The News and Information Publication of The Society of Rheology
Volume 92 Number 1, July 2023

Rheology Bulletin

πάντα ῥεῖ

Inside:

- Data-Driven Rheology
- Bingham Medal
- Metzner Award
- SoR Fellows

STILL THE WORLD'S MOST VERSATILE RHEOMETER

2 New Accessories to Broaden your Research

Enhanced Powder Characterization

Measure flow, shear, wall friction, and compressibility, all under application-relevant temperatures

1-click data analysis provides clear, quantitative results

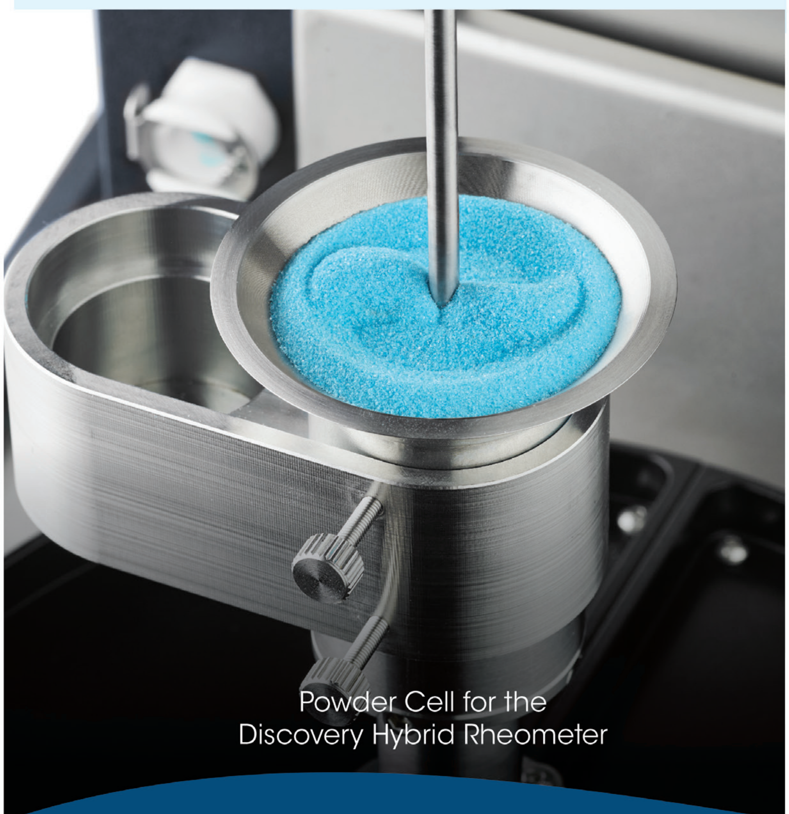
Switch between liquids, solids, and powder testing in <10 seconds!

Automation for Polymer Melt Rheology

80% more walk-away time – load your sample and go!

5x more consistent measurements – even between users and site locations

Get quality measurements in <30 minutes training time



Powder Cell for the Discovery Hybrid Rheometer

Auto-Trim for the Discovery Hybrid Rheometer

Waters™ | TA Instruments®

tainstruments.com

Executive Committee

(Jan 1 2022-Dec 31 2023)

Table of Contents

On the Cover: Viscoelastic Twister by Lise Morlet-Decarnin & Sébastien Manneville, ENS Lyon, CNRS. (1st Place, Gallery of Rheology, 93rd SoR Annual Meeting, Chicago, IL) – Flow birefringence in a solution of a surfactant wormlike micelles, an aqueous mixture of soap and salt, when injected with a syringe into the same solution. Looking through crossed polarizers, the flowing sample displays iridescent colors that allow visualizing how the wormlike micelles align under flow.

The *Rheology Bulletin* is the news and information publication of The Society of Rheology (SoR) and is published yearly in July (in non-pandemic years). Subscription is free with membership in The Society of Rheology. Letters to the editor may be sent to Paulo E. Arratia at *parratia@seas.upenn.edu*

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

Membership Committee (2023)
Michelle Calabrese
Safa Jamali, chair
Carina Martinez
Hadi Mohammadigoushki
Antonio Perazzo
Simon Rogers
Travis Walker
Chunzi Liu (student)

Education Committee (2023)
Matt Armstrong
Kenddra Erk
Reza Foudazi
Jim Gilchrist, co-chair outreach
Matthew Helgeson, chair
Ryan Poling-Skutvik
Maggie Qi
Brittany Rauzan (industry forum)

Bingham Award Committee
Ralph Colby (2023-2025)
Cari Dutcher (2022-2024)
Suzanne Fielding (2021-2023)
Emanuela del Gado (2021-2023), chair
Ali Mohraz (2022-2024)
Denis Rodrigue (2023 -2025)
Eric Shaqfeh (2021-2023)

Metzner Award Committee
Arezoo M. Ardekani (2022-2024)
Rajesh Khare (2021-2023), chair
Sachin Velenkar (2023-2025)
Jay Schieber (2022-2024)
Charles Schroeder (2023-2025)

SoR Fellowship Committee
Surita Bhatia (2021-2023)
Will Hartt (2023-2025)
Savvas Hatzikiriakos (2022-2024)
Saad Khan (2021-2023)
David Venerus (2022-2024)

Journal Publication Award Committee
Randy H. Ewoldt (MAL)
Gareth McKinley
Kelly Schultz (MAL)
Dimitris Vlassopoulos (Editor)
Roseanna Zia (Associate Editor)

Meeting Policy Committee
Jonathan Rothstein, co-chair (VP)
Andrew M. Kraynik, co-chair
Kalman Migler (Secretary)
Albert Co (Webmaster)
Kendra Erk (95th Program)
Safa Jamali (95th Program)
Roger Bonnecaze (95th Local)

Audit Committee
Brian Edwards (2022-2024)
Anthony Kotula (2022-2024), chair
Jeffrey Martin (2023-2025)
Jonathan Rothstein (ex officio)

Financial Advisement Committee
Lisa Biswal (2021-2023), chair
Rekha Rao (2023-2025)
Phil Sullivan (2022-2024)
Jonathan Rothstein (ex officio)

Diversity, Equity, and Inclusion Committee (2022)
Lilian Hsiao
Peter Gilbert
Ali Mohraz
Susan Muller
Jae Park
Kelly Schultz
Maryam Sepehr
Katie Weigandt, chair
Arman Ghaffarizadeh (student, 2022-2023)

Nominating Committee (2023)
Marie-Claude Heuzey
Aditya Khair
Norman Wagner, chair

SoR Ad-Hoc Centennial Celebration Committee
Albert Co
Morton Denn
Safa Jamali
Andy Kraynik
Gareth McKinley
Faith Morrison
Vivek Sharma, chair

SoR Ad-Hoc Future of Meetings Committee
Mubashir Ansari
Gordon Christopher
Sara Hashmi
Marie-Claude Heuzey
Jason Maxey
Jonathan Rothstein, chair
Lih-Sheng Turng

SoR Ad-Hoc Constitutional Committee:
Randy Ewoldt (Chair)
Kalman Migler
Kelly Schultz
Maryam Sepehr

Journal of Rheology Editorial Office

Editor — *Dimitris Vlassopoulos*
Associate Editor — *Roseanna Zia*
Editorial Assistant — *Ania Bukowski*

Society Service Appointments

Webmaster — *Albert Co*
Editor of Rheology Bulletin and Communication Coordinator (2022-2023) — *Paulo E. Arratia*
Social Media Director — *Christine Roberts*
Director, International Outreach Program (2022-2023) — *Gerald G. Fuller*
Student-Member Travel Grants Administrator (2022-2023) — *Maryam Sepehr*
SoR Historian (2022-2023) — *Gareth McKinley*

External Committees/Organizations for 2023

American Institute of Physics (AIP)
SoR Designee to AIP Governing Board
Eric Furst (Mar 2023-Mar 2026)

SoR Member Representative to AIP
Anne Grillet (2022-2023)

SoR Liaison to AIP Education Committee
Matt Helgeson (2022-2023)

SoR Liaison to AIP Committee for Underrepresented Minorities
Kelly Schultz (2021-2023)

SoR Liaison on AIP History Committee
Gareth McKinley (2023-2025)

SoR Liaison on AIP Public Policy Committee
Kathleen Weigandt (2021-2023)

AIP Publishing (AIPP)

SoR Designee to AIPP Board of Managers
Gareth McKinley (2022-2024)

SoR Representatives on AIPP Publishing Partners Committee
Peter Olmsted (2021-2023)
Simon Rogers (2022-2024)

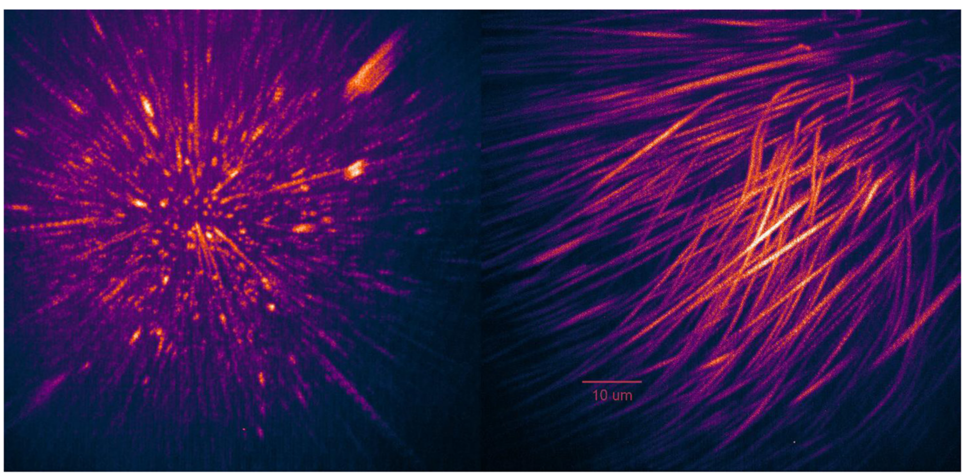
International Committee on Rheology

SoR Delegate to ICR
Norman Wagner (2022-2023)

Secretary to the ICR
Gerry Fuller

US National Committee on Theoretical and Applied Mechanics

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



Painting Fireworks: Thin films of paint dry fast, leading to fluid instabilities which result in defects in the final coating. Marangoni stress creates beautiful recirculation patterns, leaving a mottled appearance in the dried film. Multiple Particle Tracking (MPT) microrheology of drying paints “explodes like fireworks”, exposing their material properties.

Image by: M.C. Roffi[1], C. L. Wirt[2], S. V. Barancy[3], R. Roc[3], & J. F. Gilchrist[3]

1-Lehigh University, Chemical and Biomolecular Engineering Department; 2-Case Western University, Chemical and Biomolecular Engineering Department, 3-PPG Industries, Inc.

You are a rheologist!

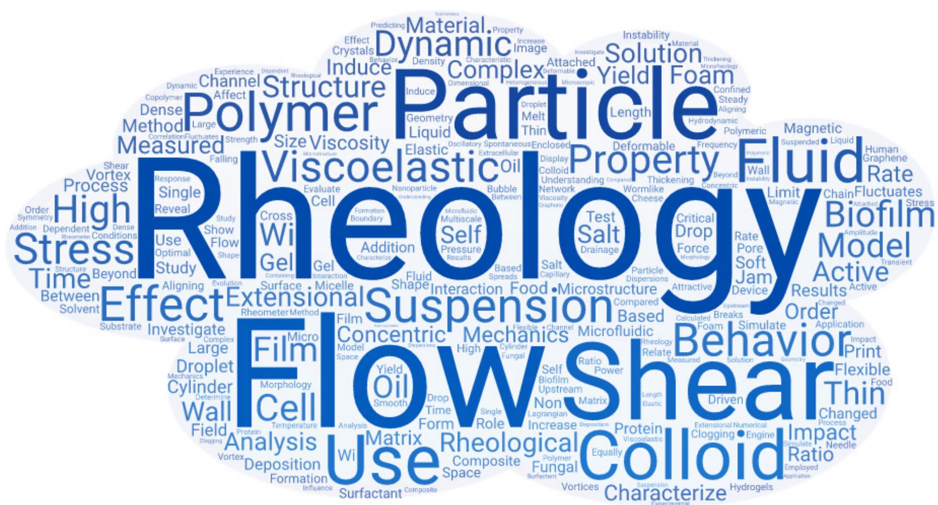
It was fantastic to see all the happy faces talking about rheology and catching up with old friends at our Annual Meeting in Chicago last fall. This year we will not hold a separate meeting but will instead combine forces with the International Congress on Rheology being held in Athens, Greece this summer. There were over 1000 presentations submitted and it looks to be a very exciting meeting. The 2023 Bingham Medalist, Jeffrey Morris, will present a plenary lecture and the Metzner Award winner, Sujit Datta, gives a keynote lecture both on Thursday afternoon. We will present their awards at the banquet Thursday evening August 3rd as well as recognizing our new class of Fellows and the JOR Publication Award winner. SOR is sponsoring 39 travel awards to attend the International Congress including 32 students and 8 early career rheologists.

We are also constitutionally required to have a Business Meeting of our membership each year. That meeting will be hybrid on Monday October 16th, 2023, from 9 am to 1pm. I hope you will save the date and join us in College Park, MD. There will be free food and an opportunity to hear presentations from our 2023 medal and award winners. As an all-volunteer society, we would also love to hear your feedback.

I also wanted to share a reflection I had at our fantastic meeting in Chicago. It was great to come together as a community again to share good times and great research. My post-doc who was attending her first in-person SOR Annual Meeting commented that she didn't think she was a rheologist because her presentation didn't show a viscosity versus shear rate curve. This reflected a sentiment that I have heard from other people, but I was surprised because her research is on understanding flow in 3D print applications. Now I love rheometry, and my group has an excessive collection of 10 different instruments from 7 different manufacturers to measure viscosity or modulus. But rheology is more than that. Rheology is defined as the study of deformation and flow of matter. And as we all know, #everythingflows! I wanted to share what I told my post-doc, of course ***you are a rheologist***! Whether you are synthesizing new materials with interesting flow characteristics, analyzing active matter, investigating instabilities that appear in flow or discovering new ways to characterize the flow properties of materials; whether you are studying colloids, polymers, gels, granular or bio-materials; whether you work in industry, in a lab, in vivo or in silico, you are all at the heart of rheology.

I look forward to seeing you in Athens where the exciting diversity of rheology will be on full display.

Regards,
Anne M. Grillet,
President of The Society of Rheology



Report from Chicago: 93rd SoR Annual Meeting

By Simon Rogers

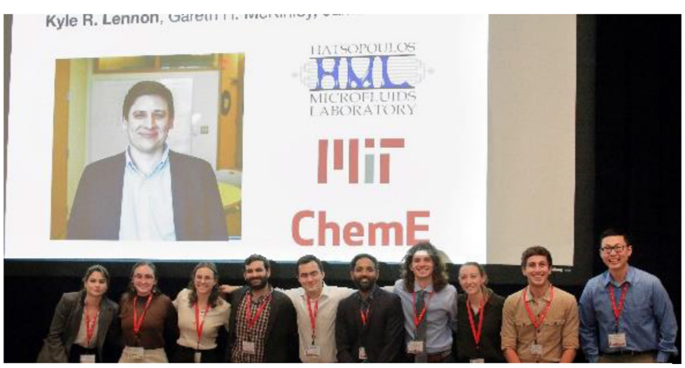
Simon Rogers receives the 2022 Metzner Award from SoR President Anne Grillet.

The 93rd Annual Meeting of The Society of Rheology (SoR) was held in Chicago, Illinois on October 9-13, 2022, coinciding with the Chicago Marathon. The technical program was developed by Charles Schroeder and Emanuela Del Gado, while local arrangements were made by Simon Rogers with assistance from Andy Kraynik. The meeting was wildly successful, the talks were stimulating, and it was great to connect with friends and colleagues once again.

The Sheraton Grand Chicago served as the venue for the meeting. The events spanned four floors of the hotel and attendees had stunning views of the Chicago River and easy access to downtown attractions. The first to take place in Chicago since 1951, the 93rd Annual Meeting had a total of **532 in-person attendees** and was the largest meeting of the Society of Rheology to date.

The third Rheology Research Symposium (RRS) was held on October 8-9. The event brought together students and professionals to explore career development in the field of rheology, and aimed to provide mentoring and increase diversity, equity and inclusion within SoR. The symposium also provided a chance for early career rheologists to get to know some of the senior members of our society, making social connections that facilitated numerous scientific discussions later in the week.

Short courses were offered during the weekend preceding the Annual Meeting. Norm Wagner, from the University of Delaware, and George Petekidis, from the University of Crete and FORTH, presented one-day short courses entitled “Introduction to Rheology” and “Rheology of Colloidal Glasses and Gels”, while Jon Seppala and Leanne Friedrich, both from NIST, presented a one-day short course entitled “Rheology in Additive Manufacturing”. Some registrants opted to enroll in a two-day short course, combining the Introduction to Rheology course with either of the two other courses. A total of 54 participants attended the short courses, with 31 in person, 15 online, and 8 online students who received the scholarships for students at international institutions.



Session in honor of the late Jim Swan.

Charles Schroeder and Emanuela Del Gado organized a stellar technical program. The meeting had 14 thematic sessions, including a special session dedicated to the late Jim Swan, as well as the poster session, which included the annual Student/Post-doc Poster Competition, and the Gallery of Rheology Contest. Because of the record number of abstracts submitted and a strong desire to provide a broader platform for dissemination of the high-quality rheological research taking place around the world, oral presentations were shortened to 20 minutes to accommodate more participants.

There were 406 oral presentations, 130 poster presentations, and 8 entries in the Gallery of Rheology Contest. The plenary lectures were given by LaShanda Korley from the University of Delaware and Jacinta Conrad from the University of Houston. Wilson Poon from the University of Edinburgh, the 2022 Bingham Medalist, delivered the Bingham Lecture remotely. The 2022 Metzner Awardee, Simon Rogers from the University of Illinois at Urbana-Champaign, presented his research to a receptive and engaged crowd early on the final day of the conference.

Rheological vendors demonstrated their products Monday through Wednesday in a dedicated exhibitor room. As always, the Society greatly appreciates the strong support by device manufacturers and welcomes their continued participation in our annual meetings.

A welcoming reception, sponsored by TA Instruments, was held during

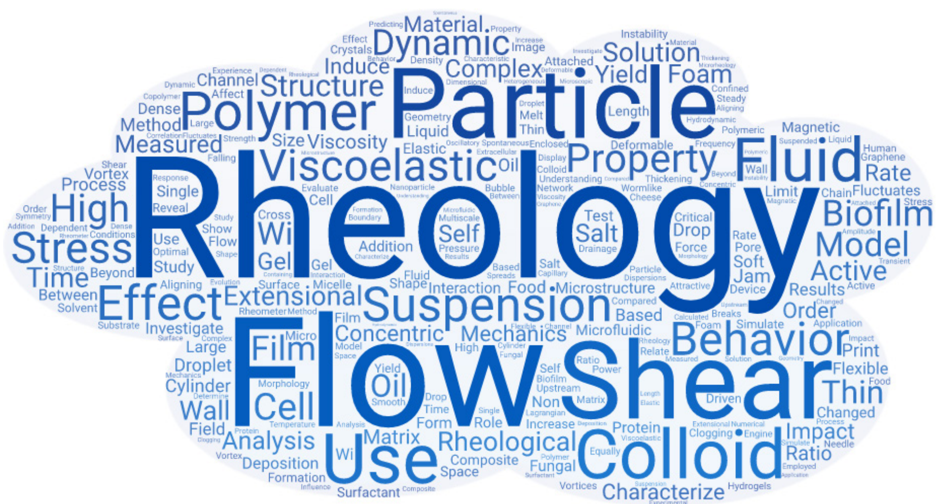
Rheology trivia night in Chicago

the evening of Sunday October 9th in the Chi bar inside the Sheraton Grand hotel. A Student-Industry Forum, sponsored by American Institute of Physics, occurred during the lunch break on Monday October 10th. The second annual Student Trivia Night, featuring "rheology-themed" trivia, was held Monday evening at Northman Beer & Cider Garden. Organized by student leaders, the trivia night has quickly become a favorite event that early career researchers can look forward to each year.

The Society Business Meeting during the lunch break on Tuesday October 11th and was very well-attended. The events for Tuesday evening were the Awards Reception and the Awards Banquet. Warm words were said by Dimitris Vlassopoulos about Wilson Poon at the start of the Awards Banquet, and Simon Rogers was affectionately roasted by Norm Wagner before receiving his award. The Journal of Rheology publication award was accepted by Kyle Lennon, Gareth McKinley, and Laura Swan on behalf of her late husband, Jim. Laura addressed the attendees and reminded us how dedicated Jim was to his work and to the Society, and how honored he would have been to have received the award.

The last event of the week in Chicago was the Poster Session and Reception during the evening of Wednesday October 12th. Held in a spacious room in the lower level of the venue, the Poster Reception, sponsored by Anton Paar, was a conference highlight for many. Attendees feasted on local Chicago fare, in addition to pasta and dim sum. Krutarth Kumani (UIUC) won the Student Poster Competition, Steffen M. Recktenwald (Universität des Saarlandes) won the Post-Doc Poster competition, and Lise Morlet-Decarnin (ENS de Lyon) won the Gallery of Rheology Contest (see Bulletin's cover image).

Attendees were overwhelmingly positive about the 93rd Annual Meeting, and many expressed a desire to return to Chicago for a future meeting.



Diversity, Equity & Inclusion Report

By Kathleen Weigandt

The Society of Rheology (SOR) Diversity, Equity, and Inclusion (DEI) Committee is working to develop policies, practices and programs that will lead to a diverse and inclusive community of rheologists. The Rheology Research Symposium (RRS) is a flagship program led by the committee. It was originally sponsored by the AIP Venture Capital Fund and as of 2022 is now fully funded by the SOR. The RRS is designed to welcome up-and-coming student rheologists into the Society with mentoring and professional development programming during the weekend leading up to the annual SOR meeting. At the Chicago meeting we welcomed 26 graduate students from around the world to participate in the 3rd Annual RRS. The students were assigned to small groups with mentors from academia, government labs and industry and participated in programming that included career planning, overcoming career obstacles, networking, scientific communication with the public, and an introduction to the SOR. I want to express my sincere gratitude to all the volunteer mentors and panelists that helped to make the 2023 RRS a success. The next RRS will take place in conjunction with the 95th Annual Meeting in Austin Texas in October of 2024.

3rd Annual RRS Group Picture, SoR Annual Meeting, Chicago, IL

In 2019 the SOR adopted an official Code of Conduct for society activities and in 2020 a Diversity, Equity and Inclusion statement was adopted. It is the goal of the society that every SOR sponsored event be welcoming to all participants and free from any form of discrimination, harassment, or retaliation. This is achievable if we all work together to create a collegial, inclusive, and professional environment by acting respectfully toward our colleagues, whether engaging in lively scientific debate or social conversations. At the 2022 SOR meeting in Chicago we piloted new formalized in-person and online harassment reporting processes. The online reporting system is facilitated in partnership with the AIP through AIPs Navex EthicsPoint online portal: https://secure.ethicspoint.com/domain/media/en/gui/67627/index.html. As a society we pride ourselves on having welcoming meetings and the new reporting mechanisms will help provide needed feedback to achieve this goal for all rheologists.

If you would like to become involved in the DEI efforts of the society or volunteer for a future Rheology Research Symposium, please reach out to the DEI committee. Current committee members include Arman Ghaffarizadeh (Carnegie Mellon University, student member), Peter Gilbert (Queen's University), Lilian Hsiao (North Carolina State University), Ali Mohraz (UC Irvine), Susan Muller (UC Berkeley), Kelly Schultz (Lehigh University), Maryam Sepehr (Chevron), and Katie Weigandt (NIST, Chair).

Join the Student Slack Channel for the Society of Rheology!

Are you a passionate trainee exploring the fascinating world of rheology? Looking to expand your network and connect with like-minded individuals? Search no further! We proudly present the Society of Rheology's exclusive Student Slack Server, a communication space specifically designed and reserved for students and postdocs in rheology!

By joining the Slack channel, you are expanding your network and opening doors to future opportunities that will shape your career in rheology. Launched in Fall 2021, we currently have 85 active members and counting! During conferences (SoR, AICHE, APS, ACS, and more!), the Slack channel is a communication hub for SoR student members to connect. Join us to forge friendships and professional relationships.

Stay ahead with SoR news with our server! We routinely post announcements about conference deadlines, SoR seminars, and frontier research in rheology fields! Be the first to know about the latest developments in rheology!

SoRStudent
Future flows

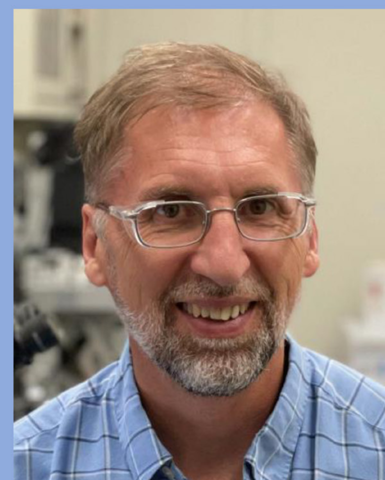
Scan the QR code to join us and embark on an unforgettable adventure with fellow rheology enthusiasts worldwide. If you have any questions, don't hesitate to contact your student representatives, Arman Ghaffarizadeh (sghaffar@andrew.cmu.edu) and Chunzi Liu (lcz@seas.harvard.edu).

πάντα ῥεῖ

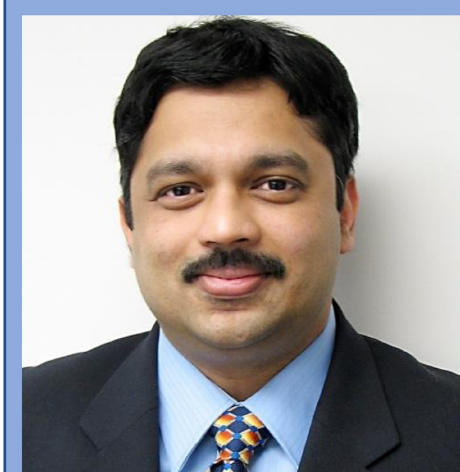
Announcing the 2023 Fellows of the Society of Rheology

Emanuela Del Gado, Georgetown University

Paulo de Souza Mendes, Pontifícia Universidade Católica do Rio de Janeiro (PUC-Rio)



Steve Hudson, National Institute of Standards & Technology



Srinivasa R. Raghavan, University of Maryland

Charles Schroeder, University of Illinois Urbana-Champaign

Evelyne van Ruymbeke, Université Catholique de Louvain

News from the Journal of Rheology

Publication Awards

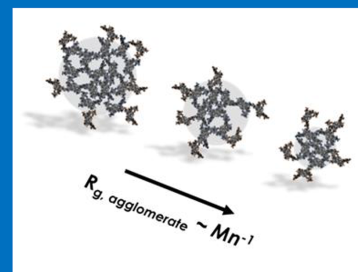
2023 Award

Julie B. Hipp[1], Jeffrey J. Richards[2], & Norman J. Wagner[1]

[1]University of Delaware, [2]Northwestern University

"Direct measurement of the microstructural origin of shear-thickening in carbon black suspensions"

J. Rheo., **65**(2), 145-157 (2021)



2022 Award

Kyle L. Lennon, Gareth H. McKinley, & James W. Swan

Massachusetts Institute of Technology

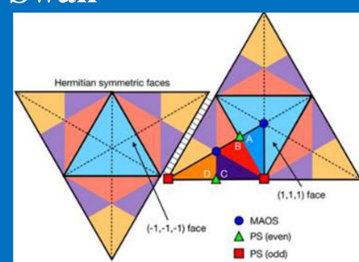
"Medium amplitude parallel superposition (MAPS) rheology:"

P1: *Mathematical framework & theoretical examples*

J. Rheo., **64**(3), 551-579 (2020)

P2: *Experimental protocols and data analysis*

J. Rheo., **64**(5), 1263-1293 (2020)



JNNFM-RA-JoR Online Seminar Series returns this fall!

Journal of Non-Newtonian Fluid Mechanics | JOURNAL OF RHEOLOGY® | Rheologica Acta

JOURNAL OF RHEOLOGY®

Follow JoR on Twitter! @JoRheology

πάντα ῥεῖ

Sujit Datta
2023 Metzner Award

By William R. Schowalter

It is my great pleasure to write a brief description of the impressive career and persona of Sujit S. Datta, recipient of the 2023 Arthur B. Metzner Early Career Award of the Society of Rheology. Sujit is an associate professor in the Department of Chemical and Biological Engineering at Princeton University. His citation reads:

> *For pioneering studies of 3D visualization and modeling of complex fluids in complex environments, showing how flows of soft and living matter are altered by the confinement and structural disorder of many real-world settings, and for guiding development of new approaches to environmental remediation, energy production, agriculture, water security, and biotechnology.*

Professor Datta's path to this award has been especially interesting, and it reflects the broad but thorough grounding in education he has received as well as his innate drive to expand the boundaries of knowledge to which he contributes.

Sujit grew up in Toronto and is a Canadian citizen. During his middle- and high-school years his family lived in Abu Dhabi, where he attended an International School that provided Sujit with both a strong academic foundation and culturally enriching experiences for which he continues to be grateful. He was eager to experience life in the United States, and in 2004, he enrolled at the University of Pennsylvania, expecting to expand his knowledge of jazz music and to major in philosophy. It was after his initial year at Penn that the first glimmer of today's Sujit Datta emerged, ignited by an introductory course in university-level physics, during which philosophy was overtaken by physics and mathematics. He credits this awakening to an exceptional professor in charge of the course and in whose lab Sujit spent time during the rest of his undergraduate career studying the quantum mechanical behavior of carbon nanomaterials. By introducing Sujit to the world of research and scientific inquiry, this was an experience that has had a lasting impact on his career.

Sujit's interest in research was intensified by meeting David Weitz at Harvard and learning about the fascinating properties of soft (or "squishy") materials. Sujit started his PhD research under Weitz by studying the rheology of emulsions and then moved on to mapping the dynamics of multiphase flows in 3D porous media using confocal microscopy to uncover new features of the properties of immiscible liquid mixtures. During this period Sujit became aware of the enormous opportunities available in the study of complex fluids in porous media. In particular, he points to the influence of a classic paper he discovered while he was a graduate student. The paper was coauthored by Metzner himself (R.J. Marshall and A. B. Metzner, *Ind. Eng. Chem. Fundamentals,* **6**, 393-400 (1967)), and it motivated some of the research Sujit later continued at Princeton.

During his PhD studies, Sujit also became aware of the importance of rheology in living systems. This motivated him to pivot for his postdoctoral studies to the field of biology. He joined the laboratory of Rustem Ismagilov in Chemical Engineering at Caltech, as part of a collaboration with a team of biologists to study the gut microbiome. Sujit quickly went from doing experiments in microfluidics to doing surgery on mice. Through the creative application of ideas and tools from soft matter to address questions in biology this research eventually led to a new understanding of how dietary polymers in the gut influence the properties of its contents and its protective mucus lining. (See *PNAS* **113**, 7041 (2016).)

Hence when Sujit arrived at Princeton in 2017 he was well prepared to launch his independent career along two parallel and occasionally intersecting paths. One is to study the dynamics of complex fluids flowing through porous materials and to link microscale processes to macroscopic rheological behavior. The other is to use the tools and approaches of rheology to study the dynamics of living microbial systems, not in liquid cultures as is typically done in the lab but, as Sujit describes it, "in the complex environments where the cells live and work."

With respect to flow through porous media, Sujit's experimental expertise has allowed him to unravel the coupling between pore space geometry, fluid flow, and microstructural deformation, and to show how the combination can in some cases lead to unusual macroscopic transport behavior. For example, Sujit and his coworkers discovered that flow of polymer solutions through pore arrays can be unexpectedly bistable, stochastically switching between two distinct unstable flow states due to the interplay between elongation and relaxation of polymers as they are advected between pores (*Journal of Fluid Mechanics*, **890**, A2 (2020) and *Physical Review Fluids*, **6**, 033304 (2021)). Another example is the anomalous increase in the macroscopic resistance generated during polymer flow through porous media, a phenomenon that had eluded explanation for more than 50 years. (See the Metzner publication cited earlier.) Sujit's lab established that the pore-scale onset of unstable chaotic fluctuations arising from flow-induced polymer elastic stresses helps to generate this strong increase in the flow resistance (*Science Advances*, **7**, eabj2619 (2021)). These findings not only help to deepen understanding of polymer solution flows, but they also provide quantitative guidelines to inform their applications at large scales. Sujit's lab has used a similar approach to unravel the dynamics of other complex fluids, such as immiscible fluid mixtures and colloidal dispersions, in porous media (e.g., *Science Advances*, **6**, eabc2530 (2020) and *Physical Review Fluids*, **6**, 014001 (2021)). Building on these advances, Sujit is currently exploring how such flow behaviors can be harnessed for improved solute mixing/dispersion and removal of trapped immiscible fluids (e.g., contaminants) from porous media.

Another example to which Sujit has paid special attention is the ultimate "soft" porous medium, *viz*., hydrogels. He and his coworkers have shown how polymer chemistry, gel microstructure, and external constraints inherent in many natural environments control how hydrogel materials deform and fracture. (See *e.g*., *Science Advances*, **7**, eabd2711 (2021) and *Physical Review Letters*, **123**, 158004 (2019).)

I mentioned earlier Sujit's interest in studying microbial systems in "real" spaces. An excellent example is his development of a method to interrogate bacteria, from the scale of a single cell to that of an entire population in crowded 3D spaces similar to many of their natural habitats. Using this platform, Sujit and his coworkers have shown how current understanding of bacterial transport, based on studies performed in bulk liquids, is incomplete. For example, he has elucidated ways in which confinement in a crowded medium fundamentally alters how bacteria spread via motility or growth at both the single-cell and population scales, and he has developed mathematical models inspired by classic ideas of transport processes and rheology to predict these behaviors. (See, for example, *Nature Communications* **10**, 2075 (2019); *Physical Review Letters*, **128**, 148101 (2022); *PNAS* **119,** (43) e2208019119 (2022).) This work exemplifies an important frontier for our field in the use of principles of rheology to shed light on the workings of complex living and active systems.

The Datta lab at Princeton is an exciting and bustling place occupied by students, postdocs, and visitors across different fields and at various stages of their careers. In his six years, Sujit has advised 14 postdocs and 10 graduate students. One of the numbers of which he is most proud is the nearly 30 undergraduates who have worked with him, several of them coauthoring refereed publications. Sujit's emphasis on providing research opportunities for undergraduates reflects the pivotal influence his time in a physics lab at Penn has had on his career.

Since its founding in 2009, the list of Metzner Early Career Awardees has proved to be a magnificent predictor of outstanding future leaders in our field. I'm certain the 2023 recipient will be another member of that distinguished group.

Jeff Morris 2023 Bingham Medalist

by Morton Denn

Jeffrey F. (Jeff) Morris, Professor of Chemical Engineering and Director of the Benjamin Levich Institute at the City College of New York, the flagship science and engineering college of the City University of New York, is the recipient of the 2023 Bingham Medal of the Society of Rheology "in recognition of his transformative research on the flow of suspensions, particularly of the mechanics of discontinuous shear thickening, and his application of rheology to practical problems in suspension flow, including his novel work on the rheology of hydrate-forming emulsions." This is the culmination of a series of major awards for Jeff, including the 2022 Weissenberg Award of the European Society of Rheology, the 2020 Stanley Corrsin Award in Fluid Mechanics of the American Physical Society, and the 2017 Shell Thomas Baron Award in Fluid Particle Systems of the American Institute of Chemical Engineers.

Jeff is the youngest of four children. He grew up in Cullowhee, North Carolina, in the Smoky Mountains, where his father taught chemistry at Western Carolina University. His mother worked as a nutritionist for the county and sometimes taught at the University. Jeff was offered a scholarship to Georgia Tech, and he decided to study chemical engineering because of the close connection to science, with three full years of chemistry in the curriculum; to our benefit he stuck it out, despite finding the early courses in chemical engineering to be less inspiring than those in physical chemistry, mathematics, and mechanics. He had two meaningful industrial summer jobs: The first, after his third year at Georgia Tech, was at Exxon's Baton Rouge refinery and included visits to the nearby petrochemical plant; this experience gave him an appreciation of the process industries and the realization that his interest was on individual phenomena, and not the process scale. The other, after graduation, was at Mobil's Paulsboro, New Jersey laboratory working with catalysts, where he found that he loved doing research.

Jeff went to CalTech for graduate study, and his interest in transport properties and fluid mechanics led him to do his PhD research with John Brady. He was excited by Brady's description of the statistical aspects of the problems that he was studying and the relation to ideas from thermodynamics, and that excitement is clearly exhibited in his own subsequent work. His first important publications on suspension rheology come from his joint work with Brady. After completing the PhD he did a postdoc with Shell in Amsterdam, working with Willem Boersma, who as a post-doc himself at Caltech a few years before had introduced Jeff to shear thickening.

Jeff's first job after completing his PhD and postdoc was a chemical engineering faculty position at Georgia Tech. He then spent two years working with Halliburton on a range of rheology problems involving particle-laden flows in petroleum exploration and production, particularly fracturing fluids (gels at the time) and proppant slurries and cement. Those years at Halliburton are reflected in his deep understanding of the practical issues associated with the processing of particulate systems. When a position opened at the Levich Institute (City University of New York, CCNY), we made sure to bring it to his attention. He stood out in the pool of applicants, and we were pleased to be able to hire him in 2005. He served as Chair of the CCNY Chemical Engineering Department from 2013 to 2016 and has been the Director of the Levich Institute since 2015. Jeff has had active collaborations and visiting positions in France, including continuous appointments in the French national laboratory system (CNRS) from 1999 until 2010 as a research leader of a major research program funded by the FERMAT Foundation from 2016 to 2020. He has been named as an inaugural CNRS *Ambassador-Fellow* for 2023-2026.

The nomination for the Bingham Medal addressed several distinct but related contributions. A body of work that started with his PhD research with Brady employed Stokesian Dynamics and Smoluchowski theory to establish the micromechanical basis for the normal stresses in suspensions and the coupling of flow to non-equilibrium structure and bulk properties. Jeff and his students developed the suspension balance concept to show that a gradient in the particle contribution to the continuum stress, known as the *particle pressure,* will drive particle migration. They have shown that the particle pressure in the shear flow of a non-Brownian suspension is a rigorous continuation of the equilibrium osmotic pressure. With colleagues at Laboratoire FAST in Orsay they have shown that the particle pressure can be directly measured under shear.

In landmark papers in Physical Review Letters and Journal of Rheology

Jeff and family relax a bit on the beach.

(JOR), the latter the recipient of the 2015 JOR Publication Award, Jeff and co-workers demonstrated the minimal ingredients needed to reproduce experimentally observed discontinuous shear thickening, wherein the viscosity undergoes a large discontinuous increase at a critical shear rate. They demonstrated that the dominant stress transmission mechanism at the transition must change from lubrication to contact friction, providing a rational basis for shear thickening and showing how it is related to shear jamming. This study forms the basis for the widely used Wyart-Cates model of suspension shear viscosity, which was generalized by Jeff and coworkers to a consistent model for the rheology of concentrated suspensions of spheres (the winner of the 2020 JOR Publication Award). This transformative body of work has propelled the field forward by prompting theoretical work to describe the coupling of the macroscopic behavior to the microstate and experimental work to assess the controlling physics at interparticle contacts. More recent work combines network theory with simulations to show the existence of states that provide a theoretical foundation for the Wyart-Cates model.

Gas hydrates, or clathrates, form when a small guest molecule is captured in a "cage" of hydrogen-bonded water to form a crystalline solid. An emulsion will undergo an abrupt change in properties with the formation of clathrates, and clathrates can cause jamming in petroleum pipelines carrying oil and gas along with water and brine. Jeff and his coworkers at CCNY and Chevron have focused on understanding hydrate formation and its impact for the design of new mitigation strategies. By coupling rheology to visualization, they showed that hydrate morphology at the particle surface has a significant effect on the rheological transition associated with hydrate growth, and they related this morphology to oil-soluble surfactants and asphaltenic components in the organic phase. Jeff then developed a novel approach using salt to control the thermodynamic state, hence the material composition (hydrate/aqueous/organic) for modeling the rheology. This body of work has developed a framework in which the control of material composition allows study of the mechanical basis for behavior, creating a rational foundation of constitutive and flow models needed for flow assurance and other applications.

Jeff has been an active member of the rheology and complex fluids community. For the Society of Rheology, he was an Annual Meeting Technical Program Chair and he chaired the Nominating and Bingham Medal Committees. He was one of the organizers of an extended Kavli Institute Workshop on the Physics of Dense Suspensions, and he co-edited a special issue of JOR on the subject, as well as co-organizing a widely attended online symposium with discussions published in JOR. He is an Associate Editor of the Journal of Fluid Mechanics. In addition to his many well-written reviews, he is the co-author with Élisabeth Guazzelli of *A Physical Introduction to Suspension Dynamics*, a textbook for those new to an area that requires the integration of concepts from fluid mechanics and statistical physics.

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.

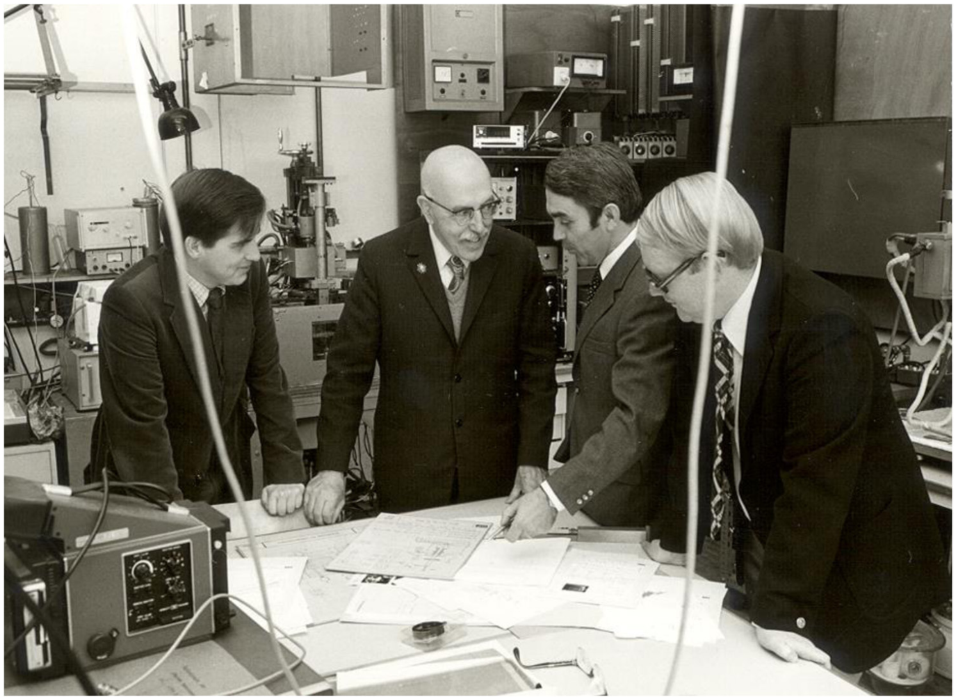
– Adopted by the SoR Executive Committee, 10 June 2017

Images from the Archives

Submitted by Gareth McKinley & Martin Laun

In October 1974, Professor Georgi Vinogradov from Moscow, Soviet Union, visited Joachim Meissner's laboratory to discuss extensional rheometry using rotating clamps. Meissner had developed this technique because it was capable of reproducing differences in drawability observed in the tubular film blowing of commercial polyethylene melts with slightly different branching structures: https://doi.org/10.1515/iupac.42.0003. Meissner was soon to become a professor at ETH Zurich, with Martin Laun taking over his lab. In the second BASF rheology lab, which had been headed by Helmut Münstedt since 1973, the focus was on the development of an automated filament stretching rheometer that imposed a constant tensile stress. Over the following years their joint efforts extended the range of transient extensional rheology data towards at least a quasi-steady state. Seminal experiments on a series of commercial polymer melts distinctly improved our understanding of the role of chain branching in controlling the transient extensional rheology and the stability of melt processing operations. Manfred Wagner's network model with a strain-dependent damping function provided a good description of these experimental results. In 1981, Meissner, Münstedt, Laun, and Wagner were collectively awarded the Annual Award of the British Society of Rheology. Münstedt moved to the University of Erlangen in 1993. Laun remained as the chief rheologist at BASF until his retirement in 2006, with teaching assignments at the University of Dortmund from 1999 and later at the University of Bayreuth until 2014. He was awarded the Weissenberg Medal in 2000 and was elected a Fellow of the Society of Rheology in 2017.

The Russian Society of Rheology (who organized the AERC in 2011) is now named in honor of Vinogradov; more details of his career in rheology and tribology are available at the Vinogradov Society's website: http://www.ips.ac.ru/rheo/eng/GV.HTM



October 1974: (from left) Helmut Münstedt, Georgi Vinogradov, Joachim Meissner and Martin Laun in the BASF Rheology Lab, Ludwigshafen, Germany

Note from the Editor: This is the first in what we hope will be a regular series of images of rheological significance from the archives. If you have interesting or rare photos of moments from rheological history (people, conferences, rheometers etc.) please share them with the SOR Historian, Gareth McKinley at MIT or with the Bulletin Editor. The Society of Rheology will celebrate its Centennial at its' 100th Meeting in October 2029.

Rheologist in the Spotlight

Christopher W. Macosko

SOR Fellow Christopher W. Macosko was awarded the **Goodyear Medal** at the 2023 Annual Meeting of the ACS Rubber Division's 2023 meeting in Ohio. The medal honors individuals for "*outstanding invention, innovation, or development which has resulted in a significant change or contribution to the nature of the rubber industry*". Chris received a B.S. degree in Chemical Engineering from Carnegie Mellon University and earned his Ph.D. degree in Chemical Engineering in 1970 from Princeton University, where he worked under the supervision of Prof. Bryce Maxwell. Macosko and a fellow graduate student, Joe Starita, co-founded the company Rheometrics, whose instruments significantly advanced the field of rheology and which is now part of TA Instruments. Early in his academic career, Chris and his graduate students Doug Miller and Enrique Valles performed pioneering and highly-cited work developing basic relations for crosslinking polymerization, including the growth of molecular weight, branching, crosslink network formation, crosslink density, swelling and sol fraction [1 – 4]. Macosko has also been the recipient of the Stein Award in Materials from the American Institute of Chemical Engineers, the International Award of the Society of Plastics Engineers, and the 2004 Bingham Medal of the Society of Rheology (for more details see https://www.rheology.org/sor/Awards/Bingham/MacoskoC)

References

1. A new derivation of average molecular weights of nonlinear polymers, C.W. Macosko and D.R. Miller, Macromolecules 1976, 9, 199-206. https://pubs.acs.org/doi/10.1021/ma60050a003
2. A new derivation of post gel properties of network polymers, D.R. Miller and C.W. Macosko, Macromolecules 1976, 9, 206-211; reprinted in Rubber Chem. & Tech. 1976, 49, 12. https://pubs.acs.org/doi/10.1021/ma60050a004. 534
3. Properties of networks formed by end linking of poly(dimethylsiloxane), E.M. Valles and C.W. Macosko, Macromolecules 1979, 12, 673-679. https://pubs.acs.org/doi/10.1021/ma60070a025
4. Structure and viscosity of poly(dimethylsiloxanes) with random branches, E.M. Valles and C.W. Macosko, Macromolecules, 1979, 12 (3), pp 521–526, DOI: https://pubs.acs.org/doi/10.1021/ma60069a036

Data-Driven Rheology: could this be a new paradigm?

By Safa Jamali

Synopsis

Over the past couple of years, Artificial Intelligence (AI) has powered transformative changes in numerous technological areas from accelerated drug discovery platforms to advanced manufacturing, and to weather forecasting. Large language models (LLMs) such as ChatGPT and Google's Bard are quickly popularizing use of AI in daily tasks. With the largest tech companies getting into an arms race over the latest AI developments, rapidly growing data-driven scientific discovery, and industries transforming towards automation, emergence of AI/ data-driven methodologies in rheology is inevitable. Hence it may be beneficial to reflect on the advent and growth of these frameworks, review some of the areas in which they have been applied to rheology, and potential future directions. For the remainder of this article, different categories of AI methodologies such as neural networks, regression models, transformers, etc. are generally referred to as "*data-driven*" sciences and tools, to provide a categorical context and perspective as opposed to "*computational*" sciences and tools.

Computational vs. Data-Driven Science and Engineering

With the advent and popularization of computers in the second half of the 20th century, virtually every scientific discipline began using them. Today, "*computational*" techniques are established and widely relied upon tools that are commonly used to predict, benchmark, and validate "*experimental*" results and to provide a more detailed insight into physical underpinnings of the phenomenon under question. In computational science and engineering, the goal is to numerically solve for a particular model, e.g., a flow, or a design problem. Thus, the process begins with adoption of a model, which may be theoretically or empirically derived from a set of observations. These constitutive models are often combined with transport equations, e.g., conservation of mass and momentum laws, for the actual solution of a flow problem. This is followed by representation of the system at hand, for instance through meshing the computational space. Finally, a numerical solver is chosen to solve for different variables of the model.

In the context of non-Newtonian fluid mechanics and rheology, adaptation of computational tools was almost immediate. While legendary rheologists such as Tanner, Caswell, Crochet, Denn, and Armstrong started working on developing computational frameworks for non-Newtonian fluid mechanical problems, the earliest computational papers on viscoelastic fluids appeared in 1975 (*1-3*), with focus symposia held from 1978 onwards (IUTAM symposium on Non-Newtonian Fluid Mechanics in Louvain-la-Neuve, Belgium) . At the same time, several different computational schemes such as Brownian Dynamics (BD) (*4*), Immersed Boundary Method (IBM), Discrete Element Method (DEM) (*5*), and Lattice Boltzmann Method (LBM) (*6*) were developed, leading to development of Stokesian Dynamics (SD) (*7, 8*) that transformed the field of suspension mechanics and rheology. With a consistent growth of computational power (Moore's prediction that the number of transistors in a circuit, i.e. a proxy for computational capacity, doubles every two years has held since 1965), computational tools have become significantly more powerful and hence an undeniably essential pilar of science and engineering in general, and rheology more specifically.

Similar to these computational approaches, data-driven methodologies also date back several decades. In fact, the earliest papers focused on use of statistical and regression models (the birthplace of neural networks) in rheology date back to the early 1960s (*9, 10*). Data-driven frameworks broadly use parametrized models (such as deep neural networks, instead of a differential equation or a polynomial representation in computational frameworks) that are solved using statistical inference principles (such as Bayesian or maximum likelihood algorithms, instead of numerical solvers in computational frameworks). Through these statistical regressions, a "*prediction*" is made based on a series of input parameters, and the goal is to minimize the difference between the predicted quantity and the observed data. In 1986, the very first neural network was introduced (*11*), and only a few years later the first physics-guided neural network that was used to model a physical process (welding) found a comparable accuracy with traditional modeling schemes (*12*). In fact, the first paper showing that physical models of interest can be directly embedded within the structure of a neural network appeared more than three decades ago (*13*).

While data-driven methods have been around for as long as the computational ones have been, and they can be fortified with the physical principles that one believes in, they have been often labeled as *deceitful black boxes* that are not reliable for scientific or engineering applications. But why? There are two main reasons for this, perhaps unjust, infamy. First and foremost, while computational and data-driven methods alike rely on raw computing power and the ability to perform the underlying operations fast and efficiently, for classical (non-physics-based) data-driven models a certain population/ size is required for the data to become statistically meaningful. In contrast, the size of a computational/numerical solution (performed with appropriate care) may not be as influential on its validity. However, this difference has been largely mitigated over the past decade or so by the tremendous growth in our ability to store and analyze data. The second obstacle to data-driven science and engineering has to do with the ability to perform differentiation on a computer. The overwhelming majority of physical laws/equations of interest in science and engineering in general, and in rheology more specifically, involve fluxes or flows of relevant quantities up or down gradients of another physical variable, and thus are of differential nature. This makes a computer program's ability to compute derivatives rapidly and accurately, ultimately the rate-limiting factor in successful scientific and engineering applications. Although methods of embedding differential equations into neural networks existed since the 90s, they were initially very inefficient and tedious as one had to manually derive the backpropagation rules that constrained the neural networks. Interestingly, automatic differentiation (as a class of computer techniques for computation of derivatives) was being used for a long time for computational fluid dynamics models. Nonetheless, only recently and over the past decade, has the field of machine learning became aware of these algorithmic differentiation tools (*14*, *15*), which has led to development of a new class of machine learning platforms called physics-informed neural networks or PINNs (*16*).

Data-Driven Rheology

With the rise of scientific machine-learning in general, and particularly physics-informed machine-learning, a wide variety of machine-learning packages (from transformers to neural networks) have been embedded with physical laws that have to be respected in any particular application. At the same time, progress towards more efficient, free, and open-source machine learning platforms such as PyTorch and TensorFlow, as well as unprecedented computational power available in personal computers have made data-driven methodologies accessible to everyone. Therefore, it is essential to tailor these rapidly growing methodologies to rheology and leverage these advances. In the following, a brief account of work in data-driven rheology to date is provided.

Figure 1 presents an schematical view of data-driven rheological efforts to date, with respect to some general categories: (i) digital rheometry, and use of machine learning in predicting material functions, (ii) automatic model selection and model discovery from experimental data, (iii) data-driven non-Newtonian fluid mechanics, and (iv) automatic and data-driven characterization integrated with experimental capabilities. Still to date, there are relatively few reports on applications of machine-learning, or data-driven techniques in general, to rheology and non-Newtonian fluid mechanics. Yet, most of these have focused on adaptation of physics-informed neural networks to solve for different non-Newtonian flows either in a forward or an inverse fashion (*17-21*). These often include coupling conservation laws and a non-Newtonian constitutive model that is solved for a given geometry of interest. In contrast to classical computational schemes that strictly require well-posed initial and boundary conditions to solve the differential equations of interest, these data-driven solutions generally are not contingent on such strict requirements and can provide relatively accurate solutions without initial or boundary conditions as well.

Other *multi-fidelity* data-driven approaches have been developed, in

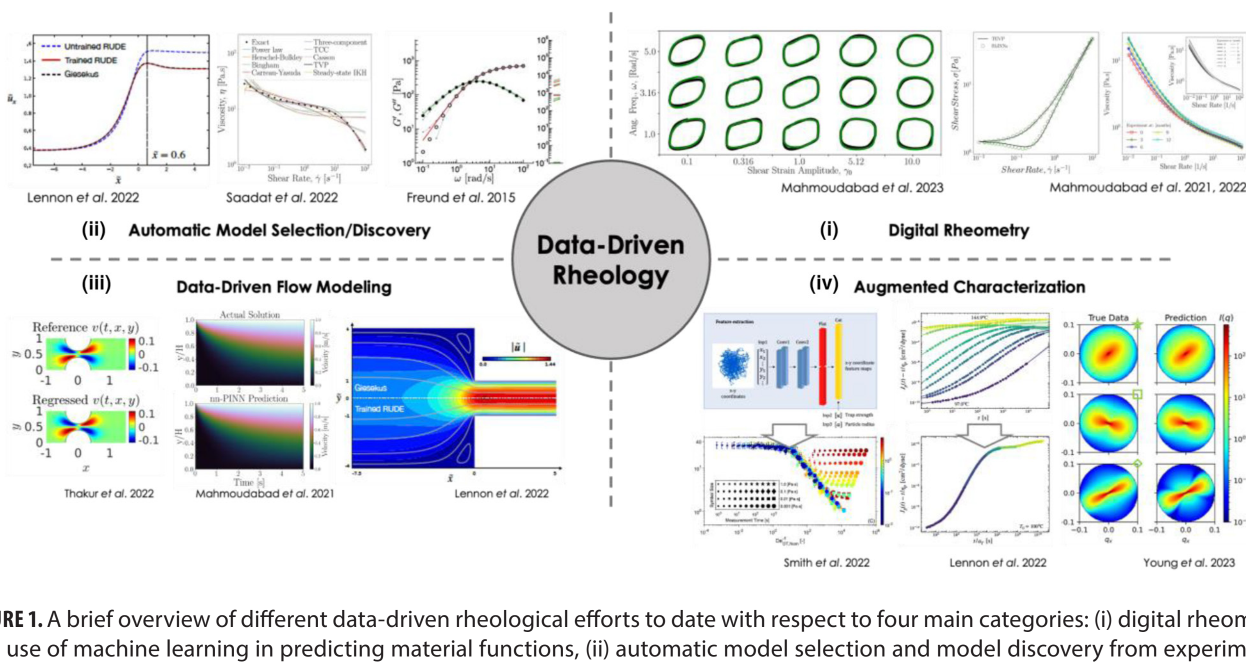


FIGURE 1. A brief overview of different data-driven rheological efforts to date with respect to four main categories: (i) digital rheometry, and use of machine learning in predicting material functions, (ii) automatic model selection and model discovery from experimental data, (iii) data-driven non-Newtonian fluid mechanics, and (iv) automatic and data-driven characterization integrated with experimental capabilities. Representative images are re-printed from right to left,: top row: (18) hysteresis and flow curves solved through RhINNs, (23) SAOS to LAOS data driven prediction of fumed silica gel rheology, (26) moduli benchmarking using Bayesian model selection, (27) automatic generalized Newtonian fluid model selection, (21) tensorial model construction through RUDE, and bottom row: (29) complex fluid structure prediction from scattering data, (28) automatic superposition of rheological measurements, (30) automated characterization of microrheology, (21) flow modeling through RUDE, (22) RhINN vs. numerical solution of a stress growth flow, and (19) a viscoelastic flow through contraction.

which the scarcity of high fidelity data is made up for by abundance of lower fidelity data, providing reliable platforms for prediction of different rheological properties (for example, evaluating the viscosity of a multi-component rheologically complex system, the drag coefficient of a particle in viscoelastic medium, or the stress response of a complex fluid) (*22-25*). For instance, early work suggests that by combining phenomenological models and additional experimental measurements, digital rheometer (*23*) and fluid (*21*) twins can be constructed, in place of a real physical system. While choosing the appropriate rheological model to describe a set of observed rheological behavior is traditionally left to the rheologist, data-driven techniques can also enable automatic and data-centric selection of models. For example, Freund and Ewoldt (*26*) developed Bayesian inference models capable of providing quantitative criteria for model selection. More recently, neural networks with automatic model selection capability were reported as well (*27*).

Apart from data-driven model predictions and/or selection, one of the areas in which data-driven methodologies have made significant progress is in high-throughput and automatic characterization of complex fluids. For instance, exhaustive and laborious manual superposition of data to deduce universal behavior can be performed virtually instantaneously using data-driven techniques (*28*). Other characterizations of complex fluids using machine learning include recent studies on the use of small-angle x-ray scattering patterns to model the microstructure of complex fluids under flow (*29*), and microrheological measurements from particle trajectories (*30*).

Perspective

The goal of this article is ultimately to provide a brief account of where we stand with respect to data-driven applications to rheology, but more importantly an outlook of what potential transformations can be enabled by data-driven methodologies in rheology and non-Newtonian fluid mechanics. Figure 2 presents a few ways in which data-driven techniques can be integrated with, and potentially transform experimental, theoretical, and computational efforts in rheology.

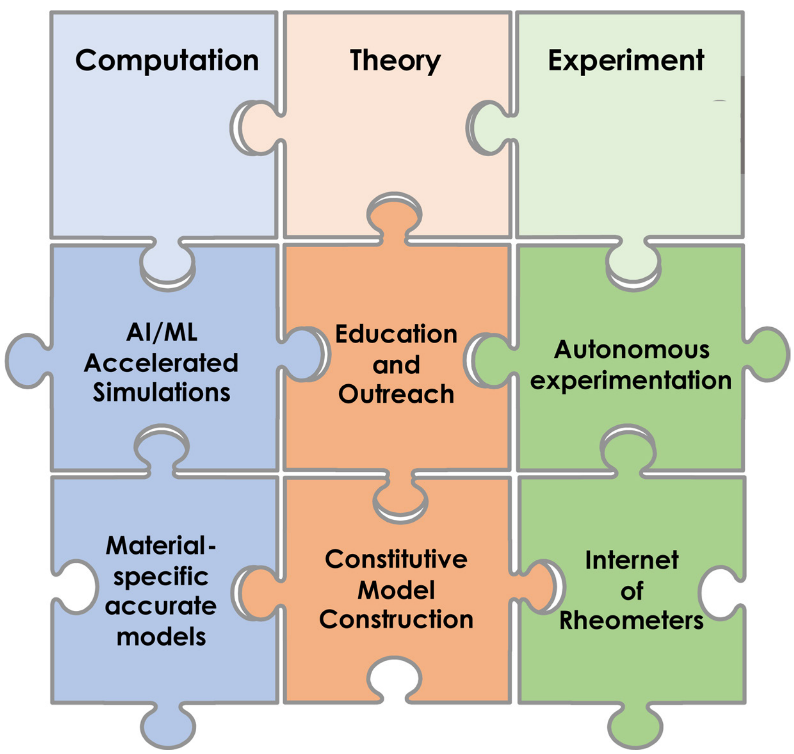


FIGURE 2. Schematic overview of the handshake between data-driven rheology, and experimental, theoretical/foundational, and computational rheology. Each piece of the puzzle underneath in the lower rows provides an example of potential impact by introduction of data-driven techniques.

From an experimental perspective, and with tremendous growth in robotics, autonomous laboratories have emerged as viable platforms for accelerated scientific discovery. Whether it is microscopy, scattering, or rheometry, high throughput testing of materials is now a reality. Today's technologies however are of the "*human-in-the-loop*" nature, where inevitably the human operator eventually becomes the rate-limiting factor. Reliable scientific and informed machine learning frameworks that can filter bad data, learn from the experimentation in real time, and make decisions based on those observed data can be transformative in this area. Often, for a systematic study of a particular problem, a thorough study of an extensive parameter space is required. This commonly is prohibitive and extremely expensive. Nonetheless, novel machine learning techniques (e.g., Deep Reinforcement Learning) have proven effective in alleviating this issue and eliminating the need for manual exploration of the state space. Looking into new possibilities enabled in this technological advancement era, one can also imagine interconnection and communication of rheometers and construction of an "*internet of rheometers*". With the ease of access to cloud storage of data, and with further development of data-driven methods that perform exceptionally well with large data volumes, sharing the experimental data that are collected separately could be extremely beneficial for the entire community. Breakthrough technologies in the image processing, medical applications, and many other fields using ML platforms have been made possible only through sharing and using large data sets. In a similar fashion, a community-wide effort in establishing a large, open, and standardized data repository from rheologists will enable a great leap forward in digital rheometry and potentially rheological sciences in general.

As described previously, a clear area of impact [for data-driven techniques] will be in data-driven non-Newtonian fluid mechanics, and in replacing numerical solutions with data-driven counterparts. Neural networks that are constrained with conservation and constitutive equations of interest can accurately solve different non-Newtonian fluid mechanical problems without the strict need for well-posed initial or boundary conditions (note that this is not a general statement, but merely a possibility in some forms of neural networks). On the other hand, data-driven assimilation of experimental observation and the solution to constitutive equations that describe a general behavior in the material can tailor the predictions to that material specifically. In other words, data-driven solutions that also leverage observational data (through multi-fidelity platforms for instance) offer system-specific models that are fully capable of describing the material at hand while respecting the fundamental physical laws at play.

Apart from these, a major [and almost certain] area of significant impact by machine-learning techniques will be in acceleration of numerical simulations. The common practice in simulations, whether it is Molecular, Brownian, Stokesian Dynamics, or Discrete Element Method, is to solve for the particles' equation of motion from the different forces and torques acting on every point particle, at every single time step. In fact, this repetitive and rather straightforward operation presents the bottleneck for acceleration of these simulations. Machine learning platforms such as Graph Neural Networks have shown excellent potential in learning these operations, and can be used in place of the numerical operators within the computer programs. Machine-learning accelerated Molecular Dynamics (*31, 32*) have shown up to 100-fold speed up of calculations already, and are expected to continue in that direction. Google's JAX package offers free and open-source codes for MD, DFT, the Navier-Stokes equations, and CFD already. Expecting a major leap forward in fast simulations using machine learning algorithms is certainly plausible.

From a fundamental/theoretical perspective, data-driven methodologies can bring a new paradigm as well. Constitutive and phenomenological modeling of complex fluids has been one of the major thrusts of the rheological sciences so far. Generally, the goal is to develop closed-form differential (or integral) equations that describe the stress response of a material to an applied deformation and yield different material functions. Objectivity issues and the necessity of accounting for non-linear viscoelasticity have led to the development of a wide variety of different constitutive models with different frame-invariant differential operators (e.g., upper-convected, lower-convected, corotational, etc.). Recent developments suggest that neural networks not only are capable of constructing functional forms of different derivatives (*33*), but also can learn and find non-linear operators using universal approximation functions (*34*). This can be potentially transformative in how we construct constitutive models.

Finally, it is this author's belief that we can benefit tremendously from large language models such as ChatGPT or Google's Bard in educational and outreach activities. Science that cannot be communicated well [to audiences of different backgrounds] will eventually lose relevance and cease to survive. Rheology, although relevant to many aspects of our daily lives, is not the easiest of sciences when it comes to communication with non-experts. LLMs can be useful in aiding in technical communication at different levels, and to pique others' interest in our science. This is an example response received from ChatGPT when asked to "*Describe thixotropy to a high school student*": "*Thixotropy is a fascinating property exhibited by certain materials that become less viscous or flow more easily when they are agitated or shaken but return to their original thicker or more viscous state when they are left undisturbed. It's like a magical behavior where a substance seems to become runnier when you stir or shake it, but then becomes thick again when you stop. This property is commonly observed in things like certain paints, gels, and even some types of food products like ketchup.*" While this response may not necessarily be the most scientifically accurate description of thixotropy, one should remember that it is generated to communicate a rather complex concept to a high school student. One can ask these models for suggestions on outreach events and activities targeted to different audiences (if you have not already done this, try and you will be positively surprised) …

A word of caution

The debut of AI and data-driven techniques and the rate at which it is growing is truly an unchartered territory. While unprecedented numbers of publications emerge every year on these topics, scientific journals have begun regulating use of different AI technologies (such as LLMs) in technical discourse. Although at a different scale, and happening in very different times, there are also analogies between the advent of computational sciences and of data-driven sciences. With computers emerging as powerful tools for performing otherwise prohibitive calculations, many numerical schemes were developed over the past 50 years. Nonetheless, not all of these techniques are appropriate for rheological or non-Newtonian fluid mechanical problems. Today, we are observing a plethora of different data-driven platforms being developed, and similarly, not all of those will be suitable options for rigorous scientific studies. Hence it is essential for each (scientific) community to explore these developments with rigor and to identify the limitations and advantages of each methodology with respect to the problem at hand. Historically, the validity of computational algorithms and the veracity of their capabilities was established by rigorous comparison with asymptotics and analytics. However, by replacing these mathematical practices with numerical operations performed on a computer, one could argue that the computational sciences eventually found their firm position in our community, at the cost of the new generation of engineers and scientists' ability to comfortably perform some foundational and fundamental functions such as asymptotic analysis and dimensional analysis. With many of the mathematical and statistical underpinnings of data-driven techniques hidden in the program's back-end, and ease of use being at the fore of every effort in this area, such loss of fundamental knowledge can be more severe with the popularization of AI and machine learning.

Finally, a reflection on the rise and establishment of computational rheology, and its parallelism to data-driven rheology: arguably the science of rheology (or science in general) before the 1970s consisted of theoretical and experimental efforts; however, today computational research has become an integral part of rheological sciences. It is reasonable to envisage data-driven sciences becoming an equally important and complementary part of our research efforts as well. Rigorous and robust integration of data-driven, computational, experimental, and theoretical approaches will hold the key to future breakthroughs in rheology.

Acknowledgment

I would like to thank Gareth McKinley, Morton Denn, Robert Armstrong, and Milad Saadat for their insightful

comments, historical perspective, and discussions in writing this article.

References

1. R. I. Tanner, R. Nickell, R. Bilger, Finite element methods for the solution of some incompressible non-Newtonian fluid mechanics problems with free surfaces. *Computer Methods in Applied Mechanics and Engineering* **6**, 155-174 (1975).
2. J. Black, M. M. Denn, G. Hsiao, in *Theoretical Rheology*. (Applied Science Publishers Ltd., 1975), pp. 3-30.
3. M. J. Crochet, G. Pilate, Numerical study of the flow of a fluid of second grade in a square cavity. *Computers & Fluids* **3**, 283-291 (1975).
4. D. L. Ermak, J. A. McCammon, Brownian dynamics with hydrodynamic interactions. *The Journal of chemical physics* **69**, 1352-1360 (1978).
5. P. A. Cundall, O. D. Strack, A discrete numerical model for granular assemblies. *geotechnique* **29**, 47-65 (1979).
6. D. d'Humieres, P. Lallemand, U. Frisch, Lattice gas models for 3D hydrodynamics. *Europhysics Letters* **2**, 291 (1986).
7. J. F. Brady, G. Bossis, Stokesian dynamics. *Annual Review of Fluid Mechanics* **20**, 111-157 (1988).
8. G. Bossis, J. F. Brady, Dynamic simulation of sheared suspensions. I. General method. *Journal of Chemical Physics* **80**, 5141-5154 (1984).
9. H. Frisch, Statistics of random media. *Transactions of the Society of Rheology* **9**, 293-312 (1965).
10. W. Ames, V. Behn, Application of the method of composition and linear regression analysis to a problem involving a pseudoplastic suspension. *Transactions of the Society of Rheology* **5**, 53-66 (1961).
11. D. E. Rumelhart, G. E. Hinton, R. J. Williams, Learning representations by back-propagating errors. *Nature* **323**, 533-536 (1986).
12. K. Andersen, G. E. Cook, G. Karsai, K. Ramaswamy, Artificial neural networks applied to arc welding process modeling and control. *IEEE Transactions on industry applications* **26**, 824-830 (1990).
13. D. C. Psichogios, L. H. Ungar, A hybrid neural network-first principles approach to process modeling. *AIChE Journal* **38**, 1499-1511 (1992).
14. A. G. Baydin, B. A. Pearlmutter, A. A. Radul, J. M. Siskind, Automatic differentiation in machine learning: a survey. *Journal of Machine Learning Research* **18**, 1-43 (2018).
15. A. Paszke *et al.*, in *NIPS 2017 Autodiff Workshop*. (2017).
16. M. Raissi, P. Perdikaris, G. E. Karniadakis, Physics-informed neural networks: A deep learning framework for solving forward and inverse problems involving nonlinear partial differential equations. *Journal of Computational Physics* **378**, 686-707 (2019).
17. M. Mahmoudabadbozchelou, G. E. Karniadakis, S. Jamali, nn-PINNs: Non-Newtonian physics-informed neural networks for complex fluid modeling. *Soft Matter* **18**, 172-185 (2022).
18. M. Mahmoudabadbozchelou, S. Jamali, Rheology-Informed Neural Networks (RhINNs) for forward and inverse metamodelling of complex fluids. *Scientific Reports* **11**, 12015 (2021).
19. S. Thakur, M. Raissi, A. M. Ardekani, ViscoelasticNet: A physics informed neural network framework for stress discovery and model selection. *arXiv preprint arXiv:2209.06972*, (2022).
20. B. Reyes, A. A. Howard, P. Perdikaris, A. M. Tartakovsky, Learning unknown physics of non-Newtonian fluids. *Physical Review Fluids* **6**, 073301 (2021).
21. K. R. Lennon, G. H. McKinley, J. W. Swan, Scientific Machine Learning for Modeling and Simulating Complex Fluids. Proceedings of the National Academy of Sciences, 120 (27) e2304669120, (2023).
22. M. Mahmoudabadbozchelou *et al.*, Data-driven physics-informed constitutive metamodeling of complex fluids: A multifidelity neural network (MFNN) framework. *Journal of Rheology* **65**, 179-198 (2021).
23. M. Mahmoudabadbozchelou, K. M. Kamani, S. A. Rogers, S. Jamali, Digital rheometer twins: Learning the hidden rheology of complex fluids through rheology-informed graph neural networks. *Proceedings of the National Academy of Sciences* **119**, e2202234119 (2022).
24. M. Boodaghidizaji, M. Khan, A. M. Ardekani, Multi-fidelity modeling to predict the rheological properties of a suspension of fibers using neural networks and Gaussian processes. *Physics of Fluids* **34**, 053101 (2022).
25. S. A. Faroughi, A. I. Roriz, C. Fernandes, A meta-model to predict the drag coefficient of a particle translating in viscoelastic fluids: a machine learning approach. *Polymers* **14**, 430 (2022).
26. J. B. Freund, R. H. Ewoldt, Quantitative rheological model selection: Good fits versus credible models using Bayesian inference. *Journal of Rheology* **59**, 667-701 (2015).
27. M. Saadat, M. Mahmoudabadbozchelou, S. Jamali, Data-driven selection of constitutive models via rheology-informed neural networks (RhINNs). *Rheologica Acta* **61**, 721-732 (2022).
28. K. R. Lennon, G. H. McKinley, J. W. Swan, A data-driven method for automated data superposition with applications in soft matter science. Data-Centric Engineering, V4, e13, (2023).
29. C. D. Young, P. T. Corona, A. Datta, M. E. Helgeson, M. D. Graham, Scattering-Informed Microstructure Prediction during Lagrangian Evolution (SIMPLE)–A data-driven framework for modeling complex fluids in flow. *arXiv preprint arXiv:2305.03792*, (2023).
30. M. G. Smith *et al.*, Machine learning opens a doorway for microrheology with optical tweezers in living systems. *arXiv preprint arXiv:2211.09689*, (2022).
31. Z. Li, K. Meidani, P. Yadav, A. Barati Farimani, Graph neural networks accelerated molecular dynamics. *The Journal of Chemical Physics* **156**, 144103 (2022).
32. S. Schoenholz, E. D. Cubuk, Jax md: a framework for differentiable physics. *Advances in Neural Information Processing Systems* **33**, 11428-11441 (2020).
33. Z. Chen, Y. Liu, H. Sun, Physics-informed learning of governing equations from scarce data. *Nature Communications* **12**, 6136 (2021).
34. L. Lu, P. Jin, G. Pang, Z. Zhang, G. E. Karniadakis, Learning nonlinear operators via DeepONet based on the universal approximation theorem of operators. *Nature Machine Intelligence* **3**, 218-229 (2021).

Biography

Safa Jamali is an Associate Professor of Mechanical and Industrial Engineering at Northeastern University, where he has been since 2017. He received his PhD from Case Western Reserve University's Macromolecular Science department, followed by two years of Postdoc training at MIT's Chemical Engineering, Mechanical Engineering and Energy Initiative. His research group's activites are currently focused on developing and using a series of data-driven and computational techniques to study physics and rheology of complex fluids. Science-based data-driven methods and machine-learning platforms for rheological applications have been a major thrust of his efforts in recent years.

Of Biscuits & Breakthroughs: Reflecting on the Layers of Oreology's Impact and Adding a New Twist

By Crystal E. Owens (crystalo@mit.edu), A. John Hart, Gareth H. McKinley (gareth@mit.edu)
MIT Department of Mechanical Engineering, Cambridge, MA 02139

1. Introduction and Reception

In April 2022, we introduced Oreology, from the Nabisco *Oreo* for "cookie" and the Greek *rheo logia* for "flow study," as the study of the flow and fracture of sandwich cookies. We published our findings in the "Kitchen Flows" special issue of Physics of Fluids[1], firmly establishing the creme filling of the common Oreo as a fluid. Our original intent was to create an engaging, digestible lesson on rheology based on the perfect food-analogy for parallel plate rheometry, but the response from the community was remarkable. Over the last year, the paper has received over 114,000 views and 18,000 downloads, it has been the subject of over 150 news articles in at least 12 languages, and it has received 3 (!) citations. In this article, we wish to describe the impact and reception of the original paper, and to add a satisfying conclusion to our search for the perfect Oreo split.

Optimal Oreo consumption is an act of precision and balance[2]. Hold, twist, and separate. This has the obvious advantage of starting with one cookie and ending with two. However, this edible game often ends with one wafer holding 95% or more of the creme, leaving the other wafer feeling a little bare (Figure 1a), much like our paper view-to-citation ratio. In addition, we[1] and others[3] have found that this is not a random choice of one wafer, like a coin flip, but that the creme is pre-determined to favor one particular wafer based on its original position in the box. We believe this peculiar behavior can be traced back to the cookie's birthplace, the production line, where the creme-winning wafer was likely the first of the two to contact the creme, after which the cookies were placed orderly into the final packaging, preserving the conferred directionality. In our first study, we found this in-box bias was a universal truth for Regular, Double Stuf, and Mega Stuf cookies, describing 80% of failures, as well as for different flavors, although vanilla wafers were more prone to crack, likely due to less optimized mechanics.

Our Oreo odyssey had one core mission: to establish a method of opening that would persuade the creme to split evenly between the two wafers. However, the creme retained its original bias despite our best efforts at varying parameters,

FIGURE 1. (a) Original results describing a consistent bias of creme adhering to one side upon cookie separation, adapted from our original paper. (b) An exception to the rule: NBC's report[4] showcasing cookies split after being stored in a hot car, displaying some creme on all wafers (courtesy NBC Universal). (c) A replication of our study by a Thermal Physics class at the University of Gröningen in the Netherlands (courtesy Prof. Thomas Schlathölter).

whether it was rotation speed, changes in normal force, or other protocols. Despite these nearly null results, our research was widely shared by curious scientists and was sprinkled across headlines such as the generous "Age-old Oreo mystery solved by MIT scientists" [5] and the ironic "Ph.D. candidate works for 6 months to engineer perfectly split Oreo"[4]. Our results were replicated in homes, labs, and even on news shows (Figure 1b), as well as for related sandwich desserts, notably Pierre Hermé macarons and Prince cookies[6]. And the pedagogical impact of our work was widespread, finding a place in classroom demonstrations to teach students about concepts from adhesion to torsion and, of course, rheology (Figure 1c).

We were ready to close the cookie jar on our favorite dessert. But one common suggestion, raised by no fewer than 15 separate emails to the paper authors, was a request to better understand the role of temperature. We had unfinished business, so it was time to return to the lab.

2. Coercing an Even Creme Split, and the "Hot Cookie Phenomenon"

We had reasoned that uneven creme splitting was due to the delicate balance between adhesive and cohesive forces, in which Oreo creme preferred to fail adhesively, delaminating from one wafer. To tune the Oreo behavior, then, perhaps we merely needed to soften the creme. What we have newly discovered through additional experiments (perhaps coincident with various lab parties) is that Oreos show a dramatic change in behavior when heated. Our first direct observation of this phenomenon happened during a news interview. The pack of Oreos, left on the reporter's car dashboard in the sun the previous afternoon, ended up unintentionally sabotaging our demonstration (Fig 1b), and so we dub this effect the "hot cookie phenomenon" (HCP). Cars exposed to the direct summer sun can often reach 50-55°C (122-131°F)[8], giving a likely temperature range over which this could occur.

To examine the hypothesized HCP, Oreos were again mounted on our laboratory rheometer (DHR-3; TA Instruments), with the lower Peltier plate set to an elevated temperature. Due to the low thermal diffusivity expected for creme (around 0.1 mm^2/s [9]), the cookies were left to equilibrate for 15 minutes at the elevated temperature before being twisted to failure and then being separated vertically. As the temperature set point increased, the yield stress decreased nearly 50x from 13.8 kPa to 0.3 kPa while the yield strain increased from 0.3 to 1.5 strain units, consistent with the creme softening and increasing in ductility (Figure 2a).

More importantly, for temperatures of 55°C and above, the creme was observed to split progressively more evenly (Figure 2b), with 80%, 60%, and 50% of the creme by mass remaining on the upper half for tests at 55, 65, and 75°C, respectively, compared to nearly 100% at 25°C. This indicates that one can not only ensure a relatively even split, but one can fine-tune the evenness of the split by temperature. In addition, at higher temperatures the

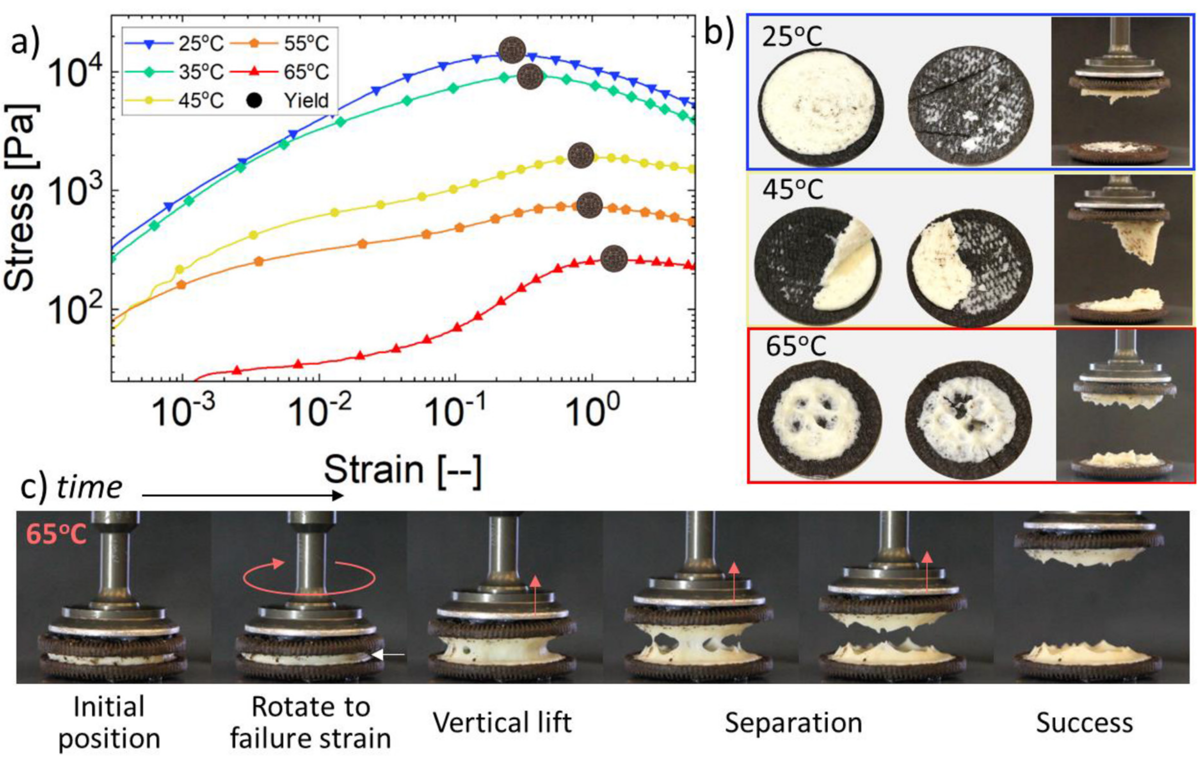


FIGURE 2. The "Hot Cookie Phenomenon." (a) Evolution of shear stress as a function of applied shear strain (rotation) for a range of temperatures. The yield point is marked with a filled circle. (b) Images of separated cookies are shown for 25, 45, and 65°C with the top wafer on the left side and the bottom wafer on the right side. (c) A time series of images shows an Oreo being tested in torsion followed by vertical separation.

FIGURE 3. (Left) Perfectly separated Oreo using the HCP at 65^{o}C. **(**Right**)** Close-up image of the lower wafer, with a satisfying amount of creme.

Oreo creme was observed to shear evenly and then split with a series of peaks and ridges upon axial separation of halves (Figures 2c and 3), a phenomenon that has been noted before for the fingering instability of colloidal gels between two separating plates [10].

These rheometric results were confirmed by bulk heating, i.e. placing Oreos in the microwave for 5-15 seconds, which also resulted in the desired creme split (data not shown). In the lab, we further discovered that, due to the low thermal diffusivity, an Oreo placed on a hot plate for a short time (5 min) could be coaxed to split with the creme always separating to leave the bottom (heated) wafer bare and remain affixed to the top (room temperature) wafer, regardless of original orientation in the box. Thus, by manipulating temperature, we have mastered Oreo failure and we are able not only to predict, but also to direct, where the creme will land when splitting the wafers (within statistical bounds of variation).

Finally, once a cookie was cooled back to room temperature, failure remained more even. Though not perfectly symmetric, each wafer retained at least a coating of creme, as in Figure 1b. More generally, the HCP means that Oreos in boxes shipped or stored in hot weather will show different failure phenomena than gently handled Oreos, and that cookies still warm from heating in a microwave, warm oven, or toaster oven may give more symmetric creme division. A further thermo-rheological probe test in our lab revealed that a cookie heats up on a hot plate from a room temperature of 25^{o}C to 65^{o}C with a time constant of $\tau_{heat} \approx 76$ seconds, requiring $5\tau_{heat} \approx 6$ minutes to reach the desired elevated temperature. When cooling back to 25^{o}C, however, we find a time constant of $\tau_{cool} \approx 317$ seconds, requiring $5\tau_{heat} \approx 26$ min to reach thermal equilibrium. This high thermal inertia is most likely due to the significant crystallization time for cooling sugars[11]. Such phenomena are thermo-rheologically complex and affect the properties of other sugary desserts like ice cream and chocolate.

This signals a word of caution to eager readers or parents: Oreos can cool down very slowly, meaning that they could still be hot long after being removed from the heat source. Remember to eat carefully after heating, or perhaps dunk cookies in milk to speed up the cooling process!

References

1. Owens, C. E., et al. On Oreology, the fracture and flow of "milk's favorite cookie". Phys. Fluids 34, 043107 (2022).
2. Oreo Twist Lick Dunk TV Commercial. YouTube https://www.youtube.com/watch?v=Oe6lBGO6OSk (2011).
3. Starostinetskaya, A. Princeton Physicists Solve Oreo Cream Mystery. VegNews (2016).
4. Niezgoda, A. Ph.D. candidate works for 6 months to engineer perfectly split Oreo. NBC News (2022).
5. Melore, C. Age-old Oreo mystery solved by MIT scientists. StudyFinds (2022).
6. Lalande, V. (Scilabus). How does the design of a cookie change the way that we eat it? https://www.youtube.com/watch?v=sd1f4xRgieM (2022).
7. Breidinger, S. L. & Steffe, J. F. Texture Map of Cream Cheese. J. Food Sci. 66, 453–456 (2001).
8. Al-Rawashdeh, H. et al. Investigation of the Effect of Solar Ventilation on the Cabin Temperature of Vehicles Parked under the Sun. Sustainability 13, 13963 (2021).
9. Agrawal, A. K., et al. Effect of incorporation of ginger juice in various rates on the freezing and thermal properties of ice cream. Asian J. Dairy Food Res. 34, 92 (2015).
10. Divoux, T., et al. Criterion for Fingering Instabilities in Colloidal Gels. Phys. Rev. Lett. 124, 248006 (2020).
11. Leducq, D., et al. Phase change material for the thermal protection of ice cream during storage and transportation. Int. J. Refrig. 52, 133–139 (2015).

In Memoriam: Tom McLeish (1962 – 2023)

By Michael Cates

Tom McLeish, who won the Bingham Medal of the Society of Rheology in 2010, died of pancreatic cancer on 27 February 2023, at the tragically early age of 60.

Tom was among the leading contributors of his generation to theoretical polymer rheology, particularly that of branched polymers. Such polymers are ubiquitous in the plastics industry, as well as in many other applications domains, where their rheological behaviour is found to depend in a highly nontrivial way on the underlying branching architecture. The problem is challenging at three levels: first understanding how a single branched chain moves in a given environment; second, understanding how different chains affect each other's motion by collectively creating that environment; and third, dealing with the fact that branching architectures are almost always random, so that every chain is different from every other in size and structure.

The tube theory of polymer rheology was pioneered in the 1970s by Pierre-Gilles de Gennes, Sam Edwards and Masao Doi. It is based on an elegant simplification: that any one chain is constrained by its entanglements with others to reside in a topological 'tube'. This idea was immediately successful for unbranched chains, but before long it was in the domain of branched polymers that the tube concept often faced its most demanding challenges. In overcoming such challenges, a newly sophisticated and powerful incarnation of the tube theory was forged. Its creation involved many distinguished scientists, but in the domain of branched polymer rheology, Tom was surely a first among equals.

For example, the extremely broad relaxation spectrum of branched polymers allows the thermal or forced motion of one chain to strongly alter the entanglement state of another, through mechanisms called thermal and convective constraint release. It also means that relatively mildly entangled chain segments, near the periphery of the branching chain architecture, relax fast enough to become effectively a solvent bath for the those that lie deeper within it. Tom and his collaborators introduced two key distributions, the seniority and priority distributions, to quantify the resulting effects on linear and nonlinear rheology, for polymers of any statistically defined branching architecture and size distribution.

Armed with these and other powerful tools, Tom and his colleagues could predict the response of many classes of molten polymeric materials to different regimes of stress and invent simpler models that could reliably predict the same rheological responses. This work led to many key insights, including those lucidly summarized by Tom in his 2002 review article (Tube Theory of Entangled Polymer Dynamics, Advances in Physics v51 pp 1379-1527):

> *"An entangled segment of a branched polymer in the melt will contribute to the bulk stress via both its orientation (tensor property) and stretch (scalar property). These quantities will relax with different characteristic timescales. The segment will stretch in flow, but only up to a maximum ratio, given by the effective number of free ends attached to its delimiting branch points."*

Crucially for many applications, McLeish's theories explained the huge rheological differences between unbranched or lightly branched chains and their more highly branched counterparts (such as low-density polyethylene, LDPE). These differences include, for example, *opposite* nonlinear behaviours (strain softening versus strain hardening) in extensional flows. Moreover, branched chains show hardening even for planar rather than uniaxial extension, contrary to previous expectations that planar extension should instead be similar to shear flow (which shows strain softening). Tom's contributions to polymer rheology have thus included major breakthroughs not only in basic science, but also for the plastics industry.

McLeish sometimes took delight in giving quixotic names to his simple models, such as the Pom-Pom Model, or, in full, the *Ron-Tom Pom-Pom Polymer Model* – acknowledging the model's coinventor, Ron Larson (Bingham Medal 2002). Indeed, Tom was always the first to acknowledge the crucial scientific roles of his numerous collaborators. He saw science as very much a collective enterprise–often being willing to set aside personal research goals to take on leadership roles within that larger enterprise.

Within and beyond his main research field of rheology, Tom took delight in showing how mathematical ideas can unite different scientific endeavours. He held a lifelong interest in astronomy, and at one conference got talking to another physicist about how magnetic flux lines get entangled near the sun. Tom was rightly proud of the astrophysics research paper that he co-authored, following that chance encounter.

More generally, McLeish's interests extended far beyond science; they included both history and theology, and he worked tirelessly to break down the barriers between the sciences and the humanities, not least in his two books, *Faith and Wisdom in Science*, and *The Poetry and Music of Science*. For example, in his work with philosophers on 'emergence', Tom argued that the nature of topological effects (e.g., in ring polymers) exemplifies 'top-down causation', bolstering the case against reductionism.

His extreme interdisciplinarity had some notable successes. For example, Tom co-authored important historical studies of the scientific theories of the 13th century scholastic philosopher and Bishop, Robert Grosseteste. In a beautiful example of historic-scientific detective work, Tom and his collaborators realized Grosseteste's theory of colour would become scientifically coherent, if only a single word were added to the Latin text they were studying. Could it be a typo? This turned out to be exactly the case–the missing word was found to be present in an earlier version; lost through the transcription error of medieval copyists.

Tom was never afraid to step beyond the comfort zone of his existing scientific knowledge. In the past two decades, that fearless approach bore fruit in a series of innovative contributions to biological physics. Some of these built on his ideas about polymer motion, including beautiful work on the stretching of silk fibres, and on how small signalling molecules cooperatively bind to flexible protein polymers through a mechanism called entropic allostery. But other contributions built on his comprehensive knowledge of theoretical physics, using it to explore how physical principles contain nature's capacity for endless variation, at levels ranging from the genome, through cells, and upwards to organisms and populations.

Meanwhile, Tom's scientific laurels, though he never rested on them, were accumulating. Prior to the Bingham Medal in 2010 he won the Gold Medal of the British Society of Rheology (2009) and the Weissenberg Award of the European Society of Rheology (2007). In 2011 Tom was elected as a Fellow of the Royal Society, the UK's national academy of science. There he became a Council Member and Trustee, and played a key national role in curriculum development and science education, as Chair of the Society's Education Committee. Besides this, Tom was a highly effective Pro-Vice Chancellor at Durham University for six years; he founded and helped run a Centre for Doctoral Training in soft materials across three Universities; and he led a series of major industrial research collaborations.

Within and beyond all these roles, Tom profoundly influenced a large number of younger scientists. As a mentor he was compassionate, understanding of others' difficulties, and had an extraordinary ability to enthuse people to achieve their own best work. That enthusiasm, and Tom's generosity with his own ideas, was an inspiration not just to his immediate colleagues, but to the wider scientific community.

Tom McLeish completed his PhD in Cambridge with Robin Ball, in the group of Sam Edwards, in 1987. Just two years later he joined the faculty of the University of Sheffield, and soon after that was appointed to a Professorship in Polymer Physics at the University of Leeds, at the youthful age of 31. In 2008 he moved to Durham as Pro-Vice-Chancellor and Professor of Physics, before moving in 2018 to the University of York. There he held the Chair of Natural Philosophy, with a joint appointment in Physics and Mediaeval Studies.

Tom was a genuine polymath: a man passionate about science, but whose passions equally embraced music, literature, languages, public speaking, good food and wine, the outdoors, history, friendship, and above all his religious faith. He will be sorely missed by all who knew him.

Tom McLeish is survived by his wife, Julie, and their four children.

Obituary

Robert A. Mendelson (1930 – 2020)

Robert A. Mendelson passed away on January 10, 2020, from a stroke. Bob was born on December 17, 1930, in Cleveland, Ohio. He remained in Cleveland for his education and in 1952, received his B.S. in Chemistry from Case Institute of Technology. He then continued at what was then Case Western Reserve University and received his Ph.D. in Physical Chemistry in 1956. Bob was an accomplished research scientist and rheologist, having developed the material used for the first Coca-Cola bottle. He was also instrumental in commercializing PVC and ABS plastics. Bob published more than 40 papers and patents on topics as diverse as temperature dependence of rheological properties, GPC determination of LCB and the effect of chain branching on subsequent melt rheology. He served on the steering committee for the establishment of ISO standards for rheology, and in 1983 Bob received the Arthur K. Doolittle Award of the Polymer Materials Division of American Chemical Society for his work on new styrene-based terpolymer blends.

Mendelson served as Secretary of The Society of Rheology from 1973-1977. He was elected to the office of President from 1989-1991 and SoR Fellow Emeritus in 2015. While president, Mendelson worked to help put a halt to regulations which would prohibit federal employees from serving on executive committees for scientific societies; an important issue for a volunteer-led society which has benefited greatly from the service of numerous NBS and NIST employees as Executive Officers of the Society. He also led the Society during a key publishing transition in which the Society (in conjunction with AIP) took over the role of publishing the Journal of Rheology from John Wiley & Sons. Bob will be fondly remembered as a humble man of few words and unquestionable integrity. He was committed to the principles of fairness and equality. Bob will be missed by all who knew him.

Editor's note*: This obituary was scheduled to appear in an earlier edition of the Rheology Bulletin. Unfortunately, the article was "lost" during the pandemic, but a version can be found on our website, https://www.rheology.org/sor/fellowship/MendelsonR. This is an attempt to remediate the situation.*

Secretary's Report

Kalman Migler

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

Executive Committee Meeting, Fall 2022

Motion to approve $500 budget for student gathering at the American Institute of Chemical Engineers (AIChE) annual conference.

Motion: Society of Rheology (SoR) to hold virtual business meeting in Oct 2023.

Motion: Recommendation to put $300k into the Total Stock Market Index Fund over 6 months to be reviewed next spring meeting and simultaneously consult with financial adviser to recommend a better diversified portfolio. (invest $100K at a time over 2- month intervals, which takes us to the next ExCom meeting).

Membership (Business) Meeting, Fall 2022

Motion: Approve the 2023 budget, as presented

Interim Executive Committee Meeting, December 2023

Motion that we allocate $20k of budget for a bookkeeper.

Motion that we make Jonathan Rothstein Treasurer for 2023, subject to his agreement.

Executive Committee meeting Spring Meeting, April 2023

Motion: The Journal of Rheology will transition from a "transfer of copyright" agreement to an "exclusive license to publish" agreement. (License to Publish Agreement means that authors hold copyright, and grant SOR an exclusive license to publish).

Motion: Technical Program Chairs have freedom to schedule 20- or 25-minute talks in the annual meeting, with the understanding that there is a preference for 25-minute talks when practicable.

Executive Committee Interim, June 2023

The Executive Committee met to hear the report of the Constitutional Committee, which was charged with proposing amendments, where warranted, to the constitution and rules. The Executive Committee decided that several updates are warranted, and will proceed with a proposal to the membership, in accordance with the relevant rules governing amendments. Proposed amendments are planned to be presented at the next full Society Business meeting.

Treasurer's Report

By Jonathan Rothstein

The Society of Rheology (SoR) is currently in good financial condition. For the year 2022 the SOR ran a small deficit of $10,653 (see Summary Table). This deficit compared to the relatively large surplus of 2021 and is the result of the large cost of the 2022 Annual Meeting in Chicago. The Chicago meeting lost $169,000. This loss was offset by the profits made from the publication of the Journal of Rheology.

In 2023, the SOR will not host a meeting because of the International Congress of Rheology (ICR). As a result, a return to profitability is expected in 2023. In 2024, the SoR will host its Annual Meeting in Austin, TX. Moving forward, the Treasurer's expectation is that the goal of the SoR is to run a cost-neutral meeting, however, this may require substantial increases in registration fees to achieve. There will need to be significant discussion about the financial goals of the Society of Rheology and how best to sustainably support the broad mission of the Society of Rheology in the future. This includes the cost of meetings and whether to maintain a cost neutral philosophy.

Budget highlights for 2023 (approved in Chicago, see Table 2) include funding for the student travel grants to the ICR, $33K, additional funding of the rheology venture fund, $30K, along with increases in interest payments from investment of our reserves through Schwab investments. The budget for 2023 is also included in Table 2.

This report will detail the major activities of the Society of Rheology and how they are accounted for in the American Institute of Physics (AIP), the American Institute of Physics Publishing (AIPP), the Schwab account, and QuickBooks online account. There are several highlights. Each section of this report is built around a major activity for the SOR. **Below is a simplified summary of the major accounts and totals for 2022. A detailed accounting is presented following this summary.**

SOR has significant financial reserves, a strong brand, and a dedicated membership base. The accompanying charts document expenditures and revenues for the specific time periods in the Society's history. The dues revenue was in-line with previous years. The net revenue for SOR in 2022 is predominately due to the subsidy created by the combination of constant revenue and the decreased production cost for the Journal of Rheology along with several one-time decreases in expenses resulting from the publishing agreement with American Institute of Physics Publishing (AIPP).

We are a society with appreciable financial reserves that require more extensive oversight and management. The Executive Committee has recognized this transition and taken three definitive steps: the establishment of a regular formal audit, financial advisement committees, and an AIPP partnership for publishing the JOR.

The Society greatly appreciates the contributions from the three members of the Audit Committee: **Anthony Kotula (Chair), Brian Edwards and Jeffrey Martin**. The Audit Committee has already met, examined the books, reported to the Executive Committee and delivered recommendations on the accounting practices for the Society at the 2022 Annual Meeting. These recommendations have been implemented.

The Society also appreciates the contributions from the three members of the Financial Advisement Committee: **Lisa Biswal (Chair), Rekha Rao, and Phil Sullivan**. This committee is charged with developing specific recommendations for investments based on the directions given to it by the Executive Committee. This committee presented a report to the Executive Committee in 2022 and the recommended investment strategies are currently being implemented.

The third major change that started in 2019 (and continues into 2023) was the five-year publishing partnership with the AIPP for the Journal of Rheology. While this arrangement has several implications, here we will address the impact on the treasury. The partnership will guarantee revenue of $100K/yr. to the Society of Rheology. Any net revenue greater than the $100K minus the expenses, will be split with AIPP in a 50-50 arrangement.

Society of Rheology
January- December 2022

Revenue		Expenses	
Chicago Meeting	-$ 169,077	AIP expenses	$ 35,969
Dues	$ 66,590	Awards	$ 28,111
Journal of Rheology	$ 261,986	Journal of Rheology	$ 48,018
Pledges	$ 15,000	ExCom	$ 10,971
Interest Income	$ 2,250	Student Travel	$ 45,567
Misc.	$ 10,423	Other	$ 29,189
Total Revenue	**$ 187,172**	**Total Expenditures**	**$ 197,824**
Summary Table		**Net Revenue[1]**	**–$10,653**

Journal of Rheology

Beginning in 2019, the SOR began a publishing partnership with AIPP, resulting in increased revenue through consortium marketing and decreased cost of producing the journal resulting in increased JOR net revenue. As this data in Figure 1

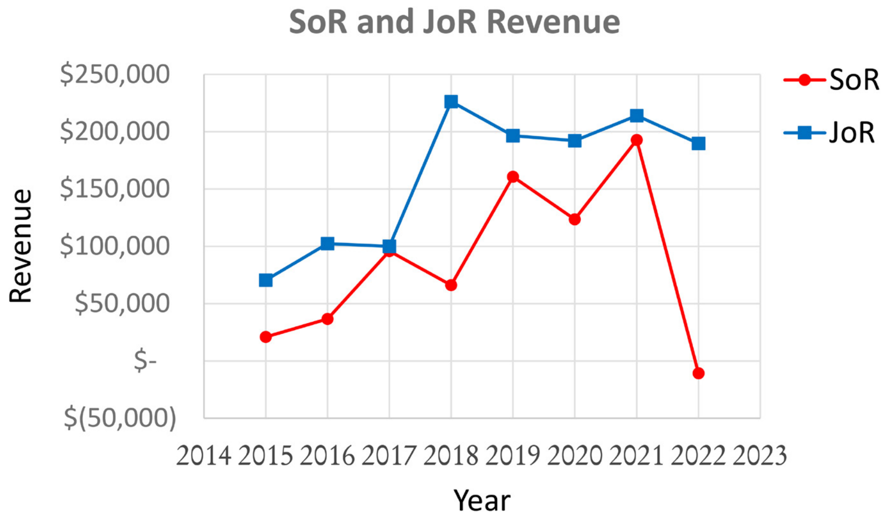


FIGURE 1. The annual net revenue from the Society of Rheology and the Journal of Rheology.

suggests, JOR is not a fixed, nor a guaranteed, source of revenue over time. The original partnership agreement runs until the end of 2023. A new 5-year agreement is expected to be signed in June. There are still several unresolved threats to this economic model. The largest of these is Gold Open Access. Open Access policies at the national and international levels may result in libraries no longer being willing to pay for a full or even partial subscription to a hybrid journal such as JOR. It is important to recognize that even small changes in the revenue, library subscriptions, or cost of production of JOR will significantly affect the net annual revenue.

Society of Rheology

As shown in Figure 2, the revenue for the SOR outside of the journal is mainly from two sources: membership dues and interest on reserves. Prior to 2016 the dues revenue remained flat. A modest dues increase was proposed and approved in 2016, resulting in an annual increase in revenue from ~$40K to ~$60K. The interest on the reserves over the last 10 years has been quite modest and in 2021, this revenue collapsed due to a sudden drop in interest rates. With the rise in interest rates over the last year, the interest revenue has rebounded slightly. The return on investments is expected to rise in 2023 with the investment of the reserve accounts in higher interest rate bonds and stocks based on the financial committee's investment plan.

The expenses associated with running SOR have risen quite significantly recently. In addition to the increasing costs of running the SOR, strategic investments into fulfilling the mission of the SoR like supporting student travel grants, the Rheology Research Symposium (RRS) and the Rheology Venture Fund (RVF) have been added to the annual expenses of the SoR. It is reasonable to assume that the expenses associated with SOR operations will continue to increase with no offsetting increase in revenue.

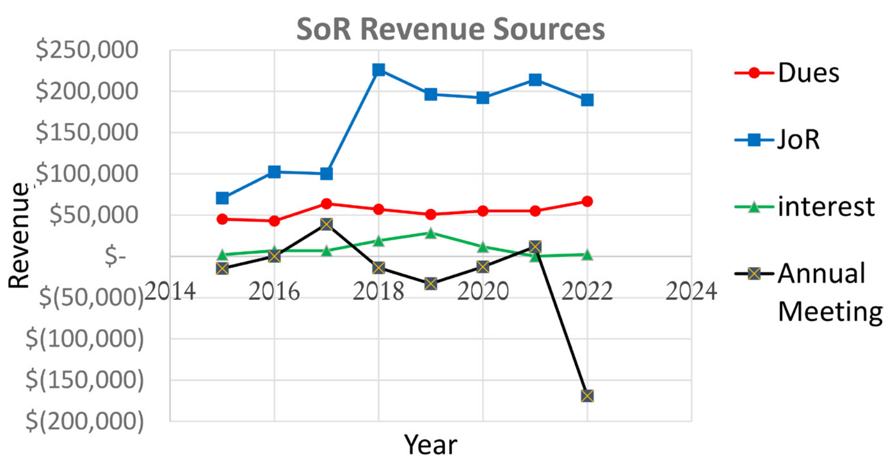


FIGURE 2. Revenue from SOR (with the Journal of Rheology shown separately) from 2015-2022.

Society Meetings

The meetings we have grown accustomed to attending are not feasible at locations such as Chicago, Austin, Boston, and even Santa Fe without some financial subsidy or a significant increase in registration fees. In Chicago this subsidy exceeded $160K. SOR also takes on significant liability in hosting these meetings. SOR narrowly avoided paying out on the liability of a $300K contractual obligation to cancel the planned February 2021 Austin meeting. Typically, SOR has four or five such contracts for future meeting spaces at any given time. This total exceeds $1M in contracted liability for future meetings. While the probability of losing this substantial outlay due to unforeseen circumstances is small, 2020 has demonstrated that it is a possible outcome. This potential liability is covered only by our reserves.

Professional Services

SOR is the smallest of the AIP member societies. We are also the only AIP Member Society that has no professional staff. Everything SOR does is based on the efforts of volunteers. THANK YOU! Increasingly, as these responsibilities grow, these volunteer efforts are being replaced with subsidized positions. For example, the successful operation of JOR requires two subsidized Editors, the bulletin editor has transitioned to a subsidized Communications Coordinator, the Treasurer position now works with professional bookkeepers, and our meetings are now being planned with help by professionals from APS. Additional areas of future investment may include professional staff to assist Albert or a future webmaster with our website. There are always significant unanticipated

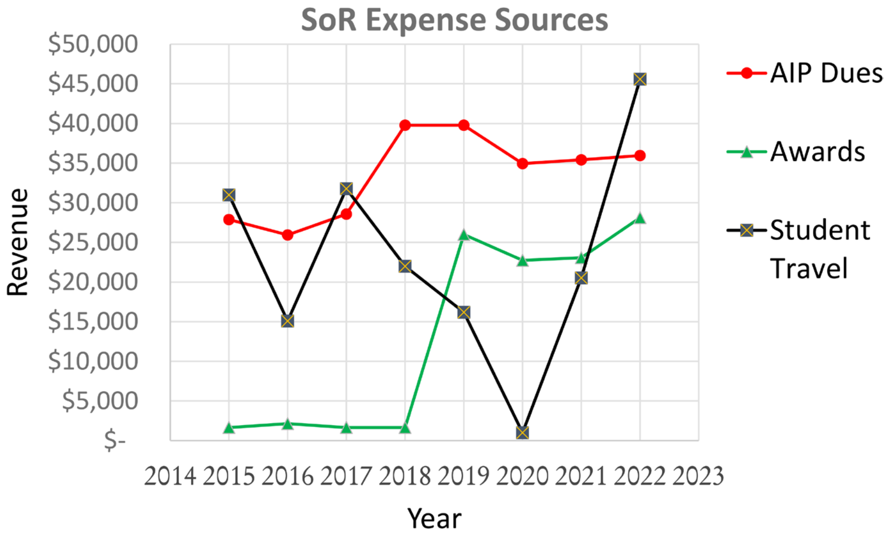


FIGURE 3. Operating expenses for SOR (without JOR) from 2015-2022

expenses, for example, in 2023 there is $20K in legal fees to help deal with copyright issues associated with short courses and possible future distribution of short course videos online.

Reserves

Where did the SOR financial reserves come from? The reserves shown in the balance sheet are a result of planned net revenue from the SOR for the period 1929-2004 augmented by net revenue from JOR for the period 2005-2021. By 1997, SOR had accumulated $777K in reserves by generating revenue streams (primarily dues) greater than expenses. The reserves, as currently envisioned, anticipate a one-year shock to the system with a return to previous conditions. For example, having to pay $300K to cancel a single meeting (such as we nearly had to

TABLE 1. Detailed Income and Expenses of the SOR from 2019-2023.

The Society of Rheology Receipts and Disbursements	**2023 Budget**	**2022**	**2021**	**2020**	**2019**
RECEIPTS					
Dues	$ 55,000	$ 66,590	$ 55,166	$ 55,154	$ 50,890
Interest	$ 8,000	$ 2,250	$ 101	$ 11,688	$ 28,493
Venture fund(asset)	$ -	$ -			
Journal of Rheology	$ 239,631	$ 261,986	$ 239,631	$ 239,813	$ 275,613
Donations	$ -	$ 15,000		$ 1.51	
Miscellaneous	$ -	$ 10,423			$ 10,000
Annual Meeting (net)	$ (10,000)	$ (169,078)	$ 11,548	$ (12,566)	$ (33,001)
Short Course (net)	$ -	$ -	$ -	$ -	$ 10,371
TOTAL RECEIPTS	**$ 292,631**	**$ 197,172**	**$ 306,446**	**$ 294,090**	**$ 342,366**
DISBURSEMENTS					
AIP Dues Bill & Collect.	$ 36,000	$ 35,969	$ 35,417	$ 34,940	$ 39,769
Contributions and Prizes	$ 25,000	$ 28,111	$ 23,062	$ 22,742	$ 25,996
Journal of Rheology	$ 50,000	$ 48,018	$ 47,563	$ 43,407	$ 49,308
Bulletin	**$ 10,000**	$ 1,371		$ 9,799.70	$ 18,920
Executive Cmt. Meetings	$ 10,000	$ 10,971	$ 1,605		$ 9,318
Pres. Discretionary Fund	$ 5,000	$ 4,718	$ -		
Treas. Discr. Fund	$ 3,000	$ 1,637	$ -	$ 755	
Bulletin Editor support	$ 4,000	$ -	$ -		
Progr. Chm. Discr. Fund	$ 5,000	$ -	$ -		
Webmaster Discr. Fund	$ 5,000	$ 313		$ 2,702	
International Activities Fund	$ 3,000	$ -	$ -		
Liability Insurance	$ 8,000	$ 6,336		$ 7,189	
Accountant	$ 3,000	$ 5,462			
History Project	$ 3,000	$ 1,092			
Legal Fees	**$ 20,000**	$ 8,210		$ 17,581	
Student member travel	**$ 33,000**	$ 45,567	$ 20,532	$ 1,000	$ 16,200
RRS		$ -			
RVF	**$ 30,000**	$ -			
DEI		$ -			
Annual meetings, future	$ 5,000				
Website	$ 1,000	$ -		$ 566	
Targeted Investments	$ -				
Miscellaneous	$ -	$ 50		$ 29,906	$ 22,135
TOTAL DISBURSEMENTS	**$ 259,000**	**$ 197,825**	**$ 128,179**	**$ 170,587**	**$ 181,646**
Net	**$ 33,631**	**$ 10,653**	**$ 192,795**	**$ 123,503**	**$ 160,720**

TABLE 2. Sources of Revenue for Journal of Rheology.

Journal of Rheology	2022	2021	2020	2019	2018	2017
Advertising Sales				$ 4,313	$ 27,085	$ 33,000
Royalties				$ 3,709	$ 18,285	$ 22,000
Single-Copy Sales					$ 2,863	
Consortium Access Fees				$ 5,000	$ 54,432	$ 53,169
Consortium Subscription					$ 94,025	$ 86,663
Subscriptions				$ 17,591	$ 112,083	$ 100,340
AIPP Guarantee	$ 100,000	$ 100,000	$ 100,000	$ 100,000		
AIPP Profit sharing	$ 161,986	$ 139,613	$ 139,813	$ 45,000		
Total Revenue	**$ 261,986**	**$ 239,613**	**$ 239,813**	**$ 275,613**	**$ 308,773**	**$ 295,172**

TABLE 3. Journal of Rheology expenses and net revenue.

	2022	2021	2020	2019	2018	2017
Revenue	**$ 261,986**	**$ 239,613**	**$ 239,813**	**$ 275,613**	**$ 308,773**	**$ 295,172**
Fixed cost				$ 31,854	$ 126,818	$ 122,492
Print				$ 17,454	$ 49,071	$ 64,000
Online					$ 24,772	$ 22,250
Total Expenses	**$ 48,018**	**$ 47,563**	**$ 44,707**	**$ 49,308**	**$ 200,661**	**$ 208,742**
NET	**$ 213,968**	**$ 192,068**	**$ 195,106**	**$ 226,305**	**$ 108,112**	**$ 86,430**

do in 2001 in Bethesda or the 2021 Austin meeting) would completely deplete the funds in the meeting reserve. This model does not anticipate long-term changes in the revenue and expense model for JOR. Our history has shown that the current profitability of JOR is not fixed. Our performance also shows that the expenses associated with running SOR will continue to increase and therefore rely more and more on the uncertain subsidy provided by JOR.

Our reserves allow time for future Executive Committees to respond to these one-time or systemic changes. The reserves provide future Executive Committees the opportunity and flexibility to consider new innovative initiatives or just to keep the Society running in times of crisis.

The reserves also offer the opportunity to buffer the uncertainty associated with the subsidy required by JOR revenue to keep SOR running. Establishing interest revenue and using a portion of that interest income to fund SOR operations is a path that has been used in the past (pre-2007). To increase the return on investment requires exposure to downside risk on our principal. The finance committee is charged with making recommendations to the executive committee around this balance between risk to

TABLE 4. Balance sheet for SOR from 2018-2022.

The Society of Rheology, Inc. Balance Sheet	**2022**	**2021**	**2020**	**2019**	**2018**
Assets					
Cash in checking account(s)	$ 80,871	$ 142,871	$ 47,741	$ 46,727	$ 27,774
Balance in AIP account	$ 562,945	$ 608,866	$ 449,440	$ 354,665	$ 862,081
Schwab (Reserve1)	$ 950,550	$ 945,384	$ 947,471	$ 942,513	$ 1,018,793
Schwab (Reserve2)	$ 612,221	$ 608,866	$ 608,604	$ 602,731	
Accounts Receivable	$ 161,638	$ 1,654	$ 88,151	$ 129,885	$ 1,197
Prepaid Expense	$ 11,000	$ -	$ (8,500)	$ 36	$ 36
Total Assets	**$ 2,379,225**	**$ 2,307,641**	**$ 2,132,907**	**$ 2,076,557**	**$ 1,909,880**
Liabilities and Net Assets					
Liabilities					
Deferred revenue	$ 29,374	$ 13,166	$ 32,245	$ 126,398	$ 122,190
Venture Capital Fund	$ 26,455	$ 26,900	$ 27,000		
Total Liabilities	**$ 55,829**	$ 40,066	$ 59,245	$ 126,398	$ 122,190
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	$ 1,774,048	$ 1,143,662	$ 1,020,159	$ 859,439	$ 791,586
Net Revenue	-$ 653	$ 192,795	$ 123,503	$ 160,720	$ 66,105
Total Net Assets	**$ 2,323,395**	$ 2,266,457	$ 2,073,662	$ 1,950,159	$ 1,787,690
Total liabilities and net assets	**$ 2,379,225**	**$ 2,306,523**	**$ 2,132,907**	**$ 2,076,557**	**$ 1,909,880**

principal and return on investment. The reserves function like that of an endowment for SOR operations to offset future expenses and financial shocks.

How large a reserve should SOR maintain? As our past has shown, the current net revenue from JOR is not assured, yet the expenses of running SOR continue to increase. As the revenue from SOR remains flat, any financial shocks or increased future operating expenses must be paid from these reserves. There are significant future expenses that will require funds. In this uncertain future, the current temporary surplus from JOR should be considered a safeguard against future unexpected expenses and liability exposure. The presence of the reserves allows SOR and the Executive Committee to focus on our mission, 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.

Explosive Droplets

Splashes, captured by the microsecond flashes, reveal
craters form when your eyes drop millimeter-size bombs
into a cup of tea. The shock creates a splash, plumes
rise like tulip petals, then recede. The rage diffuses.
The snapshots remain.

Before the sparks, before silver bromide, raindrops
exploded unheard over ponds on earth.

When an incarnated teardrop surged on Rukmini's cheek,
Krishna rushed to deposit it on his palm, saying:
'Beloved! Don't you realize a drop from your eyes
on earth can cause *Pralaya*, the apocalyptic deluge?'

If your eyes keep dropping grenades,
our world will blast away. Only in the monsoon,
you can let your eyes cloud and release
memoirs into the mud streams of paddy fields.
Only in the monsoon, the heartbroken
explosive droplets create drum-beat splashes
for an orchestra of rejuvenation.

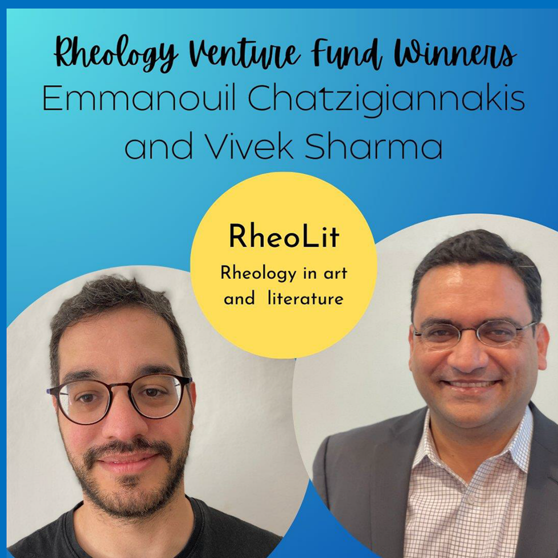
Rain drops - image from Wikimedia

Biography

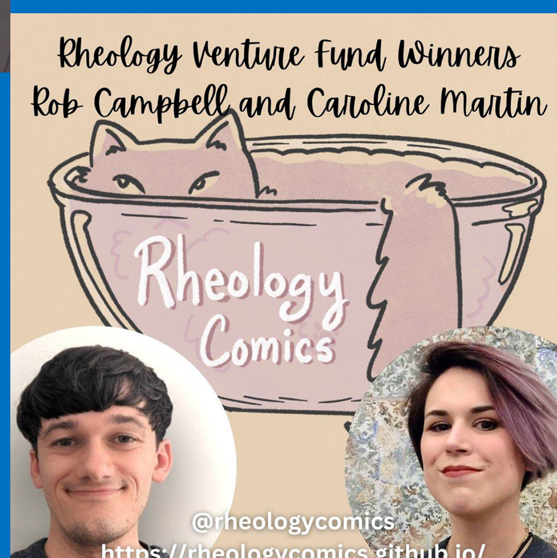
Vivek Sharma first collection, *Saga of a Crumpled Piece of Paper,* was shortlisted for the Muse India Young Writer Award 2011. His poems in English appear in *Atlanta Review, The Cortland Review, Mythium, Bateau, Breakwater Review, Muse India,* and *Physics of Fluids,* among others. Vivek publishes poems and translations in both English and Hindi. Vivek grew up in Himachal Pradesh (in the Himalayas, India) and moved to the United States in 2001. He is a Pushcart-nominated poet, published as a scientist (and a rheologist), and teaches chemical engineering in Chicago, IL.

IΘ International Congress on Rheology

Congratulations to the 2023 SoR Venture Fund Winners



Introducing **RheoLit**, connecting rheology and art: paintings, film, fiction, poetry, sculpture, music, and dance.



RheoLaughs, the **Rheology Comics** project aims to connect technical details to the everyday joys of rheology. First issue, "*The Rheology of Cats,*" coming up in Summer of 2023.

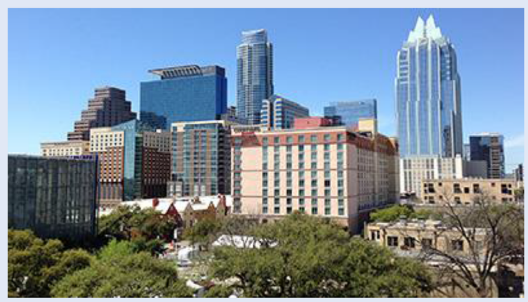
I'm a Rheologist project: Kendra Erk, Parth Kelkar & Akul Seshadri (Purdue University) will be designing new SoR-themed swag to debut in the SoR Austin 2024 meeting

Future Meetings & Workshops

19th International Congress on Rheology
July 29 - August 4, 2023
Athens, Greece

19th European School of Rheology
September 15 - 19, 2023
KU Leuven, Belgium

Annual European Rheology Conference (AERC)
Spring, 2024
Leeds, UK



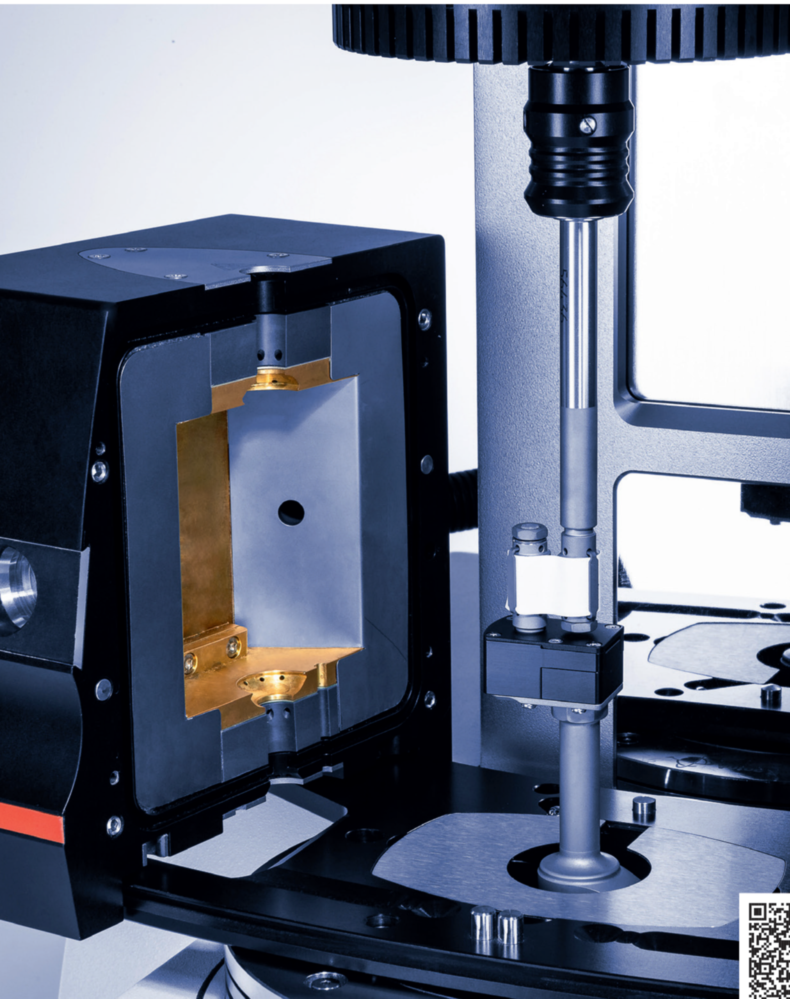
95th SoR Annual Meeting
October 2024
Austin, Texas

96th SoR Annual Meeting
October 19-23, 2025
Santa Fe, New Mexico

97th SoR Annual Meeting
October 25-29, 2026
Boston, Massachusetts


When Super Strength
Meets Shear Flexibility
- Discover unique insights into your rheological data
- Unparalleled reputation for worldwide support and expertise
- Powerful Rosand Capillary Rheometer or flexible Kinexus Prime Rotational Rheometer
Find out more:
www.netzsch.com/rheology
Rosand RH2000
Capillary Rheometer
NETZSCH
WARNING
ALWAYS WEAR HEAT PROOF GLOVES WHEN WORKING ON OR NEAR BARREL
Kinexus® Prime
ultra+
NETZSCH
NETZSCH
The only supplier on the market offering
Rotational and Capillary Rheometry.
NETZSCH-Gerätebau GmbH UK Branch Office
uk.thermal@netzsch.com · www.netzsch.com

Anton Paar



Trade-In Discount:
Dynamic Mechanical Analyzer Package

MCR 702e MultiDrive

3-year warranty and strong support network wherever you are

Free lifetime application support

Unparalleled Dynamic Mechanical Analyzer flexibility: bending, tension, compression, torsion DMA with market-leading precision, plus full rheological capabilities

---

Convenient setup and patented usability features: time-saving and error-reducing