Phan-Thien-Tanner paradigm (45), which have been successful in reproducing and explaining the response of a wide range of polymer melts and solutions.

For WLMs, constitutive equations are still being developed (6-8, 22, 46-50). There are two main theoretical frameworks, namely, (i) theories based on *structural variables*, and (ii) *microscopic theories*. The former are the most popular, as they portray the evolution of the internal WLM structure, explicitly related to material functions (6-8, 46, 48-49). Among these models are those in the Bautista-Manero-Puig (BMP) (6-8) and de Souza-Mendes (48-49) families. The constitutive equations in the BMP framework predict key properties of WLMs and other complex fluids, and have been successfully used to study the flow of WLMs in complex deformations (6-8). Microscopic theories study the interaction of micelles in their construction/destruction dynamics in flow, via kinetic equations whose solution is related to material properties through averages (47, 50).

Experimental studies on the flow of polymeric fluids and WLMs in complex geometries reveal rich features, with dynamic vortex-enhancement mechanisms and pressure drops. These act as alternative energy-dissipation mechanisms in contraction flows, and through drag coefficients in sphere settling, revealing instabilities manifested in particle oscillations and negative wakes (16-22, 51).

In benchmark contraction and contraction-expansion flows, complex vortex dynamics have been recorded experimentally. At low volumetric flow rates, symmetric kinematic structures are observed, similar to those observed in the contraction flow of Newtonian fluids. At high volumetric flow rate, asymmetric vortices, promoted by viscoelasticity, lead to time-dependent chaotic flows (16-22, 51).

In the sedimentation of smooth spheres in semi-dilute WLMs, oscillations in the particle descent velocity have been reported. These are caused by strong negative wakes behind the sphere; for polymeric liquids, a similar response is recorded as velocity overshoots (16-21, 51). These phenomena have been studied as flow instabilities with respect to the steady rate of descent characteristic of Newtonian fluids (22). In WLMs, these findings have been attributed to the complex dynamics of structure construction-destruction of the elongated micelles (leading to thixotropy) and the viscoelasticity of the micellar solution (6-8, 22). For concentrated mixtures, these thixo-viscoelastoplastic solutions form gels that display markedly-asymmetric yield fronts around the sphere (22, 51), as previously reported by Holenberg et al. (52) and Putz et al. (53).

One of the iconic manifestations of WLMs is a type of flow segregation called shear-banding, which is characterised by a spontaneous separation of the solution into two or more shear bands of material that coexist, supporting a constant shear stress, but with distinct apparent viscosity (8, 22, 35).

This paper presents a compendium of research work conducted by the author on computational predictions of the response of polymeric and WLM solutions in complex benchmark flows (1-8). These works illustrate the use of *computational rheology* in the numerical solution of two typical problems of non-Newtonian fluid mechanics: flows past a sphere (7), and flows through contractions and contraction-expansions (6,8). These benchmark flows have industrial and technological applicability; (i) flow around spheres is applied in particle suspension in medicine and the food industry (shelf life), and is also an approximation for clay transport in enhanced oil extraction fluids (37-40); whilst (ii) contraction-expansion flow is found in industrial equipment with pipe and fitting changes (37-40), and lies at the heart of polymer and food processing operations (22, 54).

BALANCE AND CONSTITUTIVE EQUATIONS

The general statement of the problem of non-Newtonian flow in complex geometries, i.e., generalised flow systems with changes in shape and cross section, is based on the fundamental conservation equations and appropriate constitutive equations accounting for the rheological response of the materials considered. For incompressible, isothermal, non-Newtonian flow, the mass and momentum balance equations in dimensionless form are:

$$\nabla \cdot \boldsymbol{u} = 0, \quad (1)$$

$$Re\left(\frac{\partial \boldsymbol{u}}{\partial t} + \boldsymbol{u} \cdot \nabla \boldsymbol{u}\right) = -\nabla p + \nabla \cdot \boldsymbol{T}, \quad (2)$$

where $\boldsymbol{u}$ represents the velocity, p is the isotropic pressure, t symbolises time and ∇ is the gradient operator, which acts upon the three dimensions of space. The Reynolds number $Re = \frac{\rho UL}{\eta_0}$ characterises the flow regime through the ratio of inertial forces experienced by the moving material against dissipative viscous forces. Here, ρ represents the material density, $\eta_0 = \eta_{p0} + \eta_s$ is a characteristic viscosity, given by the level of the first Newtonian plateau in the flow curve (Fig. 1a), which is defined as the sum of the viscous contributions of the Newtonian solvent η_s and non-Newtonian solute η_{p0} at vanishing deformation rates, if the fluid is conceived as a solution. U and L represent, respectively, characteristic velocity and length scales. Here, the characteristic velocity U is associated with the volumetric flow rate for flow around a sphere (Fig. 2a) and for a pressure-driven contraction flow (Fig. 2b); in contrast, U is associated with the velocity of the sliding wall of the contraction-expansion geometry in the modified Couette flow of Fig. 2c. Complementarily, the characteristic length L is related to the geometry considered: in the case of contraction-type flows, it is associated with the diameter of the constriction smallest gap, and, in the case of flow past a sphere, it is related to the particle diameter.

In non-Newtonian fluid mechanics, it is convenient to consider the fluids as solutions with solute and solvent components. This is a concept known as Elastic-Viscous Stress-Splitting (EVSS) (10-11), where the solvent is specified as Newtonian and the solute carries the non-Newtonian characteristics of the solution. This approach allows for a broad applicability of rheological concepts to the characterisation of many types of materials with diverse non-Newtonian characteristics, such as polymer solutions (16-21), biofluids (32-36), metallic alloys (55), among many others. Thus, within the framework of the EVSS, the total stress tensor $\boldsymbol{T}$ is divided into two contributions: (i) the Newtonian solvent contribution, i.e., $\boldsymbol{\tau}_s = 2\eta_s \boldsymbol{D} = 2\eta_0(1-\beta)\boldsymbol{D}$; and (ii) the contribution of the non-Newtonian solute $\boldsymbol{\tau}_p$, for which a rheological equation-of-state must be specified and provides the nonlinear characteristics of the solution. Here, $\boldsymbol{D} = \frac{1}{2}\left[\nabla \boldsymbol{u} + (\nabla \boldsymbol{u})^T\right]$ is the rate-of-deformation tensor, which collects the symmetric shear and normal deformation rates that a fluid element can experience in a three-dimensional space. Furthermore, in the diffusive term on the

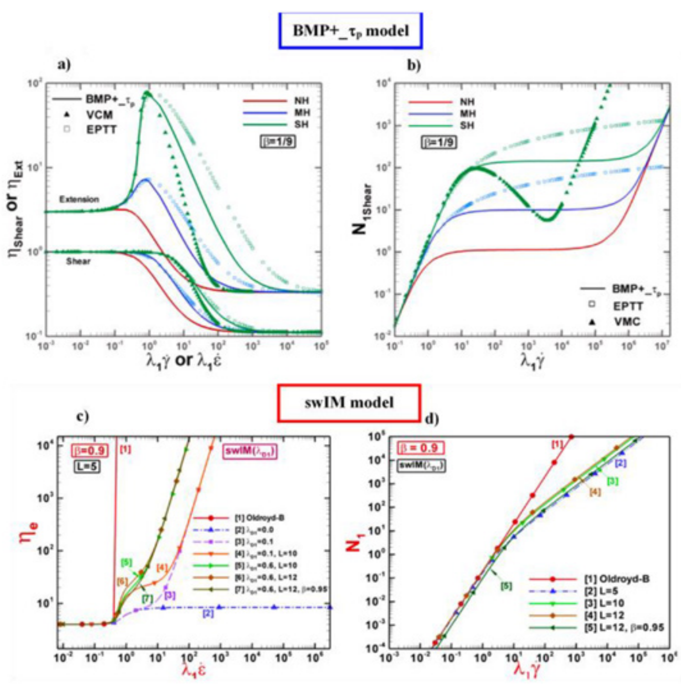


FIGURE 1. a) and b) BMP + $\_\tau_p$ model material functions in steady simple shear and uniaxial extension; rheological responses for three fluids with apparently Null Hardening (NH; $\{\omega,\xi_{G0}\} = \{4,1\}$), moderate (MH; $\{\omega,\xi_{G0}\} = \{4,0.1125\}$) and severe (SH; $\{\omega,\xi_{G0}\} = \{0.28,0.1125\}$) features; $\beta = 1/9$ - comparison against Exponential Phan-Thien-Tanner (EPTT) and Vasquez-Cook-McKinley (VCM) models. c) and d) SwanINNFM(q) swIM model extensional viscosity and first normal-stress difference in shear. Reprinted from Journal of Non-Newtonian Fluid Mechanics, Vol. 309, J. Esteban López-Aguilar, Osvaldo Resendiz-Tolentino, Hamid R. Tamaddon-Jahromi, Marco Ellero, Octavio Manero, Flow past a sphere: Numerical predictions of thixo-viscoelastoplastic wormlike micellar solutions, 104902 1-22, Copyright (2022), and from Journal of Non-Newtonian Fluid Mechanics, Vol. 273, Michael F. Webster, Hamid R. Tamaddon-Jahromi, J. Esteban López-Aguilar, David M. Binding, Enhanced pressure drop, planar contraction flows and continuous spectrum models, 104184, Copyright (2019), with the permission of Elsevier.

RHS of the solvent stress equation, the solvent fraction $\beta = \frac{\eta_s}{\eta_{p0}+\eta_s} = \frac{\eta_s}{\eta_0}$ defines a dimensionless viscosity by comparing the viscosity of the solvent η_s against the total viscosity of the solution at vanishing deformation rates $\eta_0 = \eta_{p0} + \eta_s$. The domain of this dimensionless viscosity is $0 < \beta \le 1$; here, $\beta = 1$ characterises a fluid with pure Newtonian characteristics and viscosity η_0, whilst, complementarily, the $\beta \to 0$ limit defines the response of an extremely concentrated system with non-Newtonian features. Thus, the solvent fraction β serves as a measure of the viscous solute-to-solvent contributions to the total stress $\boldsymbol{T}$.

To specify the rheological response of the non-Newtonian solute, whose stress is represented by $\boldsymbol{\tau}_p$, and focusing on WLMs, this work considers the BMP theoretical framework in its most recent variant: the BMP + _τp model (6-8). This rheological equation-of-state predicts the essential rheological response of WLMs (25-31). For this purpose, the solute stress obeys a generalised Oldroyd-B-type differential form:

$$f\boldsymbol{\tau}_p + De\overset{\nabla}{\boldsymbol{\tau}}_p = 2(1-\beta)\boldsymbol{D}, \tag{3}$$

where the Deborah number $De = \lambda_1 \frac{U}{L}$ modulates the viscoelastic properties of the solution through the relaxation time of the material $\lambda_1 = \frac{\eta_{p0}}{G_0}$, which is defined by the ratio of the solute viscosity η_{p0} and the elastic modulus G_0, both measured at low deformation rates. The viscoelastic response of the solute resides in the upper-convected derivative of the stress:

$$\overset{\nabla}{\boldsymbol{\tau}}_p = \frac{\partial \boldsymbol{\tau}_p}{\partial t} + \boldsymbol{u}\cdot\nabla\boldsymbol{\tau}_p - (\nabla\boldsymbol{u})^T\cdot\boldsymbol{\tau}_p - \boldsymbol{\tau}_p\cdot\nabla\boldsymbol{u}. \tag{4}$$

Its first term accounts for the variation of stress over time at a fixed point, the second term considers the temporal variation of stress due to motion, and the last two terms close the definition with the contribution given by the deformation of the material per se.

Finally, the first term on the LHS of Eq. (3) considers a material internal-structure functional $f = \frac{\eta_{p0}}{\eta_p}$, which, for models in the BMP formalism, is defined through a measure of the dimensionless solute fluidity. This internal-structure functional f obeys a temporal evolution through the following kinetic equation of fluid-structure construction and destruction (6-8):

$$\frac{\partial f}{\partial t} + \boldsymbol{u}\cdot\nabla f = \frac{1}{\omega}(1-f) + \left(\xi_{G_0}De - \xi f\right)\left|\boldsymbol{\tau}_p : \boldsymbol{D}\right|. \tag{5}$$

The LHS of Eq. (5) measures the spatial-temporal evolution of the dimensionless fluidity, whilst its RHS contains kinetic terms that measure the rates of internal-structure construction and destruction of the micellar solution, respectively, and which are reflected in the change of the fluidity of the material. Here, the dimensionless time $\omega = \lambda_s \frac{U}{L}$ modulates the rate of formation of internal structure of the micellar solution. Complementarily, $\xi_{G_0} = k_0 G_0 \frac{\eta_{p0}+\eta_s}{\eta_\infty+\delta}$ and $\xi = k_0(\eta_{p_0} + \eta_s)\frac{U}{L}$ are dimensionless stresses associated with the destruction of the internal structure of the material; here, k_0 is the inverse of the characteristic stress required to break the internal structure between the elongated micelles in suspension, and $\eta_\infty + \delta$ is the viscosity of the solute at high deformation rates. The mechanism of structure destruction is promoted by the magnitude of the energy dissipated by the solute per unit volume $\left|\boldsymbol{\tau}_p : \boldsymbol{D}\right|$ under flow. Furthermore, to include the formation of banded flows, the structure-destruction coefficient must take a linear functionality with respect to the rate-of-deformation tensor (8), i.e., $k(\boldsymbol{D}) = k_0\left[1 + \vartheta II_{\boldsymbol{D}}\right]$, where ϑ is the shear-banding intensity parameter, and $II_{\boldsymbol{D}} = \sqrt{\frac{1}{2}\boldsymbol{D}:\boldsymbol{D}}$ is the second invariant of the rate-of-deformation tensor.

Eq. (5) stands for the latest model-variant in the BMP family, i.e., BMP + _τp model, which considers the coupling of thixotropy and viscoelasticity in the evolution of the material structure. Additionally, it provides a non-linear evolution of the first normal-stress difference in steady simple shear, and an extensional viscosity response with hardening and softening, all in line with fingerprints of typical WLMs (see Fig. 1a-b).

For polymeric solutions, the base constitutive equation approach used is that under the SwanINNFM(q) umbrella (1-5), which is constructed within a FENE-CR framework, and supplemented with a White-Metzner functionality on the viscous coefficient. Here, the conformation-tensor $\boldsymbol{A}$-form of the base SwanINNFM(q) model is:

$$f(tr\boldsymbol{A})(\boldsymbol{A}-\boldsymbol{I}) + De\overset{\nabla}{\boldsymbol{A}} = 0. \tag{6}$$

The FENE-CR structure functional is defined as:

$$f(tr\boldsymbol{A}) = \frac{1}{1 - \frac{tr\boldsymbol{A}}{L^2}}, \tag{7}$$

where L^2 is the finite extensibility parameter. The Kramers rule translates the conformation tensor and the stress tensor signals as follows:

$$\boldsymbol{\tau}_p = \frac{1-\boldsymbol{\beta}}{\boldsymbol{De}} f(tr\boldsymbol{A})(\boldsymbol{A}-\boldsymbol{I}). \tag{8}$$

Finally, the implementation of the dissipative extensional-function $\boldsymbol{\phi}(\dot{\varepsilon}) = 1 + (\lambda_D\dot{\varepsilon})^2$ serves to devise an extensional viscosity boosting mechanism via an extension-dissipative timescale λ_D modulating the influence of the relevant extensional rate-of-deformation measure under specific complex flow and spatial geometry. $\boldsymbol{\phi}(\dot{\boldsymbol{\varepsilon}})$ is defined as a quadratic form from the truncated Taylor-series approximation of the corresponding cosh-exponential functionality. This dissipative-extensional function $\boldsymbol{\phi}(\dot{\varepsilon})$ appears in the total stress equation as follows:

$$\boldsymbol{T} = \frac{1-\boldsymbol{\beta}}{De} f(tr\boldsymbol{A})(\boldsymbol{A}-\boldsymbol{I})\boldsymbol{\phi}(\dot{\varepsilon}) + 2\boldsymbol{\beta}\boldsymbol{\phi}(\dot{\varepsilon})\boldsymbol{D}. \tag{9}$$

Multimode formulations and further functionalization have used on the viscous coefficient for specific applications – for further details, see (1-5). In Fig. 1c-d, typical response provided by the SwanINNFM(q) model variants, i.e., the swIM model, is illustrated. Here, one notes the control of the extensional viscosity response provided through λ_D, covering the window between the two limiting cases of FENE-CR and Oldroyd-B responses. In addition, these models provide a parametrisation for the first normal-stress difference in shear N_1, via a softening relative to the Oldroyd-B quadratic response.

HYBRID NUMERICAL ALGORITHM OF FINITE ELEMENTS AND FINITE VOLUMES

The mathematical problem at hand in Eqs. (1)-(9), embodies a system of non-linear partial differential equations that must be solved numerically with advanced algorithms. A hybrid numerical algorithm based on finite-element and finite-volume discretisation approximations is used in this work to obtain numerical solutions to the problem of polymeric and WLMs flow in complex geometries (1-8;12-15). This numerical algorithm is based on a hybrid scheme, built on a three-stage, semi-implicit, fractional-time scheme that utilises its finite-element discretisation for velocity and pressure, and its finite-volume approximation for stress and fluidity. This procedure combines the advantages and benefits offered by each discretisation approach individually. The Galerkin finite-element discretisation is applied to the components of the Cauchy-continuity equations [Eqs. (1)-(2)], with fractional steps for the momentum equation in Stage 1, the pressure-correction equation in Stage 2, and the incompressibility constraint in Stage 3, to ensure higher-order accuracy. Regarding its implementation, this leads to an element-by-element Jacobi iteration in space for Stages 1 and 3; whilst for pressure-correction in Stage 2, a direct Choleski solution method is used. Quadratic velocity interpolation is imposed on the triangular finite-element cell, along with linear interpolation for pressure. In contrast, for the finite-volume sub-cell, a triangular subdivision is constructed within the finite-element cell, by connecting the intermediate nodes of the triangular-cell. Here, stress and fluidity variables [Eqs. (3)-(8)] are located at the vertices of the finite-volume sub-cells; thus, interpolation of the solution is avoided. For further details, see (1-8; 12-15).

COMPLEX FLOW SETTINGS

1) **Contraction-expansion flow of polymeric solutions (1-5), and WLMs under shear-banding conditions (8).**

   In Fig. 2b, a schematic of a generalised flow domain for contraction flows is provided. Some boundary conditions are shared between the settings for the flow of polymeric liquids and WLMs. These are:

   a. No-slip boundary conditions on solid walls. Velocity is imposed as Dirichlet boundary conditions on the contraction walls.
   b. At the geometry inlet (left) and outlet (right), velocity and stress are imposed by solving the constitutive equation in simple shear flow.

   For the specific case of the flow of shear-banding WLMs (Fig. 2c):

   a) *Flow inception.* In this case, the flow is promoted through the drag exerted by the upper plate on the fluid. On the upper part of the geometry, the micellar solution moves with the plate velocity. In the lower part, the flow is fixed and anchored to the solid wall that forms the obstruction.
   b) *Frame of reference.* The geometry is a planar contraction-expansion, which we have designated as a modified Couette flow (8).
   c) *Entry and exit conditions.* Velocity may involve a single linear profile or a profile with two or more shear bands with different velocities but supporting a single stress level, characteristic of a banded flow. Pressure is readjusted by the obstacle and is maintained at a constant level in the fully-developed flow regions, as expected in a classical Couette flow.

2) **Descent of a sphere in WLMs in a tube (7).**

   Fig. 2a illustrates the flow field of a sphere descending within a micellar fluid contained in a tube. For convenience, the geometry is shown horizontally. Since the system is symmetrical, half of the flow domain is shown, where the following boundary conditions apply:

   a) *No-slip boundary condition on the surface of the sphere.* Here, the basic assumption of fluid adhesion on solid surfaces is considered as well, i.e., the velocity of the fluid in contact with the obstacle is equal to the sphere velocity.
   b) *Symmetry condition along the equatorial axis of the sphere.* A symmetry condition is applied behind and in front of the sphere, where velocity and stress are continuous.
   c) *Flow inception.* The flow in this computational arrangement is promoted by a constant velocity applied from left to right with respect to the orientation of the illustration, keeping the sphere fixed. Here, the imposed base volumetric flow rate is unitary, which is increased consecutively in the simulations. This increase in flow rate is reflected through the increase in Deborah number, which, in this case, correlates with the volumetric flow rate as follows: $De = \lambda_1 \frac{U}{L}$, where U is the approaching velocity (Fig. 2a).

   For the three examples treated in this work, the following implementations are considered for numerical stability and convergence:

   a) *The VGR correction.* Non-homogeneous extensional

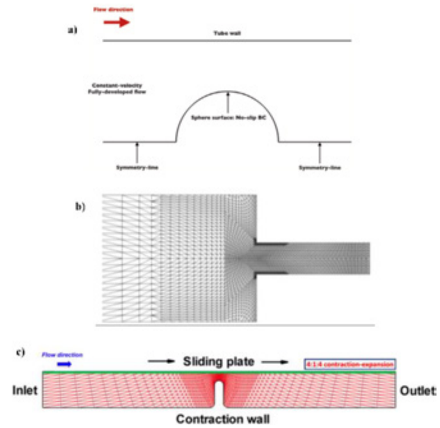


FIGURE 2. a) Schematics of flow past sphere; b) Schematics of 4:1 contraction-expansion flow; and c) Schematics of the flow through a plane contraction-expansion with rounded edges. Reprinted from Journal of Non-Newtonian Fluid Mechanics, Vol. 309, J. Esteban López-Aguilar, Osvaldo Resendiz-Tolentino, Hamid R. Tamaddon-Jahromi, Marco Ellero, Octavio Manero, Flow past a sphere: Numerical predictions of thixo-viscoelastoplastic wormlike micellar solutions, 104902 1-22, Copyright (2022), with permission from Elsevier, from Physics of Fluids, Vol. 28, J. Esteban López-Aguilar, Hamid R. Tamaddon-Jahromi, Michael F. Webster, Ken Walters. Numerical vs experimental pressure drops for Boger fluids in sharp-corner contraction flow, 103104–23, Copyright (2016), and from Vol. 35, J. Esteban López-Aguilar, Hamid R. Tamaddon-Jahromi, Marco Ellero, Octavio Manero, Shear banding predictions for wormlike micellar systems under a contraction–expansion complex flow, 063101 1-22, Copyright (2023), with permission from AIP Publishing.

deformations are specified through the relevant velocity-gradient components in the symmetry lines – this is referred to in (6-8) as the VGR correction.

b) *The ABS-f correction*. The so-called ABS-*f* correction is considered, where an absolute value operation is applied to the flow quantities used in the internal-structure *f*-functional within the constitutive equation promoting the exposure of non-linear rheological features of the material. This correction provides material function prediction (in these cases, viscosity) in line with the Second Law of Thermodynamics (6-8). For the BMP + _τ_p model, the ABS-*f* correction applies over the dissipation function $\left|\boldsymbol{\tau}_p : \boldsymbol{D}\right|$ components in Eq. (5), whilst in the SwanINNFM(q) models, this correction is implemented over the $tr\boldsymbol{A}$-components.

RESULTS

In this section, the main results of modelling the flows described in the previous section through the SwanINNFM(q) and BMP + _τ_p equations are described, for which numerical solutions were obtained using our hybrid finite-element/finite-volume numerical algorithm (1-8;12-15).

For *flow past a sphere* (7), the predictive capabilities of our numerical tools are described in terms of: (i) the dimensionless drag coefficient $\frac{K}{K_{Newtonian}}$, which reflects the energy required for a sphere to descend in a WLMs and reveals flow transitions; (ii) vortex dynamics, where the spatial evolution of the flow field behind the sphere is studied and a non-homogeneous uniaxial extensional flow is verified, i.e., with an inhomogeneous uniaxial extension rate; and (iii) the correlation of this response with the evolution of the internal structure parameter of the material *f*. For the flow through *contraction-expansion geometries,* similar signals are gathered for polymeric liquids, where significantly-augmented pressure drops and highly-dynamic vortex structures are recorded, whilst for a WLMs capable of developing shear bands (8), the results reflect: (i) velocity fields with two or more flow bands and the interaction of this structured flow with the obstruction; (ii) with this, the characteristics of a banded flow are studied in a two-dimensional geometry and their consequences on other variables, such as dimensionless fluidity and normal stresses (viscoelasticity).

1. Contraction-expansion flow of polymeric solutions (1-5)

In Fig. 3, a comparison between experimental and predictive trends on pressure drops against flow rate increase is provided for a sharp-cornered axisymmetric 4:1 contraction flow of Boger PAA/corn syrup based fluids (1). Here, the experimental viscoelastic pressure-drop augmented trends are matched quantitatively with our SwanINNFM(q) model under $\boldsymbol{\lambda}_D = 1.2$. In addition, kinematic information accompanies these trends, with a vortex-enhancement path starting with a salient-corner vortex at relatively small flow rates that grows in size and intensity with *Q*-rise, evolving into an elastic-corner vortex that dominates the constriction. Moreover, vortex-intensity $-\Psi_{min}$ follows a monotonic rising trend with *Q*-rise. This may be correlated with the basic SwanINNFM(q) extensional-viscosity η_{Ext}-response, for which $\boldsymbol{\lambda}_D \neq 0$ promotes a sustained rise (see Fig. 1c).

In Fig. 4, excess pressure drop (*epd*) against dimensionless flow rate data is provided for the flow of a similar Boger PAA/corn syrup fluid in a sharp-cornered 10:1:10 axisymmetric contraction-expansion geometry (2). Outstanding *epd* values were experimentally recorded, with the largest signal levelling over some five-to-six times that of an equivalently-viscous Newtonian corn-syrup fluid. Here, the swIM model-variant in the SwanINNFM(q) family-of-fluids captures the whole window of *epd*-response under rising λ_D. A sample of the vortex activity for these fluids is provided in Fig. 5, where, under the same 10:1:10 contraction flow settings and an average $\lambda_D = 0.3$, renders a map of the vortex-enhancement path predicted. Here, a three-staged vortex evolution with *De*-rise is recorded, with a symmetric salient-corner vortex regime at relatively small dimensionless flow rates, followed by the coexistence of salient-corner and lip vortices at intermediate *De*-numbers, to finally evolve into an elastic-corner-vortex regime at large flow rates.

In Fig. 6, attention is paid to a distinct contraction flow setting under 4:1 planar sharp-cornered configuration, in which we were able to capture the so-called *bulb flow* reported by Binding and Walters (21). Here, we provide a vortex-activity path that resembles the qualitative description provided by Binding and Walters (21), for which, after a steady regime dominated by relatively reduced salient-corner vortices, a lip vortex arises with *Q*-rise in a transitionary regime, which strengthens and coexists with the salient-corner structure, thus creating the bulb flow. This transitionary phase is characterised computationally by solution fluctuation, recorded through periodic variations of pressure, velocity and stress, illustrated here through their L2-norms.

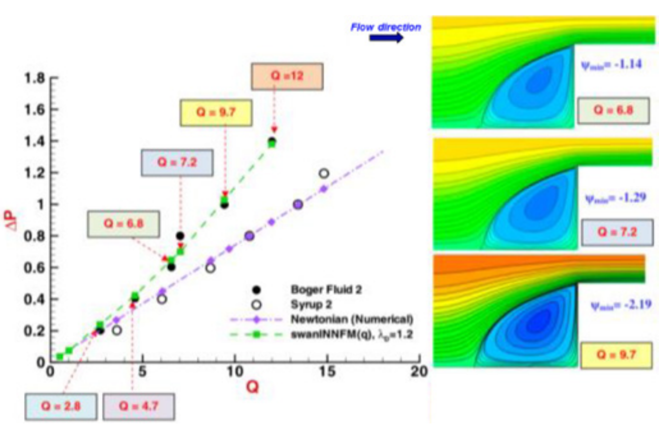


FIGURE 3. Pressure drops against flow rate, vortex intensity and streamlines; SwanINNFM(q) swIM model-variant, $\lambda_d = 1.2$. Reprinted from Physics of Fluids, Vol. 28, J. Esteban López-Aguilar, Hamid R. Tamaddon-Jahromi, Michael F. Webster, Ken Walters. Numerical vs experimental pressure drops for Boger fluids in sharp-corner contraction flow, 103104–23, Copyright (2016), with the permission of AIP Publishing.

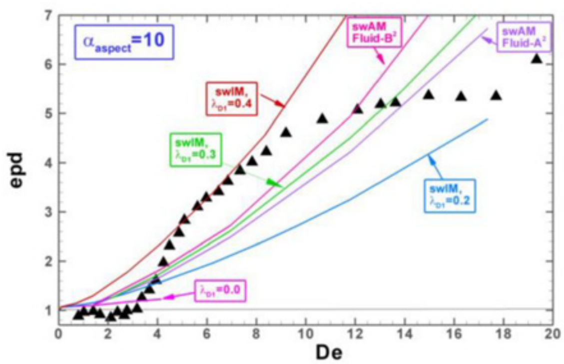


FIGURE 4. Excess pressure drop against dimensionless flow rate; SwanINNFM(q) swIM and swAM model-variant; 10:1:10 sharp-cornered axisymmetric contraction-expansion. Reprinted from Physics of Fluids, Vol. 29**,** J. Esteban López-Aguilar, Michael F. Webster, Hamid R. Tamaddon-Jahromi, Octavio Manero, David M. Binding, Ken Walters, On the use of continuous spectrum and discrete-mode differential models to predict contraction-flow pressure drops for Boger fluids., 121613–18, Copyright (2017), with the permission of AIP Publishing.

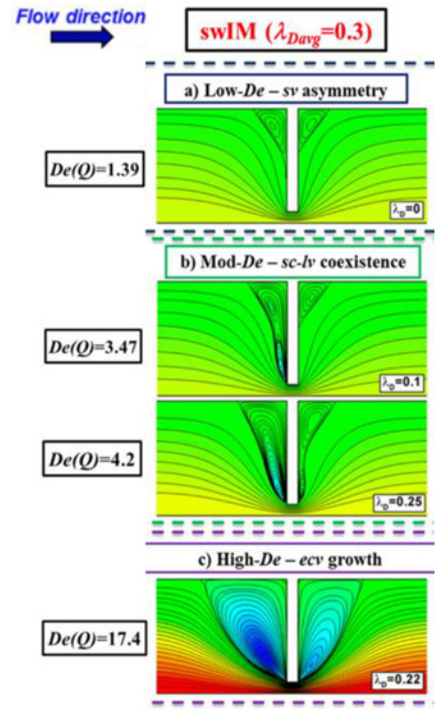


FIGURE 5. Streamlines against flow rate; SwanINNFM(q) swIM model-variant; 10:1:10 sharp-cornered axisymmetric contraction-expansion. Reprinted from Physics of Fluids, Vol. 29, J. Esteban López-Aguilar, Michael F. Webster, Hamid R. Tamaddon-Jahromi, Octavio Manero, David M. Binding, Ken Walters, On the use of continuous spectrum and discrete-mode differential models to predict contraction-flow pressure drops for Boger fluids., 121613–18, Copyright (2017), with the permission of AIP Publishing.

These kinds of trends in augmented pressure drops and vortex-enhancement mechanism are found with different flow settings and under varying constriction aspect ratios. In general, the outlined pressure-drop-against-flow-rate trends are correlated with the extensional viscosity features of the polymeric solution studied. Vortex structure and evolution have been found correlated with the first normal-stress response within the corners of the constriction. For further details on these general findings, the characteristics of the constitutive models used, and the numerical implementation, the author refers the reader to (1-5).

2. Flow past sphere of WLMs (7)

In Fig. 7, predictions obtained for the dimensionless drag coefficient $\frac{K}{K_{Newtonian}}$ are plotted against dimensionless volumetric flow rate in the form of Deborah number De, for three semi-dilute WLMs under a solvent fraction of $\beta = 0.5$ and three variations of extensional properties with extensional response apparently No-Hardening (NH), Moderate Hardening (MH) and Strong Hardening (SH) – see Fig. 1a and its extensional viscosity response. The results obtained for $\frac{K}{K_{Newtonian}}$ are referred to the ideal case of a Newtonian fluid with equivalent viscosity; this base case is plotted in Fig. 7 and appears as a unitary horizontal line. The WLMs under NH shows a stronger and abrupt decline with De-rise, even showing a plateau at high De-levels that asymptotes to $\frac{K}{K_{Newtonian}} = 0.5$. The MH case reflects a similar decrease, although its $\frac{K}{K_{Newtonian}}$ values are higher than those under the NH case. This response correlates with the relatively higher forces and viscosities, both in shear and extension, sustained by the MH solution (Fig. 1a-b), a trend that is sustained and is even more marked with the SH case. Interestingly, these declining $\frac{K}{K_{Newtonian}}$-trends are observed in typical experimental studies of sphere settling in WLMs (22).

With focus on the MH case in Fig. 7, it is worth highlighting the fluctuations recorded in $\frac{K}{K_{Newtonian}}$ at high De. These fluctuations are associated with the development of vortices behind the sphere, which are one of the key flow structures in flow past spheres, i.e., the development of negative wakes (see Fig .8a). These flow instabilities are characterised by occurring at relatively high De; for the case illustrated in Fig. 7, the critical dimensionless volumetric flow rate for the instability is $De_{crit} = 24$. Here in Fig. 8a, one can see a sample of the vortex located at the equator of the sphere, which forms, grows, intensifies and suppresses cyclically over time (see (7)). It is worth mentioning that this type of instabilities have been widely studied experimentally, happening at De numbers in the range of tenths of units (22, 51). Our research group is one of the first to report the theoretical-computational description of this phenomenon for WLMs (7).

In Fig. 8b, the dimensionless fluidity is illustrated, where a fluctuating state is apparent as a reflection of the vortex activity and the associated negative-wake cycle of Fig. 8a. One should recall that this dimensionless fluidity serves, in the BMP + $\_\tau_p$ model, to estimate the level and the evolution of the material internal structure. Thus, these graphs depict, by correspondence, the change in the structure of the material due to the deformation imposed by the obstacle. In this case, it is worth highlighting that, in the instance of fluctuations in the sphere settling velocity, the structure of the material behind the sphere shows significant variation, revealing the influence of the predominantly-extensional inhomogeneous flow in the obstacle wake. This phenomenon has been attributed as the ruling factor for the development of fluctuations in the sphere settling velocity in WLMs, associated with a mechanism of micellar sudden rupture in the sphere

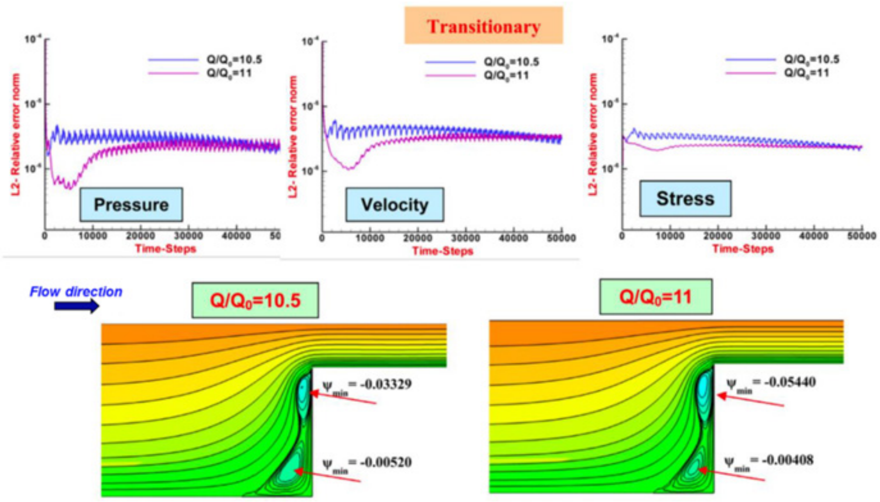


FIGURE 6. Streamlines and L2-norms. Bulb flow. SwanINNFM(q) swAM model-variant. Reprinted from Journal of Non-Newtonian Fluid Mechanics, Vol. 273, Michael F. Webster, Hamid R. Tamaddon-Jahromi, J. Esteban López-Aguilar, David M. Binding, Enhanced pressure drop, planar contraction flows and continuous spectrum models, 104184, Copyright (2019), with the permission of Elsevier.

wake due to the stretching they suffer (22, 51).

Moving on to the analysis of *concentrated WLMs*, characterised with the BMP + _τ$_p$ model, under $\boldsymbol{\beta} \rightarrow 0$, one should recognise that these materials take a semi-solid consistency, where their plastic properties are measured through an apparent yield stress. Numerical predictions are illustrated in Fig. 9 through yield-front data. These yield fronts contrast the yielded zones (fluidised; in red) close to the sphere and the unyielded zones (semi-solid; in blue). These regions are identified via the comparison of the stress experienced by the fluid, measured through the stress second invariant experienced by the solute, i.e., $II_{\bar{\bar{\tau}}_p} = \sqrt{\frac{1}{2}\bar{\bar{\boldsymbol{\tau}}}_p : \bar{\bar{\boldsymbol{\tau}}}_p}$, and the yield stress $\boldsymbol{\tau}_0$. In Fig. 9, graphical evidence is provided contrasting the effects of decreasing the solvent fraction $\boldsymbol{\beta}$ (increasing plasticity and thus $\boldsymbol{\tau}_0$) in the range $0.005 \leq \boldsymbol{\beta} \leq 1/9$, against De. Here, one may note that, under a fixed De, decreasing $\boldsymbol{\beta}$ promotes the growth of the semisolid blues zones, even finding instances where there is practically no liquefied material in the flow field; this would lead to spheres suspended in a semisolid gel. In contrast, under a fixed $\boldsymbol{\beta}$, increasing De promotes asymmetry and growth of the yielded-red zones. These asymmetries result from the combination of the WLMs thixo-viscoelastoplastic properties successfully captured with the BMP + _τ$_p$ model. Notably, these findings correspond satisfactorily with experimental reports for Carbopol and WLMs through which smooth spheres of different materials generate asymmetric yield fronts (52-53).

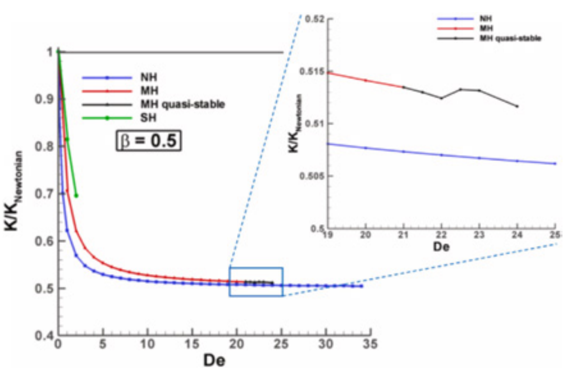


FIGURE 7. Dimensionless drag coefficient $\frac{K}{K_{Newtonian}}$ against dimensionless volumetric flow rate De; BMP + _τ$_p$ model; NH: {ω,ξ$_{G0}$} = {4,1}), MH: {ω,ξ$_{G0}$} = {4,0.1125} y SH: {ω,ξ$_{G0}$} = {0.28,0.1125}; β = 0.5. Reprinted from Journal of Non-Newtonian Fluid Mechanics, Vol. 309, J. Esteban López-Aguilar, Osvaldo Resendiz-Tolentino, Hamid R. Tamaddon-Jahromi, Marco Ellero, Octavio Manero, Flow past a sphere: Numerical predictions of thixo-viscoelastoplastic wormlike micellar solutions, 104902 1-22, Copyright (2022), with permission from Elsevier.

3. Shear Banding in Complex Deformations (8)

In this subsection, the flow of a WLM susceptible to forming shear bands is analysed, i.e., in viscosity. The flow curves and material properties of WLMs that can develop banded flows are illustrated in Fig. 10. Here, the key feature for developing shear bands is the presence of a total shear-stress T_{xy} flow curve following a non-monotonic trend (Fig. 10a): a sigmoidal curve with a negatively-sloped section in an intermediate shear-rate range. This region of the flow curve is identified as the *unstable branch*, whilst the sections with positive slope at high and low shear rates are designated as *stable branches*. In Fig. 10b, the reflection of the development of shear bands can be observed: the presence of the unstable zone in the stress causes an exaggerated shear thinning in the WLMs apparent viscosity, alongside the development of non-monotonic curves in the first normal-stress difference in shear $N_{1_{Shear}}$ (Fig. 10c); the extensional viscosity remains invariant. The development of banded flows is promoted in the BMP + _τ$_p$ model through increasing the dimensionless shear-banding intensity parameter $\zeta = \vartheta \frac{U}{L}$, which in Fig. 10 takes the values of $\zeta = \{0,3\}$. Here, the $\zeta = 0$ case represents a fluid without the ability to develop shear bands (note its monotonic curve), whilst $\zeta = 3$ characterises a fluid with an unstable branch at intermediate shear rates, capable of developing shear bands. Other models, such as the Vasquez-Cook-McKinley (VCM) model, produce similar responses (50), as depicted in Fig. 10.

In Fig. 11, numerical solutions are provided of the modified Couette flow of a banding WLM fluid under $\zeta = 3$ and a non-banding fluid under $\zeta = 0$. Here, under the banding mode (left), the development of two shear bands in U_x is observed in the fully-developed flow

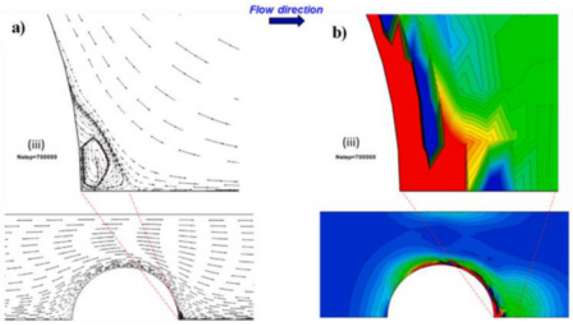


FIGURE 8. a) Stream function and b) dimensionless fluidity at $De_{crit} = 24$; BMP + _τ_p model; MH: {ω,ξ_{G0}} = {4,0.1125}; β = 0.5. Development of negative wakes. Reprinted from Journal of Non-Newtonian Fluid Mechanics, Vol. 309, J. Esteban López-Aguilar, Osvaldo Resendiz-Tolentino, Hamid R. Tamaddon-Jahromi, Marco Ellero, Octavio Manero, Flow past a sphere: Numerical predictions of thixo-viscoelastoplastic wormlike micellar solutions, 104902 1-22, Copyright (2022), with permission from Elsevier.

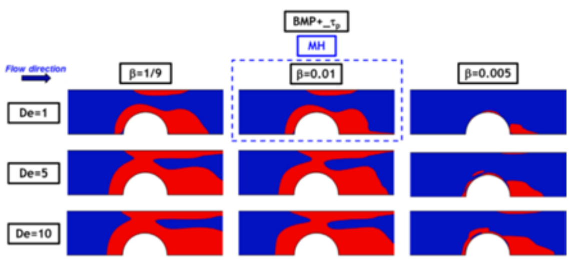


FIGURE 9. Yield fronts against flow rate and solvent fraction; BMP + _τ_p model; MH: {ω,ξ_{G0}} = {4,0.1125}; β = {1/9, 0.01, 0.001}. Reprinted from Journal of Non-Newtonian Fluid Mechanics, Vol. 309, J. Esteban López-Aguilar, Osvaldo Resendiz-Tolentino, Hamid R. Tamaddon-Jahromi, Marco Ellero, Octavio Manero, Flow past a sphere: Numerical predictions of thixo-viscoelastoplastic wormlike micellar solutions, 104902 1-22, Copyright (2022), with permission from Elsevier.

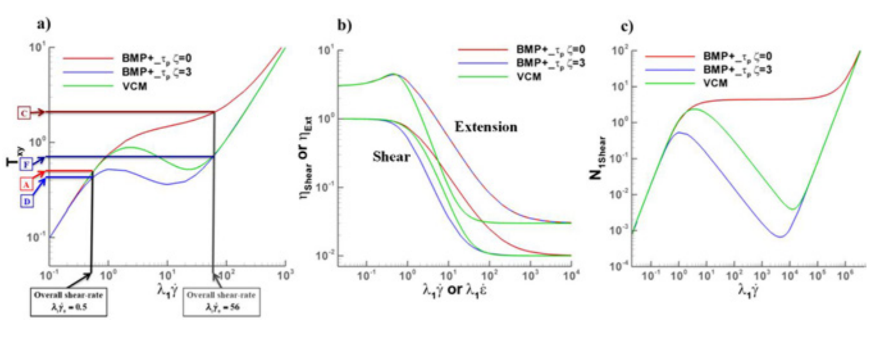


FIGURE 10. (a) Shear stress T_{xy}, (b) shear η_{Shear} and extensional η_{Ext} viscosities, and (c) first normal-stress difference in shear $N_{1_{Shear}}$; BMP + _τ_p model; {ω,ξ_{G0}} = {4,0.1136}, $\beta = 0.01$, $\zeta = \{0,3\}$. Reprinted from Physics of Fluids, Vol. 35, J. Esteban López-Aguilar, Hamid R. Tamaddon-Jahromi, Marco Ellero, Octavio Manero, Shear banding predictions for wormlike micellar systems under a contraction–expansion complex flow, 063101 1-22, Copyright (2023), with permission from AIP Publishing.

regions far from the constriction, one with red shading, which correlates with relatively high velocities, and another with blue shading, which corresponds to relatively lower velocities. This response is translated in the shear-rate $\frac{\partial U_x}{\partial y}$ plot into two bands marked by relatively high (red) and low (blue) shear rates, which occupy the flow domain, and coincide with the viscosity, fluidity and normal-stress T_{xx} bands, respectively. In contrast, the shear-stress T_{xy} and pressure P fields remain homogeneous in the fully-developed flow regions; the small fluctuations in T_{xy} are related to the discontinuity posed by the interface between the two shear bands and are minimal in magnitude.

Regarding the phenomenology observed in the contraction zone, one notes that the fully-developed banded flow developed by the fluid under $\zeta = 3$ is lost when the material interacts with the obstacle. Once the material leaves the constriction zone and advances towards the simple-shear, fully-developed-flow downstream region, the material develops shear bands again.

One can contrast the behaviour of a WLM fluid not susceptible to developing shear bands, i.e., under non-banding $\zeta = 0$ mode in Fig. 11 (right). Here, the flow structure contrasts with what was described for the banding case, since the flow fields do not display abrupt changes in the form of bands, although asymmetry is maintained, promoted by the thixo-viscoelastic BMP + _τ_p properties.

It is worth mentioning that this is one of the first theoretical-computational works capable of reproducing a shear-banded flow in a geometry that combines shear and extensional flows simultaneously (8). In addition, these predictions can be used to analyse the flow of other types of complex fluids that are processed in extruders, by idealising the contraction that materials undergo in nozzles to acquire their final shape, such as molten polymers and foods (54).

CONCLUSIONS

In this work, the area of action of Non-Newtonian Fluid Mechanics and Computational Rheology has been fundamentally explained (9-11, 37-40), and its predictive potential for problems related to its application has been illustrated through three examples applied to a variety of materials widely used in the chemical industry: polymeric (16-21) and

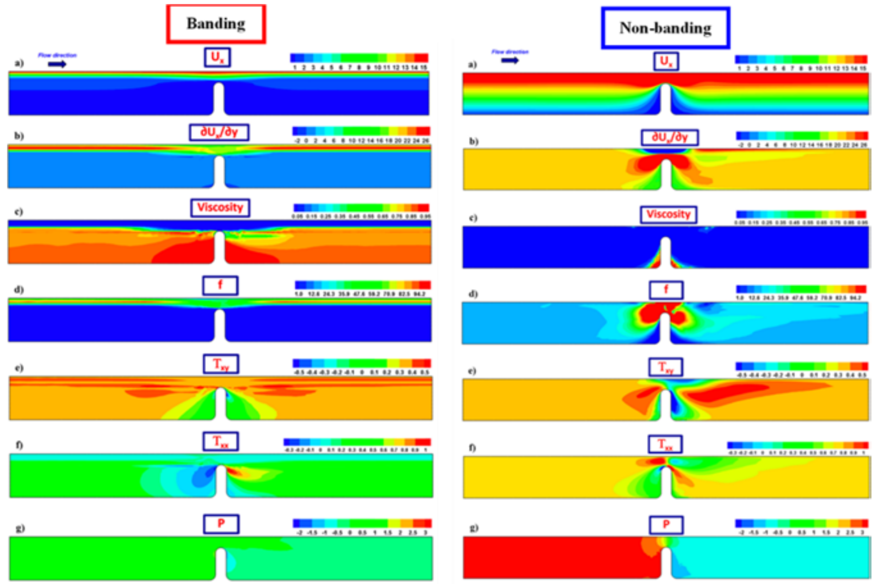


FIGURE 11. Velocity in the *x*-direction v_x, shear rate $\frac{\partial v_x}{\partial y}$, viscosity η_p, fluidity $f = \frac{\eta_{p0}}{\eta_p}$, shear stress T_{xy}, normal stress in *x*-direction T_{xx}, pressure *P*; BMP + $\_\tau_p$ model; $\zeta = \{0,3\}$, $\{\omega,\xi_{G0}\} = \{4,0.1136\}$, $\beta = 0.01$. Reprinted from Physics of Fluids, Vol. 35, J. Esteban López-Aguilar, Hamid R. Tamaddon-Jahromi, Marco Ellero, Octavio Manero, Shear banding predictions for wormlike micellar systems under a contraction–expansion complex flow, 063101 1-22, Copyright (2023), with permission from AIP Publishing.

wormlike micellar solutions (22, 26-31). The examples discussed in this article are benchmark flows in Non-Newtonian Fluid Mechanics (22, 37-40): (i) flow past a sphere and (ii) flow through diverse contraction-expansion settings. The constitutive equations used to characterise the viscoelastic and thixo-viscoelastoplastic rheological properties of polymeric and WLMs are the SwanINNFM(q) model (1-5) and the BMP + $\_\tau_p$ model (6-8). The mathematical models resulting from the consideration of the isothermal two-dimensional flow under incompressible conditions of polymeric and WLMs are solved with a hybrid finite element-volume numerical algorithm (1-8, 12-15).

With these theoretical and numerical tool-sets, we reported success in the prediction of key experimental signals in contraction-type flows of polymeric solutions, such as augmented pressure-drops with respect to Newtonian fluids, and complex vortex-enhancement routes that reveal dissipation mechanisms enabling the flow of these materials through constricted geometries (1-5), even capturing shear-banded flows in planar contraction-expansion flow-settings for WLMs (7). Computational signals for instabilities in particle settling within dilute WLMs were reported, for which fluctuations in the flow field behind the sphere are recorded through cyclical-growing vortices and highly-variable fluid structure (8). For more concentrated WLMs, asymmetrical yield fronts were captured, resembling experimental flow structures reported for Carbopol and typical WLMs (8).

Through the description of these three examples, the usefulness that theoretical-computational predictive tools can have for non-Newtonian fluid mechanics is demonstrated, where the detailed computational solution of complex flow systems with non-Newtonian materials provides numerical data that can help to model, describe, analyse, and understand flow processes of interest in industrial and technological applications for other various materials, such as metallic alloys (55), in medicine, and in bioengineering (33-37).

ACKNOWLEDGEMENTS

The author acknowledges the support from Secretaría de Ciencia, Humanidades, Tecnologías e Innovación (SECIHTI – Ex-CONAHCYT, México - grant number CF-2023-I-318), from Universidad Nacional Autónoma de México (UNAM) (grant numbers PAPIIT IN106424, PAPIME PE103125 y PAIP 5000-9172 Facultad de Química).

Author

J. Esteban López-Aguilar is a Professor of Chemical Engineering at the Chemical Engineering Department, Facultad de Química, Universidad Nacional Autónoma de México (UNAM) since 2017. He received his Bachelors (2007) and Masters (2009) degrees from UNAM, and his PhD in Chemical Engineering (2016) from Swansea University (UK), where he also carried out postdoctoral activities at the Zienkiewicz Centre for Computational Engineering (2016-2017). He is Level 1 in the National System of Researchers, SECIHTI, MX-Government. Esteban belongs to various scientific societies, including his Associate Membership to the Institute of Non-Newtonian Fluid Mechanics (UK), Visiting Fellowship to the Basque Centre for Applied Mathematics (BCAM; Bilbao, Spain), and Board Membership to the Mexican Polymer Society. His research interests focus on Non-Newtonian Fluid Mechanics, with special emphasis on computational rheology and constitutive modeling of complex fluids and soft matter, such as viscoelastic surfactant solutions, melts and polymer solutions, suspensions and biofluids.

REFERENCES

1. López-Aguilar, J. E., Tamaddon-Jahromi, H. R., Webster, M. F., Walters, K. (2016) Numerical vs experimental pressure drops for Boger fluids in sharp-corner contraction flow, Phys. Fluids **28**, 103104 10.1063/1.4966022.
2. López-Aguilar, J. E., Webster, M. F., Tamaddon-Jahromi, H. R., Pérez-Camacho, M., Manero, O. (2016) Contraction-ratio variation and prediction of large experimental pressure-drops in sharp-corner circular contraction-expansions-Boger fluids, J. Non-Newton. Fluid Mech. **237**, 39–53 10.1016/j.jnnfm.2016.10.005.
3. López-Aguilar, J. E., Webster, M. F., Tamaddon-Jahromi, H. R., Manero, O., Binding, D. M., Walters, K. (2017) On the use of continuous spectrum and discrete-mode differential models to predict contraction-flow pressure drops for Boger fluids, Phys. Fluids, **29**, 121613–18 10.1063/1.4991872.
4. Webster, M. F., Tamaddon-Jahromi, H. R., López-Aguilar, J. E., Binding, D. M. (2019) Enhanced pressure drop, planar contraction flows and continuous spectrum models, J. Non-Newton. Fluid Mech. **273**, 104184 10.1016/j.jnnfm.2019.104184.

5. López-Aguilar, J. E., Tamaddon-Jahromi, H. R. (2020) Computational Predictions for Boger Fluids and Circular Contraction Flow under Various Aspect Ratios, Fluids **5**, 85–22 10.3390/fluids5020085.
6. López-Aguilar, J. E., Webster, M. F., Tamaddon-Jahromi, H. R., Manero, O. (2018) Predictions for circular contraction-expansion flows with viscoelastoplastic & thixotropic fluids, J. Non-Newton. Fluid Mech. **261**, 188–210 10.1016/j.jnnfm.2018.09.001.
7. López-Aguilar, J. E., Resendiz-Tolentino, O., Tamaddon-Jarohmi, H. R., Ellero, M., Manero, O. (2022) Flow past a sphere: Numerical predictions of thixo-viscoelastoplastic wormlike micellar solutions, J. Non-Newton. Fluid Mech. **309**, 104902 10.1016/j.jnnfm.2022.104902.
8. López-Aguilar, J. E., Tamaddon-Jahromi, H. R., Manero, O. (2023) Shear banding predictions for wormlike micellar systems under a contraction–expansion complex flow, Phys. Fluids **35**, 063101 10.1063/5.0143432.
9. Bird, R. B., Stewart, W. E., Lightfoot, E. N. (1960) Transport Phenomena, Wiley: 1st Edition.
10. Barnes, H. A., Hutton, J. F., Walters, K. (1989) An introduction to rheology, Elsevier: 1st Edition.
11. Bird, R. B., Armstrong, R. C., Hassager, O. (1987) Dynamics of Polymeric Liquids, John Wiley & Sons: 1st Edition.
12. Matallah, H., Townsend, P., Webster, M. F. (1998) Recovery and stress-splitting schemes for viscoelastic flows, J. Non-Newton. Fluid Mech. **75**, 139–166 10.1016/S0377-0257(97)00085-2.
13. Wapperom, P., Webster, M. F. (1998) A second-order hybrid finite-element/volume method for viscoelastic flows, J. Non-Newton. Fluid Mech. **79**, 405–431 10.1016/S0377-0257(98)00124-4.
14. Webster, M. F., Tamaddon-Jahromi, H. R., Aboubacar, M. (2005) Time-dependent algorithms for viscoelastic flow: Finite element/volume schemes, Numer. Meth. Partial Differ. Equ. **21**, 272–296 10.1002/num.20037.
15. Belblidia, F., Matallah, H., Webster, M. F. (2008) Alternative subcell discretisations for viscoelastic flow: velocity-gradient approximation, J. Non-Newton. Fluid Mech. **151**, 69–88 10.1016/j.jnnfm.2006.12.009.
16. Boger, D. V. (1987) Viscoelastic flows through contractions, Annu. Rev. Fluid Mech. **19**, 157–182 10.1109/SFCS.1987.19.
17. Rothstein, J. P., McKinley, G. H. (1999) Extensional flow of a polystyrene Boger fluid through a 4: 1: 4 axisymmetric contraction/expansion, J. Non-Newton. Fluid Mech. **86**, 61–88 10.1016/S0377-0257(98)00202-X.
18. Rothstein, J. P., McKinley, G. H. (2001) The axisymmetric contraction-expansion: the role of extensional rheology on vortex growth dynamics and the enhanced pressure drop, J. Non-Newton. Fluid Mech. **98**, 33–63 10.1016/S0377-0257(01)00094-5.
19. Nigen, S., Walters, K. (2002) Viscoelastic contraction flows: comparison of axisymmetric and planar configurations, J. Non-Newton. Fluid Mech. **102**, 343–359 /10.1016/S0377-0257(01)00186-0.
20. Pérez-Camacho, M., López-Aguilar, J. E., Calderas, F., Manero, O., Webster, M. F. (2015) Pressure-drop and kinematics of viscoelastic flow through an axisymmetric contraction–expansion geometry with various contraction-ratios, J. Non-Newton. Fluid Mech. **222**, 260–271 10.1016/j.jnnfm.2015.01.013
21. Binding, D. M., Walters, K. (1988) On the use of flow through a contraction in estimating the extensional viscosity of mobile polymer solutions, J. Non-Newton. Fluid Mech. **30**, 233–250 10.1016/0377-0257(88)85026-2.
22. Rothstein, J. P., Mohammadigoushki, H. (2020) Complex flows of viscoelastic wormlike micelle solutions, J. Non-Newton. Fluid Mech. **285**, 104382 10.1016/j.jnnfm.2020.104382
23. Bird, R. B. (2004) Five decades of transport phenomena, AIChE J. **50**, 273-287 10.1002/aic.10026.
24. Denn, M. M. (2005) Fifty years of non-Newtonian Fluid Dynamics, AIChE J. **50**, 2335-2345 10.1002/aic.10357.
25. Walker, L. M. (2001) Rheology and structure of worm-like micelles, Curr. Opin. Colloid Interface Sci. **6**, 451–456 10.1016/S1359-0294(01)00116-9.
26. Yang, J. (2002) Viscoelastic wormlike micelles and their applications, Curr. Opin. Colloid Interface Sci. **7**, 276–281 10.1016/S1359-0294(02)00071-7.
27. Bonn, D., Paredes, J., Denn, M. M., Berthier, L., Divoux, T., Manneville, S. (2017) Yield stress materials in soft condensed matter, Rev. Mod. Phys. **89**, 035005 10.1103/RevModPhys.89.035005.
28. Dreiss, C. A. (2007) Wormlike micelles: where do we stand? Recent developments, linear rheology and scattering techniques, Soft Matter **3**, 956–970 10.1039/B705775J.
29. Dreiss, C. A. (2017) Chapter 1. Wormlike Micelles: An Introduction. In: Wormlike Micelles Advances in Systems, Characterisation and Applications, Royal Society of Chemistry, 1–8.
30. Rothstein, J. P. (2008) Strong flows of viscoelastic wormlike micelle solutions, Rheology Reviews, British Society of Rheology, Aberystwyth, Wales, UK.
31. Chu, Z., Dreiss, C. A., Feng, Y. (2013) Smart wormlike micelles, Chem. Soc. Rev. **42**, 7174-7203 10.1039/C3CS35490C.
32. Verdier, C. (2003) Rheological properties of living materials. From cells to tissues, J. Theor. Med. **5**, 67-91 10.1080/10273360410001678083.
33. López-Aguilar, J. E., Webster, M. F., Al-Muslimawi, A. H., Tamaddon-Jahromi, H. R., Williams, P. R., Hawkins, K., Askill, C., Chin, L.C., Davies, G., Ebden, P., Lewis, K. (2015) A Computational Extensional-Rheology Study of Two Biofluid Systems, Rheol. Acta. **54**, 287-305 10.1007/s00397-014-0830-y.
34. Tabatabaei, S., Tamaddon-Jahromi, H. R., Webster, M. F., Williams, P. R., Holder, A. J., Lewis, K. E., Davies, G.A., Griffin, L., Ebden, P., Askill, C. (2015) A CaBER computational-experimental rheological study on human sputum, J. Non-Newton. Fluid Mech. **222,** 272–287 10.1016/j.jnnfm.2015.03.005.
35. Olmsted, P. D. (2008) Perspectives on shear banding in complex fluids, Rheol. Acta. **47**, 283–300 10.1007/s00397-008-0260-9.
36. Horner, J. S., Armstrong, M. J., Wagner, N. J., Beris, A. N. (2019) Measurements of human blood viscoelasticity and thixotropy under steady and transient shear and constitutive modeling thereof, J. Rheol. **63**, 799-813 10.1122/1.5108737.
37. Owens, R. G., Phillips, T. N. (2002) Computational rheology, Imperial College Press: 1st Edition.
38. Walters, K., Webster, M.F. (2003) The distinctive CFD challenges of computational rheology. Int. J. Numer. Meth. Fluids. **43**, 577-596 10.1002/fld.522.
39. Mitsoulis, E., Tsamopoulos, J. (2017) Numerical simulations of complex yield-stress fluid flows, Rheol. Acta. **56**, 1–28 10.1007/s00397-016-0981-0.
40. Alves, M. A., Oliveira, P. J., Pinho, F. T. (2020) Numerical Methods for Viscoelastic Fluid Flows, Ann. Rev. Fluid Mech. **53**, 509-541 10.1146/annurev-fluid-010719-060107.
41. Ellero, M., Espanol P. (2018) Everything You Always Wanted to Know About S-DPD* (*But Were Afraid to Ask), App. Math. Mech. **39**, 103-124 10.1007/s10483-018-2255-6.
42. Rosales-Romero, A., Vázquez-Quesada, A., Prasanna Kumar, S. S., López-Aguilar, J. E., Ellero, M. (2024) Effects of confinement-induced non-Newtonian lubrication forces on the rheology of a dense suspension, J. Non-Newton. Fluid Mech. **329**, 105248 10.1016/j.jnnfm.2024.105248.
43. Chilcott, M. D., Rallison, J. M. (1988) Creeping flow of dilute polymer solutions past cylinders and spheres, J. Non-Newton. Fluid Mech. **29**, 381–432 10.1016/0377-0257(88)85062-6.
44. Rallison, J. M., Hinch, E. J. (1988). Do we understand the physics in the constitutive equation?, J. Non-Newton. Fluid Mech. **29**, 37–55 10.1016/0377-0257(88)85049-3.
45. Phan-Thien, N., Tanner, R. I. (1977) A new constitutive equation derived from network theory, J. Non-Newton. Fluid Mech. **2**, 353-365 10.1016/0377-0257(77)80021-9.
46. Larson, R. G., Wei, Y. (2019) A review of thixotropy and its rheological modelling, J. Rheol. **63**, 477–501 10.1122/1.5055031.
47. Hommel, R. J., Graham, M. D. (2021) Constitutive modeling of dilute wormlike micelle solutions: Shear-induced structure and transient dynamics, J. Non-Newton. Fluid Mech. **295**, 104606 10.1016/j.jnnfm.2021.104606.
48. de Souza Mendes, P. R., Thompson R. L. (2013) A unified approach to model elasto-viscoplastic thixotropic yield-stress materials and apparent yield- stress fluids, Rheol. Acta **52**, 673–694 10.1007/s00397-013-0699-1.
49. de Souza Mendes, P. R., Abedi, B., Thompson, R.L. (2018) Constructing a thixotropy model from rheological experiments, J. Non-Newton. Fluid Mech. **261**, 1–8 10.1016/j.jnnfm.2018.08.003.

50. Zhou, L., McKinley G. H., Cook, L.P. (2014) Wormlike micellar solutions: III. VCM model predictions in steady and transient shearing flows, J. Non-Newton. Fluid Mech. **211**, 70–83 10.1016/j.jnnfm.2014.06.003.
51. Datta, S., Ardekani, A. M., Arratia, P.E., Beris, A. N., Bischofberger, I., McKinley, G. H., Eggers, J. G., López-Aguilar, J. E., Fielding, S. M., Frishman, A., Graham, M. D., Guasto, J. S., Haward, S. J., Shen, A. Q., Hormozi, S., Poole, R. J., Morozov, A., Shankar, V., Shaqfeh, E. S. G., Stark, H., Steinberg, V., Subramanian, G., Stone, H. A. (2022) Perspectives on viscoelastic flow instabilities and elastic turbulence, Phys. Rev. Fluids. **7**, 080701 10.1103/PhysRevFluids.7.080701.
52. Holenberg, Y., Lavrenteva, O. M., Shavit, U., Nir, A. (2012) Particle tracking velocimetry and particle image velocimetry study of the slow motion of rough and smooth solid spheres in a yield-stress fluid, Phys. Rev. E. **86**, 066301 10.1103/PhysRevE.86.066301.
53. Putz, A. M. V., Burghelea, T. I., Frigaard, I. A., Martinez, D.M. (2008) Settling of an isolated spherical particle in a yield stress shear thinning fluid, Phys. Fluids **20**, 033102 10.1063/1.2883937.
54. Tadmor, Z., Gogos, C.G. (2006) Principles of Polymer Processing, Wiley: 2nd Edition.
55. Garcia-Beristain, I., Figueroa-Landeta, M., López-Aguilar, J. E., Garcia de Cortazar, M., Girot, F., Ellero, M. (2023) Numerical simulations of thixotropic semi-solid aluminium alloys in open-rotor and rotor–stator mixers, J. Non-Newton. Fluid Mech. **321**, 105128 10.1016/j.jnnfm.2023.105128.

I Am ~~Not~~ a Rheologist

By Kendra Erk and Matthew Kaboolian

Members of The Society of Rheology (SoR)—from students to fellows—have often uttered the phrase, "I'm not a rheologist, but…" While such comments are frequently lighthearted, self-deprecating, or expressions of humility among scientific peers, they may also reflect our collective experiences related to Impostor Phenomenon (IP).

First described by Clance and Imes in 1978, IP refers to persistent feelings of inadequacy and the fear of being exposed as a "fraud," despite evident success or competence. These feelings are especially common among high-achieving individuals—such as SoR members—and are associated with heightened anxiety, reduced professional risk-taking, and social isolation (2). Notably, research shows that IP is more prevalent among individuals from underrepresented groups in STEM, including women, LGBTQ+ and BIPOC individuals as well as individuals whose professional paths differ from those of their families, including many first-generation college students (3,4). Academic environments, particularly graduate and doctoral programs, can intensify these feelings through competitive and high-pressure cultures (5).

One effective way to counteract IP is to acknowledge and openly discuss it. As Dr. Clance noted, "It's a phenomenon experienced by many, and remembering that can help normalize it."(6) In 2023, we received a Rheology Venture Fund award to raise awareness of IP and investigate its prevalence within the SoR community. Our efforts included a presentation to graduate student members at the 2024 Rheology Research Symposium and the administration of a voluntary, anonymous survey in November 2024 (Purdue IRB: 2024-1571).

The survey included demographic and education questions as well as the Clance Impostor Phenomenon Scale (CIPS), a 20-item assessment that gauges the extent of IP characteristics in individuals.[7,8] Full details on survey design, administration, and data analysis are available on the SoR website: https://zenodo.org/records/15858083.

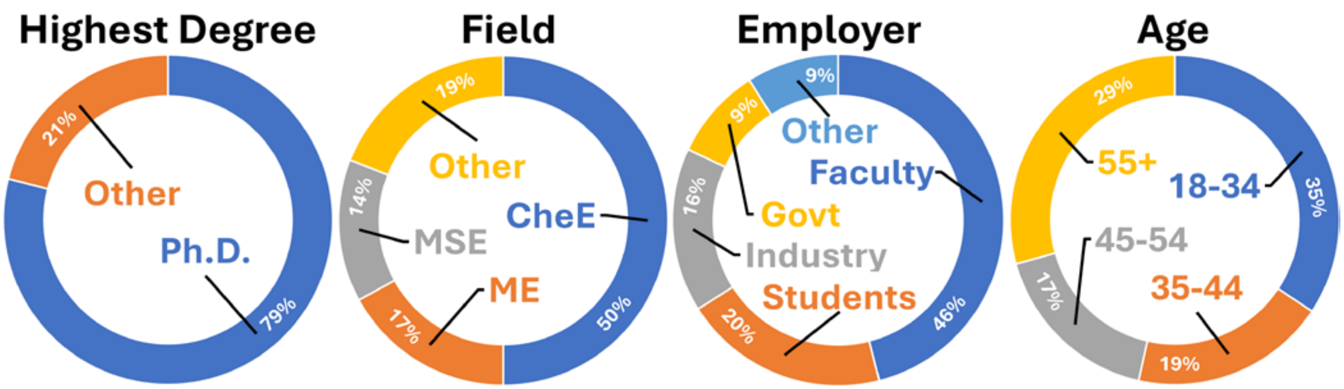
We received 151 responses, which were analyzed by Erk and Kaboolian in Spring 2025. CIPS scores were averaged and compared across various groups (e.g., students vs. non-students). Statistical significance was assessed using Welch's test and Student's t-test ($\alpha = 0.05$) and effect sizes were calculated (using Cohen's d).

Our main finding was that all SoR members have experienced feelings related to IP. The overall average CIPS score was 45 out of 80, indicating a "moderate" level of IP feelings. Distribution across CIPS categories was as follows: 29 respondents in "infrequent IP" feelings (16-32), 52 in "moderate IP" (33-48), 31 in "frequent IP" (49-64) and 18 in "often and intense IP" (65-80). The bolded groups in the accompanying table represent those with higher IP scores. Statistically significant differences were most notable in the Age and Student categories—findings consistent with existing literature. No significant differences were found between SoR members working in industry and those in academia or national laboratories. The charts indicate the aggregated characteristics of our survey respondents.

Survey findings can serve as valuable decision-making tools to guide future actions and initiatives by SoR committees and the broader rheology community. Impostor phenomenon affects a wide range of individuals—over 80% of people report experiencing IP at some point in their lives.[2] One of the most effective ways to manage impostor feelings is to talk about them openly and recognize that these experiences are widely shared. A growing number of articles offer evidence-based strategies for mitigating IP, ranging from cognitive reframing to mentorship and peer support.[8] In some cases, experiences related to IP may even catalyze personal growth and open new avenues for learning.[6]

By recognizing and quantifying impostor phenomenon within our professional community, we hope to open a dialogue among students, mentors, and colleagues in order to foster a more supportive, inclusive environment—one where all rheologists, regardless of title or background, can confidently say: "I *am* a rheologist."

Comparison Groups	Significant or Not	Effect Size
Age ≤ 34 *vs.* Age ≥ 35	Significant	Very Large
Students *vs.* Non-Students	Significant	Very Large
Non-Ph.D. *vs.* Ph.D.	Significant	Large
Non-Male *vs.* Male	Significant	Large
Non-CheE *vs.* CheE	Significant	Medium



References

1. Clance, P.R. and Imes, S.A., Psychotherapy: Theory, Research & Practice, Vol. 15, No. 3, 1978. https://doi.org/10.1037/h0086006
2. Bravata, D. M., et al., Journal of General Internal Medicine, Vol. 35, No. 4, 2020. https://pubmed.ncbi.nlm.nih.gov/31848865/
3. Muradoglu, M., et al., Journal of Educational Psychology, Vol. 114, No. 5, 2022. https://doi.org/10.1037/edu0000669
4. Cokley, K., et al. Journal of Counseling Psychology, Vol. 64, No. 2, 2017. https://doi.org/10.1037/cou0000198
5. Tigranyan, S., et al., Training and Education in Professional Psychology, Vol. 15, No. 4, 2021. https://doi.org/10.1037/tep0000321
6. Abramson, A. Monitor on Psychology, Vol. 52, No. 4, 2021. https://www.apa.org/monitor/2021/06/cover-impostor-phenomenon
7. Clance Impostor Phenomenon Scale. Access at: https://paulineroseclance.com/pdf/IPTestandscoring.pdf
8. Mak, K. K. L., et al. Frontiers in Psychology, Vol. 10, No. 4, 2019. https://doi.org/10.3389/fpsyg.2019.00671

In Memoriam: Andreas Acrivos (1928 – 2025)

By Eric S.G. Shaqfeh

The Society of Rheology is sad to announce the passing of Professor Andreas Acrivos, former Chair of Chemical Engineering at The City College of New York from 1972 to 1975, and one of the foremost scientists in the field of rheology, chemical engineering and fluid dynamics. Professor Acrivos passed away peacefully in the early morning of February 17, 2025 at his home on the Stanford campus. He was 96 years old.

Born in Athens on June 13, 1928, Professor Acrivos emigrated to the United States to pursue studies in chemical engineering. He earned his bachelor's degree from Syracuse University in 1950 and continued his graduate studies at the University of Minnesota, where he received his master's degree in 1951 and his Ph.D. in 1954. His academic career began at the University of California, Berkeley, in 1954, where he was appointed Assistant Professor and promoted to Professor in 1959. In 1962, he moved to Stanford University, where he played a pivotal role in the development of the chemical engineering program and served as department chair from 1972 to 1975. Professor Acrivos left Stanford in 1988, when he accepted the position of Albert Einstein Professor of Science and Engineering at the City College of New York. He was also appointed the Director of the Benjamin Levich Institute for Physico-Chemical Hydrodynamics at City College until his retirement in 2001. His research contributions focused on studying the properties of suspensions, emulsions, and fiber-filled materials, significantly influencing the understanding of their microstructure and microrheology. His work, in collaboration with Frankel and Leighton, on concentrated suspensions and shear diffusion, remains a cornerstone of modern rheology. Furthermore, his mentorship was crucial to the development of many distinguished scientists, such as J.D. Goddard, L.G. Leal, D. Barthes-Biesel, W.B. Russel, J.F. Brady, D. Leighton, E.S.G. Shaqfeh, and G. G. Fuller, many of whom are, or were, at the forefront of rheology.

Professor Acrivos was honored with numerous prestigious awards and distinctions, including the National Medal of Science (2001), recognizing his contributions to fluid mechanics and chemical engineering, the Fluid Dynamics Prize from the American Physical Society (1991), the Bingham Medal from the Society of Rheology (1994) and the G.I. Taylor Medal from the Society of Engineering Science (1988). In addition to these prestigious accolades, two significant awards have been established in his honor that include the Andreas Acrivos Award for Professional Progress in Chemical Engineering by the American Institute of Chemical Engineers (AIChE), recognizing outstanding professional achievements in the field of chemical engineering and the Andreas Acrivos Dissertation Award, presented by the American Physical Society, to recognize outstanding dissertations in fluid dynamics. He was a member of the National Academy of Sciences, the National Academy of Engineering, and the American Academy of Arts and Sciences. In 2001, the Hellenic Society of Rheology recognized him as an honorary member, honoring his long-standing and significant contribution to the field of rheology.

Professor Acrivos is survived by his wife Juana, his sister, Acrivy Stavropoulos, niece Maria and nephew Andreas in Athens, sister-in-law Lily Crespo Vivó and family Armando and Antonieta Crespo, their children, grandchildren and godchildren. He is also remembered by a host of graduate students, postdocs, fellow faculty and co-workers that benefited over so many years from his wisdom and mentorship.

Kurt Falke Wissbrun (1939–2023)

Kurt Falke Wissbrun, the Society of Rheology's 1992 Bingham Medalist and the President of the SOR from 1995 to 1997, passed away in New York on November 19, 2023. Kurt was born in Germany in 1930 and came to the United States in 1939. He received a B.S. degree from the University of Pennsylvania in 1952 and a Ph.D. in Physical Chemistry from Yale University in 1956. Kurt held a Dreyfus Fellowship at the University of Rochester from 1955 to 1957, after which he joined the Celanese Corporation (later Hoechst-Celanese) in Summit, New Jersey as a research chemist, reaching the top level of Senior Research Associate in 1970. He retired in 1990, but continued to work as an industrial consultant.

Kurt met Arthur B. Metzner and James L. White at a rheology short course in the early 1960's, and this was the beginning of a decades-long association with the Chemical Engineering Department at the University of Delaware. He informally co-advised a number of Metzner's Ph.D. students and he brought an industrial perspective to the Delaware rheology program. He was formally appointed as an Adjunct Professor at Delaware in 1974.

Kurt's research at Celanese, which led to twelve patents, focused on the rheology and processing of linear polyethylenes, oxymethylene copolymers, and aromatic liquid crystalline polyesters, as well as the interaction of ionic charges on polymers. His collaboration with Metzner involved studies of shear-induced phase separation of polymer solutions. His published work includes a number of landmark papers on thermotropic liquid crystalline polyester melts, and he was instrumental in facilitating the transfer of samples for use in academic research on liquid crystalline polymers. In addition to articles and book chapters Kurt co-authored the book *Melt Rheology and Its Role in Plastics Processing* in 1990 with John M. Dealy. During Kurt's years of professional activity the Society of Rheology was a venue in which academic, industrial, and national laboratory scientists and engineers could interact vigorously and influence one another and rheological science. Notably, Kurt was the last industrial recipient of the Bingham Medal.

Kurt was a golfer and he was also a devoted opera fan; for many years he had two simultaneous subscriptions to the Metropolitan Opera, with second-row-center Grand Tier seats. While still living and working in Summit he bought a small apartment in New York City near the Metropolitan Opera to avoid the late-night trip back to Summit, and following his retirement he moved to the New York apartment permanently. It was not unusual for him to go to Chicago for a weekend to see several performances at the Lyric Opera, and year-after-year he took guided opera tours to Europe with the same small group of friends. After retirement he also took courses at Columbia and Fordham, the latter just a few blocks from his apartment.

In addition to his membership in the Society of Rheology, which he represented on the Governing Board of the American Institute of Physics before becoming SOR President, Kurt was a member of the American Chemical Society, the British Society of Rheology, and Sigma Xi. He is survived by his nieces Helen and Marion Rosenau and nephew Ken Rosenau.

A short oral history conversation recorded in New York City in June, 2022, with Gareth McKinley and Morton Denn will be available on the website of AIP's Center for the History of Physics (CHP) by the time of the 2025 Santa Fe meeting.

Left to right: Morton Denn, Kurt Wissbrun, and Gareth Mckinley

David Vernon Boger (1939–2025)

By Ellie Hajizadeh

The Australian Society of Rheology is deeply saddened to announce the passing of our most distinguished member and former ASR Medallion recipient, Professor David Vernon Boger AC FAA FTSE FRS, on July 5th, 2025. It is with profound grief that we announce this loss to our global rheology community. Professor Boger was not only one of the world's most distinguished rheologists but also a founding pillar of the Australian Society of Rheology and a champion of international collaboration within our field.

Professor Boger's impact on rheology extends far beyond his groundbreaking research, including the development of the constant-viscosity elastic fluids that bear his name - "Boger fluids." As the 1994 recipient of our Society's highest honor, the ASR Medallion, he fundamentally advanced our understanding of non-Newtonian fluid mechanics and viscoelastic flow behavior, influencing countless researchers worldwide. He was equally passionate about applying rheological science to solve real-world problems, particularly in environmental applications and the minerals industry, where his work enabled the alumina industry to use 50% less water and produce solid waste rather than liquid waste, leading to much more environmentally acceptable processes.

Professor Boger played a pivotal role in strengthening international bonds within the rheology community. His leadership was particularly evident in developing the close relationship between the Australian Society of Rheology and international partner societies. On behalf of the Australian Society of Rheology, we especially acknowledge the extraordinary partnership that Professor Boger, together with Professor Jae Chun Hyun, forged between our societies. This visionary collaboration began with the inaugural Australia-Korea Rheology Conference (AKRC) held in Sydney in 2001, followed by the Korean-Australian Rheology Conference in Gyeongju in 2003. These conferences established a tradition of scientific exchange and friendship between our nations that continues to flourish today, a lasting testament to Professor Boger's commitment to international cooperation and his deep respect for Korean rheological research.

Born on November 13, 1939, in Kutztown, Pennsylvania, Professor Boger graduated from Bucknell University with a Bachelor's degree in Chemical Engineering and obtained his PhD at the University of Illinois, Urbana-Champaign in 1965. He joined Monash University as a Lecturer soon after completing his PhD, beginning his journey in rheology, a field that was completely new to him at the time. He later moved to the University of Melbourne in 1982 as Professor in the Department of Chemical and Biomolecular Engineering, where he served in various leadership roles including Head of Department and Deputy Dean, before returning to Monash University as Engineering Professor in 2010 until his retirement in 2015.

As a founding member and tireless advocate for the Australian Society of Rheology, Professor Boger understood that science knows no borders. He served as the Australian Delegate to the International Committee on Rheology for many years and was instrumental in establishing collaborative relationships with rheology societies worldwide. His scientific expertise was widely sought after; he consulted for over 90 companies worldwide and served as an expert witness in several international court cases. His commitment to mentoring young researchers and sharing knowledge across borders has left an indelible mark on our field.

Throughout his distinguished career, Professor Boger received numerous accolades, including: Companion of the Order of Australia (AC, 2024), Member of the US National Academy of Engineering (2017), Fellow of the Royal Society (FRS, 2007), Prime Minister's Prize for Science (Australia, 2005), Gold Medal of the British Society of Rheology (2004), Centenary Medal of the Commonwealth of Australia (2003), Flinders Medal of the Australian Academy of Science (2000), Walter Ahlstroem Environmental Prize of the Finnish Academy of Technology (1995), ASR Medallion (1994), Fellow of the Australian Academy of Science (FAA, 1993), Fellow of the Australian Academy of Technological Sciences and Engineering (FTSE)

As we mourn the loss of Professor Boger, the Australian Society of Rheology also celebrates his remarkable legacy. Those who knew him remember him as a warm, generous, and kind colleague who was unsparing with his time and an inspiring mentor. The international collaborations he helped establish, the scientific advances he made, and the countless researchers he inspired will continue to benefit our community for generations to come.

The Australian Society of Rheology invites colleagues who worked with Professor Boger or benefited from his mentorship to share their memories and reflections on his impact on the field. We are committed to continuing the spirit of international collaboration that he so passionately championed.

With deepest condolences and warm regards to our colleagues worldwide,
Australian Society of Rheology

Secretary's Report

By Kalman Migler

The Secretary's report consists of the motions adopted in the prior year by the Executive Committee and by the full Society, excluding pro forma motions. The full minutes are available upon request from: secretary@rheology.org

Selected Highlights from Fall 2024 and Spring 2025 Executive Committee Meetings and the 2024 Business Meeting

- Michael Moloney (CEO of AIP) reviewed work between SOR and AIP to transition the SOR website to the AIP Digital Experience Platform. He indicated that in AIP communications, they are not editorializing, but linking to facts.
- Dimitris Vlassopoulos (Editor of JOR), announced the appointment of Emanuela Del Gado as new associate editor and Safa Jamali as the new social media representative. Upcoming special issue in space applications and low-gravity research. Described a steady decline in submissions since 2020.
- Paula Arratia and Carlos López Barrón (Rheology Bulletin Editor) described that the Rheology Bulletin is mailed to members. Introduction of Carlos López Barrón as the new editor.
- Alex Giglia (AIP JOR manager) announced total revenue to JOR of $252k, including the guarantee of $120k.
- Albert Co and R. Robertson-Anderson (website) described migration of website to AIP, highlighting new potential features: newsletter, job opportunities, online courses, spotlights.
- R. Rao (financial advisements) reported on the financial investments, which are mostly equities. Proposal to hire a professional investment manager.
- Meetings: Reviewed 2024 Austin meeting with a projected loss of $85k. Updates on 2025 Santa Fe, 2026 Boston (will be expensive). Decided to hold 2028 in Madison.
- Awards: Approved recommendations for Bingham, Metzner and Fellows (discussion on calculation of number of Fellows).
- M. Helgeson and J. Gilchrist (Education and Outreach Committee) described Austin Short courses and the Rheology Academy (an online educational platform). Proposal to move several committee responsibilities to other committees: i) Future of Rheology, ii) Student-Industry Forum, iii) Knowledge Flows
- Diversity Equity and Inclusion Committee: description of harassment reporting, and how to increase diversity in the Bingham Award nominations.
- Katie Weigandt described the formation of new Community Development Committee. It has initial responsibilities of running the Rheology Research Symposium and the Student-Industry Forum.
- Gareth McKinley (SOR Historian) described oral histories being conducted at meeting with AIP.
- Safa Jamali (membership committee) related the steady decline in regular members over 10 years, though the meeting attendance has been growing.
- Mike Graham (Centennial Committee) described plans for centennial including the design of a new SOR logo.
- The following Rheology Venture Fund applications were approved:
  - Geology-Rheology Mini-session at SOR 2025. Christine Roberts, Sujit Datta
  - Rheo4kids Outreach to bring science of rheology to children and teenagers in Brazil: Monica Naccache & Priscilla Varges
  - A platform for community-driven DIY rheology projects: Ben Yavitt & Aashish Prive

Treasurer's Report

By S. Lisa Biswal

The Society of Rheology (SOR) remains in strong financial health, supported by significant reserves, a well-regarded brand, and a committed membership base. This report provides an overview of the Society's financial activities and how they are managed across various accounts, including those held at the American Institute of Physics (AIP), AIP Publishing (AIPP), Charles Schwab, and QuickBooks Online. Each section of this report is organized by major activities that support the Society's mission.

Assets of the Society of Rheology

A historical summary of SOR's assets from 2015 through 2025 is presented in Figure 1. As of the past fiscal year, total assets have grown to over $2.6 million.

The AIP account holds funds derived primarily from membership dues and revenue from the Journal of Rheology (JOR). Our publishing partnership with AIP includes a guaranteed annual payment of $120,000 and a share of additional revenue from JOR. These funds are sufficient to support the Society's routine operations.

The Schwab reserve account is intended for emergency expenditures and is invested primarily in low-risk, fixed-income assets such as certificates of deposit (CDs). In 2024, this account achieved a cumulative return of 4.5%, which is reported as interest income on the balance sheet.

In 2018, SOR established a separate Schwab investment account for long-term equity investments to further support the Society's mission. An initial investment of $225,000 in an index fund has grown to $313,000 by the end of 2024. Despite market volatility in the current fiscal year, the fund's value remains strong, with a balance of approximately $330,000 as of May 2025. The remainder of the investment account is held in CDs with yields ranging from 4% to 5%, contributing to a total 2024 return of 7.2%.

Prepaid expenses are categorized as assets and reflect funds already committed to future activities, including the annual meeting.

A balance sheet summarizing the total liabilities and net assets is shown in Table 1.

Summary of Revenue versus Expenses

For fiscal year 2024, the Society of Rheology (SOR) closed with a net revenue of $63,528 (see Table 2). It is important to note that this figure includes $75,449 in unrealized gains from the SOR Schwab investment accounts.

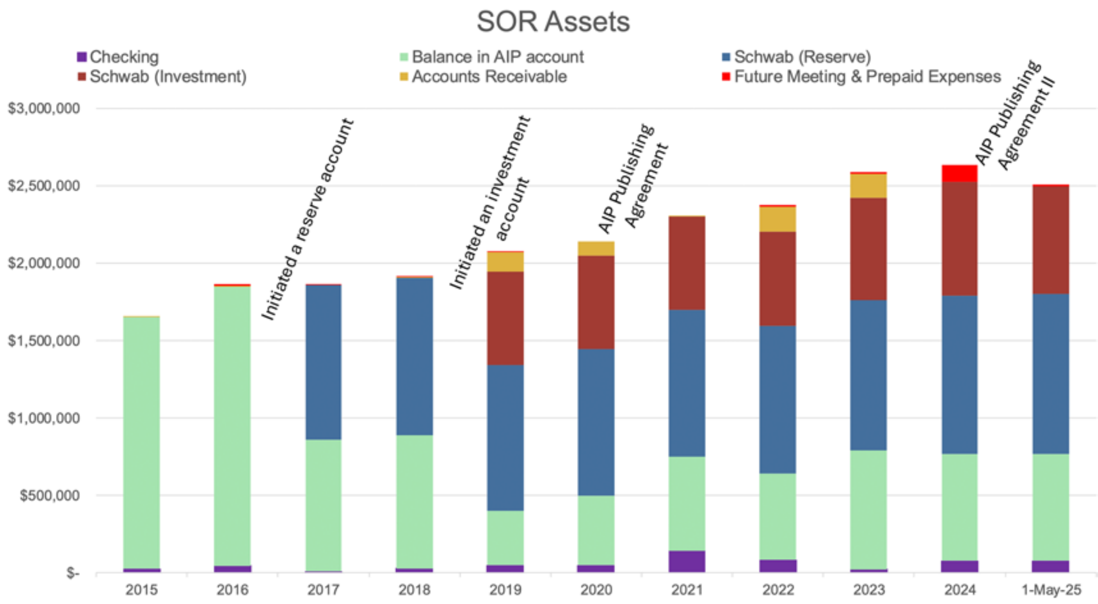


FIGURE 1. Society of Rheology Assets from 2015-2025.

TABLE 1. Balance Sheet for SOR from 2020–2025

The Society of Rheology, Inc. Balance Sheet	2024 (as Dec 31, 2024)	2023	2022	2021	2020
Assets					
Cash in checking account(s)	$ 77,733	$ 21,963	$ 82,996	$ 142,871	$ 47,741
Balance in AIP account	$ 692,926	$ 767,319	$ 562,945	$ 606,335	$ 449,440
Schwab (Reserve)	$ 1,021,603	$ 971,353	$ 954,362	$ 945,408	$ 945,006
Schwab (Investment)	$ 738,410	$ 661,111	$ 613,965	$ 608,881	$ 608,663
Accounts Receivable		$ 160,341	$ 151,638	$ 155,730	$ 141,564
Future Meeting & Prepaid Expenses	$ 128,560	$ 11,765	$ 11,000	$ 1,036	$ 36
Total Assets	**$ 2,659,231**	**$ 2,593,852**	**$ 2,376,906**	**$ 2,460,262**	**$ 2,192,451**
Liabilities and Net Assets					
Liabilities					
Deferred revenue	$ 141,811	$ 146,993	$ 29,374	$ 94,514	$ 40,745
Venture Capital Fund	$ 26,455	$ 26,455	$ 26,455	$ 27,000	$ 27,000
Total Liabilities	**$ 168,266**	**$ 173,448**	**$ 55,829**	**$ 121,514**	**$ 67,745**
Net Assets					
Publication reserve	$ 450,000	$ 450,000	$ 450,000	$ 450,000	$ 450,000
Student travel grant reserve	$ 30,000	$ 30,000	$ 30,000	$ 30,000	$ 30,000
Annual Meeting reserve	$ 300,000	$ 300,000	$ 300,000	$ 300,000	$ 300,000
Operating reserve	$ 150,000	$ 150,000	$ 150,000	$ 150,000	$ 150,000
Unrestricted	$ 1,497,437	$ 1,288,107	$ 1,408,748	$ 1,194,706	$ 1,048,400
Net Revenue	$ 63,528	$ 202,297	$ (17,671)	$ 214,042	$ 146,305
Total Net Assets	**$ 2,490,965**	**$ 2,420,404**	**$ 2,321,077**	**$ 2,338,748**	**$ 2,124,706**
Total liabilities and net assets	**$ 2,659,231**	**$ 2,593,852**	**$2,376,906**	**$ 2,460,262**	**$ 2,192,451**

Revenues of Society of Rheology

Realized revenue sources for SOR are summarized in Figure 2. The majority of SOR's income continues to be derived from publication of the Journal of Rheology (JOR), which remained stable over the past year. Due to favorable interest rates, interest income was significantly higher than in previous years.

Membership dues constitute another revenue stream, although they have declined slightly relative to prior years. AIP provided venture funds to support educational activities related to rheology. These are flow-through funds and supplemented with SOR funds.

A significant contributor to the overall financial balance in 2024 was the Annual Meeting, summarized in Table 3. In keeping with historical accounting practices, the net outcome of the Annual Meeting is reported within the revenue section. Although the meeting attracted approximately 500 attendees, revenue from registrations, short courses, and generous sponsorships (thank you!) from Anton Paar, TA Instruments, and AIP, did not fully offset the costs associated with the venue, catering, audiovisual services, and meeting logistics.

As part of SOR's commitment to supporting the rheology community, outreach activities such as the Thinkery event, the Student Trivia Night, and awards for outstanding student and postdoctoral oral and poster presentations, were expenses. The Society also covered travel expenses for plenary speakers and award recipients.

TABLE 2. Summary of SOR 2024 Net Revenue

The Society of Rheology January - December 2024			
Revenue		**Expenses**	
Dues	$ 47,143	**AIP Expenses**	$ 46,032.02
Interest Income	$ 66,379	**Awards**	$ 26,877.37
Journal of Rheology	$ 250,000	**Journal of Rheology**	$ 30,188.00
Annual Meeting (Net)	-$ 154,790	**RRS**	$ 51,224.60
Venture Fund (AIP)	$ 35,000	**SOR Venture Fund**	$ 51,963.21
		Bulletin	$ 23,610.02
Unrealized Investment Account Value		**ExCom Meetings**	$ 5,621.59
	$ 75,449	**Operations**	$ 20,136.70
TOTAL RECEIPTS	**$ 319,182**	**TOTAL EXPENSES**	**$ 255,653.51**
NET REVENUE	**$ 63,528**		

Journal of Rheology

Since 2019, the Society's publishing partnership with AIP Publishing (AIPP) has contributed to increased revenues through broader consortium marketing and reduced production costs, thereby improving net income from the Journal of Rheology. Under the terms of this agreement, SOR receives a guaranteed minimum revenue of $100,000 annually,

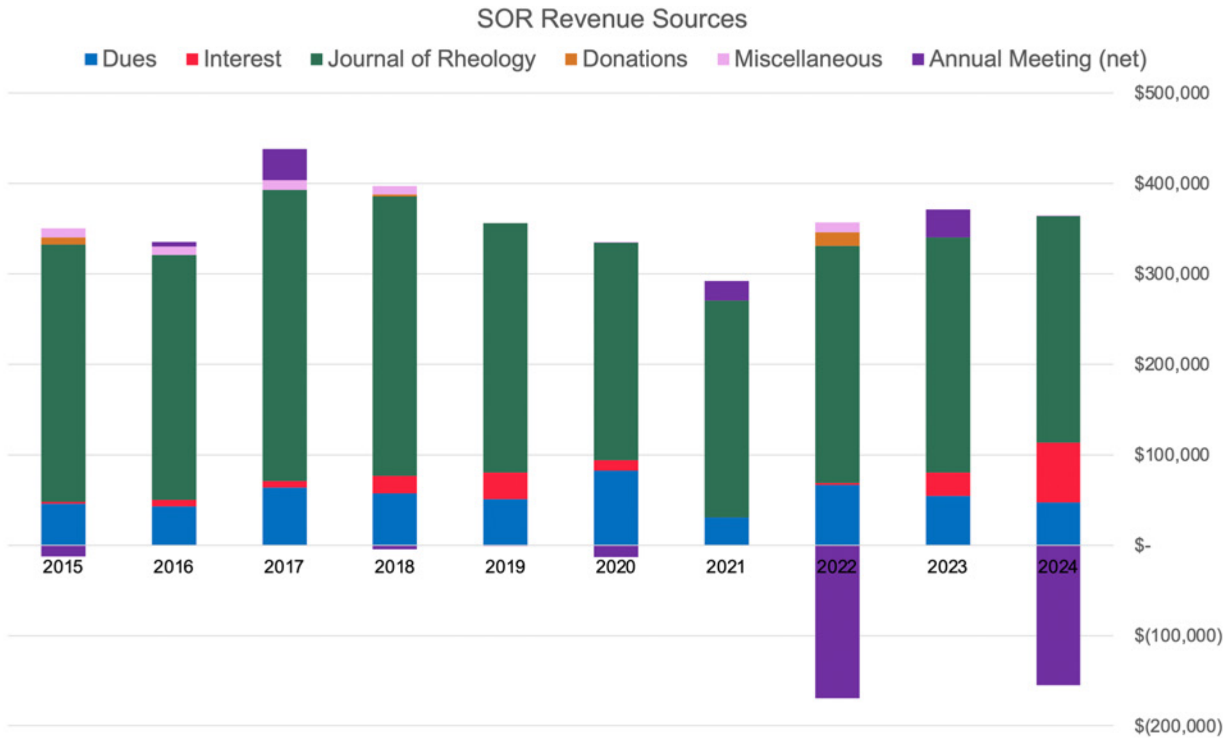


FIGURE 2. Revenue sources for SOR from 2015-2024.

with any additional net income (after expenses) shared equally between SOR and AIPP. In 2024, a new five-year agreement was signed, increasing the annual guarantee to $120,000.

As shown in Figure 3, the JOR revenue remains steady and is able to typically support the SOR operations. The bar chart illustrates SOR's net operating margin (revenues minus expenses), exclusive of unrealized investment gains, highlighting the critical financial role JOR plays in supporting SOR. Without accounting for unrealized investment income, SOR operations in 2024 resulted in a net loss of approximately $12,000.

Expenses of the Society of Rheology

To better understand the net operating loss in 2024, it is helpful to examine the Society's expenses, which are summarized in Figure 4. In addition to increased publishing and AIP partnership expenses, major expenditures in 2024 included support for mission-driven initiatives such as the Rheology Research Symposium (RRS) and the Rheology Venture Fund (RVF). Operating expenses, covering professional services such as accounting, web services, legal support, and insurance, slightly decreased compared to the previous year.

Budget for 2025

At the October 2024 business meeting, the membership voted to adopt the proposed 2025 budget, shown in Table 4. The most significant change is a one-time $50,000 allocation for migrating the SOR website to AIP-hosted infrastructure. This

TABLE 3. Summary of SOR 2024 Annual Meeting Financials

2024 Annual Meeting				
Revenue			Expenses	
Registrations	$	212,680	Rental Venues, Food, AV	$ (414,063)
Short Courses	$	43,410	Operations	$ (24,035)
Sponsorships	$	43,600	Outreach	$ (6,280)
			Honorariums/Reimburse	$ (10,103)
RECEIPTS	$	299,690	TOTAL	$ (454,480)
NET LOSS		-$154,790		

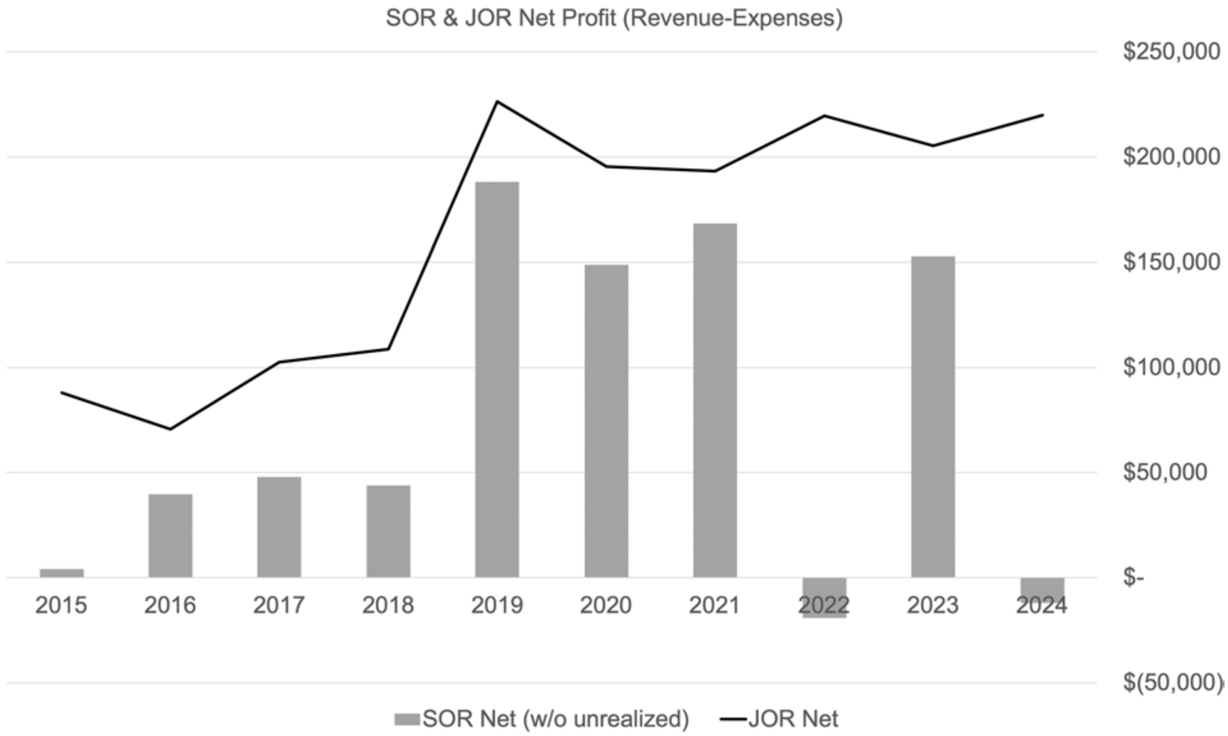


FIGURE 3. Bar chart shows SOR's net operating revenue (excluding unrealized investment gains); line plot shows annual JOR profit.

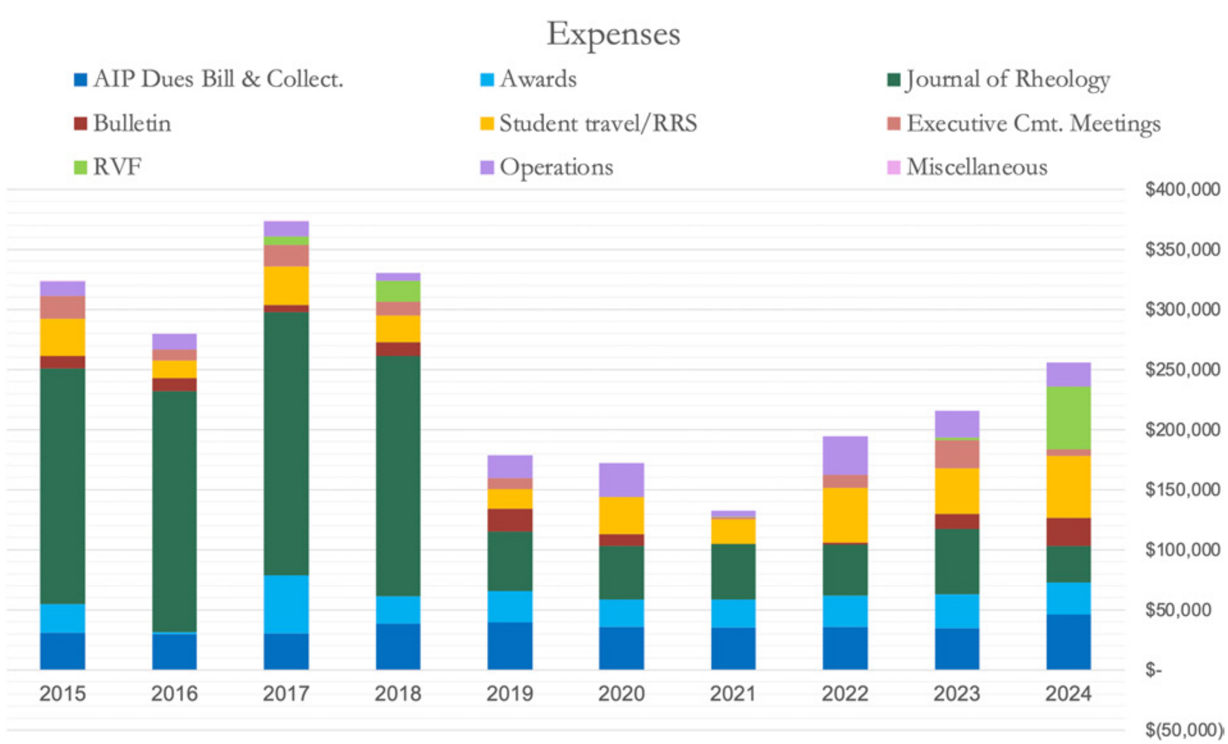


FIGURE 4. Expenses for the Society of Rheology from 2015–2024.

is expected to reduce recurring maintenance costs in future years.

The 2025 budget also includes continued support for the Santa Fe Annual Meeting ($50,000), and introduces a new Discretionary Fund for the Journal of Rheology Editor to support sponsorships of other rheology-related conferences.

As in the previous year, the 2025 budget projects a net deficit; however, the expected gains from investment returns are anticipated to offset this shortfall, maintaining the Society's overall financial strength.

The Society greatly appreciates the contributions from the three members of the Audit Committee: Jeffrey Martin (chair), Brian Edwards, and Paul Salipante. The Audit Committee meets regularly to review the Society's QuickBooks accounts and reports its findings to the Executive Committee.

The Society also appreciates the contributions from the three members of the Financial Advisement Committee: Rekha Rao (Chair), Jonathan Seppala, and Ryan Murphy. The Financial Advisement Committee reviews investment strategies to provide investment choices aligned with SORs mission and risk tolerance.

TABLE 4. Detailed list of receipts and expenses from 2020-2024 and 2025 Budget voted at the Oct 2024 business and modified at the May ExCom meeting. The budget includes a new discretionary fund for the JoR Editor to provide sponsorships to other rheology meetings

The Society of Rheology Receipts and Disbursements	**2025 Budget**	**2024**	**2023**	**2022**	**2021**	**2020**
RECEIPTS						
Dues	$ 50,000	$ 47,143	$ 54,545	$ 66,590	$ 30,309	$ 82,458
Interest	$ 40,000	$ 66,379	$ 25,728	$ 2,250	$ 100	$ 11,688
Venture fund (AIP)	$ 21,000	$ 35,000	$ -	$ -		$ -
Journal of Rheology	$ 250,000	$ 250,000	$ 259,448	$ 261,986	$ 239,936	$ 239,813
Donations				$ 15,000		
Miscellaneous		$ 1	$ -	$ 10,423		$ 2
Annual Meeting (net)	$ (50,000)	$ (154,790)	$ 31,000	$ (169,078)	$ 21,315	$ (13,132)
TOTAL RECEIPTS	**$ 311,000**	**$ 243,733**	**$ 370,720**	**$ 187,172**	**$ 291,660**	**$ 320,829**
DISBURSEMENTS						
AIP Dues Bill & Collect.	$ 36,000	$ 46,032	$ 34,997	$ 35,969	$ 35,417	$ 35,940
Journal of Rheology	$ 55,000	$ 30,188	$ 53,986	$ 42,492	$ 46,563	$ 44,407
Bulletin	$ 12,000	$ 11,610	$ 12,770	$ 1,371	$ -	$ 9,800
Bulletin Editor support	$ 4,000	$ 12,000	$ -	$ -	$ -	
Awards	$ 28,000	$ 26,877	$ 28,065	$ 25,987	$ 23,062	$ 22,742
Student travel/RRS	$ 60,000	$ 51,225	$ 38,127	$ 45,567	$ 20,532	$ 31,000
RVF	$ 51,000	$ 51,963	$ 2,021	$ -	$ 339	$ -
International Activities Fund	$ 3,000	$ -	$ 1,939	$ -	$ -	$ -
History Project	$ 15,000	$ -	$ -	$ 1,092	$ -	$ -
Executive Cmt. Meetings	$ 10,000	$ 5,622	$ 23,211	$ 10,971	$ 1,604	$ -
Pres. Discretionary Fund	$ 5,000	$ 2,226	$ 3,339	$ 4,718	$ -	$ -
Treas. Discr. Fund	$ 3,000	$ 204	$ -	$ 1,637	$ -	$ 755
Progr. Chm. Discr. Fund	$ 5,000	$ -	$ -	$ -	$ -	$ -
Webmaster Discr. Fund	$ 15,000	$ 4,859	$ 5,188	$ 313	$ 976	$ 2,702
JoR Editor Discr. Fund	$ 2,000	$ -	$ -	$ -	$ -	$ -
Website	$ 50,000	$ 692	$ 906	$ -	$ 287	
Liability Insurance	$ 8,000	$ 6,336	$ 1,370	$ 11,862	$ 1,889	$ 7,189
Accountant	$ 7,000	$ 5,143	$ 6,428	$ 5,462	$ 1,850	
Legal Fees	$ 5,000	$ 677	$ 5,407	$ 8,210		$ 17,581
Annual meetings, future	$ 5,000	$ -	$ -	$ 10,607	$ (9,274)	$ -
Miscellaneous		$ -	$ -	$ -	$ -	$ -
TOTAL DISBURSEMENTS	**$ 379,000**	**$ 255,654**	**$ 217,752**	**$ 206,257**	**$ 123,244**	**$ 172,116**
OTHER RECEIPTS						
Unrealized Change in Value		$ 75,449	$ 49,328	$ 1,414	$ 45,627	$ (2,408)
SOR Net	**$ (68,000)**	**$ 63,528**	**$ 202,296**	**$ (17,671)**	**$ 214,043**	**$ 146,306**

Amherst Rheology Lecture (CHE 757, PSE 757)

Professor H. Henning Winter

The Rheology Lectures imparted by Professor Henning Winter at UMass Amherst were uploaded to a YouTube channel by Mr. Zaw Htet Lin.

This invaluable archive of lectures is available in the link:

https://tinyurl.com/rheologylectures

Or scanning the QR code:

The rheology data analysis and plotting tool kit, "Rheo-Hub", developed by Professor H.H. Winter and Dr. M. Mours is available in the link:

https://rheology.tripod.com/TOP_P.htm

Or scanning the QR code:

Syllabus of the Polymer Rheology Course (CHE/PSE 757)

Lecture 01, Overview of Rheology Course; Rheological Phenomena
Lecture 02, Rheological Phenomena, Die Flow
Lecture 03, Definition of Stress and Strain Tensors
Lecture 04, Examples of Stress and Strain Tensors
Lecture 05, Stress and Strain Tensor Properties
Lecture 06, Transient and Steady Shear Flow
Lecture 07, Shear and Extensional Flow, Temperature Shift, Capillary Flow
Lecture 08, Capillary and Rotational Shear Rheometers
Lecture 09, Extensional Rheometry, Linear viscoelasticity
Lecture 10, Boltzmann Equation, Time-Temperature Superposition, Cox-Merz, Booij-Palmen, Gleissle
Lecture 11, Relaxation Time Spectrum, Parsimonious Spectrum
Lecture 12, Creep and Recovery, Molecular Architecture and BSW Spectrum
Lecture 13, Macromolecular Architecture Dynamics
Lecture 14, Rheology of Gelation
Lecture 15, The Critical Gel
Lecture 16, Gelation of Large Polymers, Reverse Gelation
Lecture 17, Near Critical Gels, Flow Induced Mixing of Polymer Blends
Lecture 18, Shear and Extensional Induced Mixing and Demixing
Lecture 19, Rheological Constitutive Equations
Lecture 20, Rheological Constitutive Equations for Finite Strain
Lecture 21, Rheology of Liquid Crystalline Polymers
Lecture 22, Rheology of Block Copolymers

In theaters: Rheology

By Bulbul Chakraborty

"Rheology is the science of how matter responds to external stresses. Classically, solids and liquids have distinct rheologies: defined by the presence or absence of a preferred pattern. Fragile matter does not fit within that paradigm because it lives at the margin of being a solid"

This is how I start the narration in the last scene of the play "Rheology", which ran at the off-Broadway theater, Bushwick Starr from April 15 – May 17, 2025: 22 performances. On stage were my son, who directed and wrote the play, and I.

I am a theoretical condensed matter physicist. I started out in the field of hard-condensed matter but my path meandered into soft matter in the early 1990s. For the past two decades, I have been obsessed with systems whose proximity to jamming defines their rheology. My son, Shayok Misha Chowdhury, is an Obie award-winning theater director and one of three Pulitzer finalists in Drama in 2024. About five years ago, he and I started having a conversation about my research and what rheology means. Soon, our conversation drifted to a video recording of my mother reciting the first poem by the Bengali Nobel Laureate, Rabindranath Tagore. The poem is from the point of view of groundwater that's been trapped underground inside a mountain for eons. Until, suddenly, one day a pinprick of morning sunlight penetrates the cave and wakes it up. Visualized as a woman in the poem, the groundwater remembers that who she really is a waterfall. Looking for a way out, she slams against the rocks, causing an avalanche. An avalanche that causes a massive solid mountain that has been solid for so long to disintegrate. Avalanches are core to how fragile solids respond to external stresses and define their rheology. This recording of my mother became the seed of a five-year project that culminated in the staging of Rheology this spring.

It has been an amazing journey for me. One of the most gratifying aspects has been the ability to share my excitement of the physics of sand and dense suspensions and a host of other soft matter systems, which live at the boundary of flow and rigidity. So many in the audience came up to me after the show and said that they wished that my physics lecture would have gone on longer and that if they had teachers like me they would have stayed in science. Getting to work with my son and understanding his mastery and rigorous approach to the craft of theater making and getting to know the amazing "theater nerds" has been the gift of a lifetime.

But Rheology is much more than my physics lecture on sand, which is how the play opens. As one of the reviews of Rheology (https://exeuntnyc.com/reviews/review-rheology-at-the-bushwick-starr/) so elegantly states "Fittingly for a piece that takes as one of its subjects the contested borderland between states of matter, *Rheology* itself straddles and navigates any number of boundaries: public lecture and private ritual; English and Bangla; solids and liquids; science and poetry; quiet grief and histrionic melodrama–and ultimately, and most substantively, life and death."

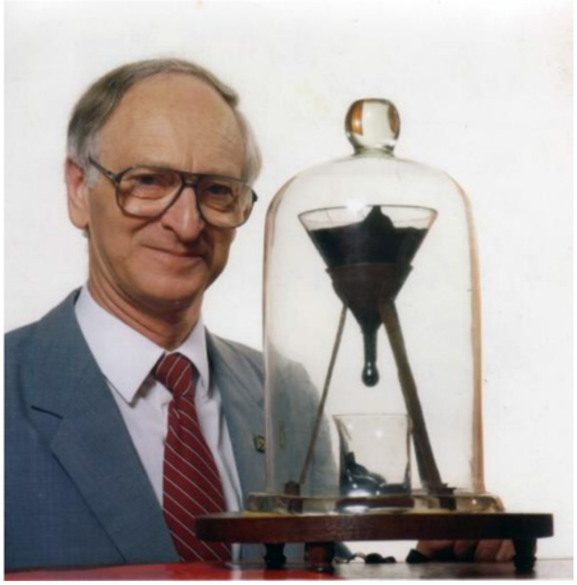
As a testament to the success of the play it will be remounted at Playwrights Horizons in the spring of 2026. I look forward to engaging again with theatergoers and talking to them about rheology, life and death and the fun of being a physicist.

Jump!

Trust the mechanics of fate, the
hydrodynamics of free fall, and the
taut stamina of ropes. Neither cowards
nor the astute will inherit the Edens on
earth. Pursue your unique search in
rarer realms. Jump!

Guess what, each minute we die a little,
so let no mortal fears make you brittle.
Knowingly take the plunge. Hit the
ground running or break a leg. Go! To
merit a beloved outcome, or to escape
the tribe of mimic men, flee: Jump!

Detach from *if only* and *what if*, the
human bondage, its labyrinths. Like
a baby bird, leave the nest. Discover
gravity, drag, thrust, and lift, the *karma*-
action philosophy, physics, and the
heroics of flight. Dare a launch, escape
velocity. Jump!



The poem "Jump!", by Vivek Sharma, evokes the longest running laboratory experiment in the world: The Pitch-Drop Experiment, started by physics Professor Tomas Parnell in 1927 at the University of Queensland in Australia (https://smp.uq.edu.au/pitch-drop-experiment). That drop that clings to the funnel and refuses to jump!

The photograph appeared in the Rheology Bulletin Vol. 76 No. 2 (2007).

Biography

Vivek Sharma's first book of verse, *The Saga of a Crumpled Piece of Paper* (Writers Workshop, Calcutta, 2009), was shortlisted for the Muse India Young Writer Award 2011. His work in English appears in *Atlanta Review, Bateau, Poetry, The Cortland Review*, and *Muse India*, among others, while his Hindi articles and verses appear in *Divya Himachal* (Hindi newspaper, India), *Himachal Mitra,* and *Argala*. Vivek grew up in Himachal Pradesh (Himalayas, India) and moved to the United States in 2001. Vivek is a Pushcart-nominated poet, published as a scientist and rheologist, and employed as a chemical engineering professor at the University of Illinois Chicago.