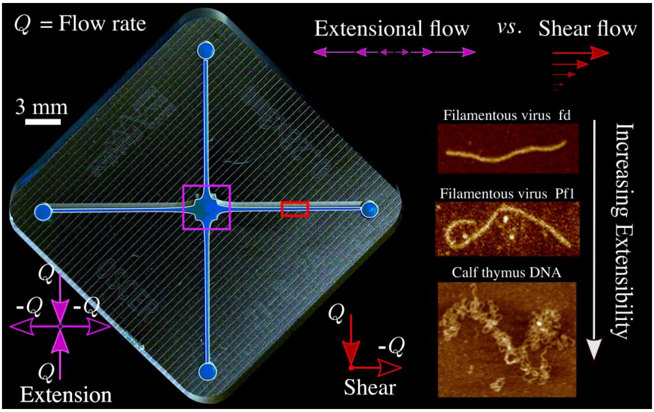
THE BRITISH SOCIETY OF RHEOLOGY

http://www.bsr.org.uk



Rheology Bulletin

ISSN-1469-4999

VOL 65 No 1 2024

THE BRITISH SOCIETY OF RHEOLOGY

OFFICERS & MEMBERS OF COUNCIL 2023-2024

T: Telephone; E: Email

The British Society of Rheology is registered as a Charity - Number 249967

THE BRITISH SOCIETY OF RHEOLOGY

BSR BULLETIN
2024, Vol. 65, No. 1

CONTENTS

EDITORIAL

I'm very grateful to Dr Vincenzo Calabrese for his article highlighting some of his work on the microfluidic cross-slot setup at Okinawa and Dr Libby Marshall's Vernon Harrison Prize article, which combines two of my favourite topics, neutron scattering and rheology. (They do go terribly well together!) We also have a fresh batch of conference reports from the recent AERC in Leeds. I'm sorry that my own neutron scattering commitments kept me from attending this meeting, but it was clearly a great success and it's pleasing to see that the BSR's travel grants and carer grants are being put to good use.

Many thanks also to Chris Ness for the Commentary of the 369th Council meeting as well as for agreeing to take over the bulletin editor role in October. I'll just finish with my triannual plea for articles: If you have recently published something that you think would interest the BSR's readership then a synopsis of your article in this bulletin could be a great way to spread the word. Please feel welcome to include a picture of yourself to go with your article if you like.

Richard Thompson, May 2024.

SUBMISSIONS TO THE BULLETIN

Submissions to the Bulletin are welcome at any time. Electronic submissions by email to the editor (r.l.thompson@durham.ac.uk) are preferred in word format (e.g. .doc or .docx). Please always provide your contact details and ensure that you have obtained copyright permission if you are reproducing figures that have been published elsewhere. The deadlines for submission are Feb. 15th, July 15th and Oct. 15th, respectively, for three issues annually.

COVER ILLUSTRATION

Microfluidic platform for extensional and shear flow (L) and micrographs of polymers and rod-like colloids under examination (R), Calabrese, p7.

Using rheology to measure the properties of multicomponent peptide-based supramolecular systems

Libby Marshall
University of Glasgow

Multicomponent systems can be used to achieve different properties and behaviours from low molecular weight gelators (LMWGs) that cannot be accessed from single component systems. My thesis describes a number of interesting multicomponent systems based on peptide-based LMWGs, prepared by (i) mixing a gelator and a non-gelator, (ii) mixing two gelators, and (iii) mixing a gelator and a cross-linking agent (Figure 1). Each of these systems provides opportunities to fine-tune the properties of the systems as well as achieve new behaviours. Rheology has been integral to all the projects within my thesis and has allowed me to characterise the bulk mechanical properties of my systems as well as investigate the effect of different factors, such as concentration ratios and temperature, on the properties of my systems.

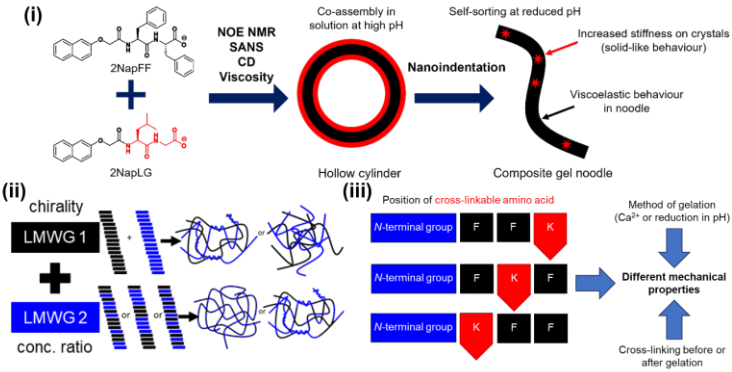


Figure 1. Summary of the projects described in my thesis: (i) preparation of a new composite viscoelastic material from the LMWG, 2NapFF, and the structurally similar crystal-forming compound, 2NapLG; (ii) determining the outcomes of mixing two structurally similar LMWGs at various concentration ratios and varying the chirality of LMWG 1; (iii) tuning the mechanical properties of gels formed from cross-linkable LMWGs.

Chapter 1. Using RheoSANS to predict the properties of gel noodles

The first chapter in my thesis was particularly exciting as I used a variety of techniques and was able to show that these techniques can be used to characterise my systems and provide information that is not readily available using standard techniques. The final outcome of this project was preparation of a new hierarchical composite material, Figure 1(i). [1]

Solutions composed of the peptide-based LMWG 2NapFF show increased viscosity when mixed with the crystal-forming functionalised dipeptide 2NapLG. This was interesting since 2NapLG alone does not form viscous solutions. Using RheoSANS, I showed that the presence of 2NapLG causes the self-assembled structures formed in the multicomponent systems to change considerably compared to single component solutions of the same 2NapFF concentration, despite 2NapLG not forming persistent structures when alone in solution. The use of rheology in tandem with small angle neutron scattering (SANS) allowed me to collect viscosity data in conjunction with the scattering data and to examine the shear alignment of the structures by considering the 2D scattering pattern (Figure 2). From the data collected, I suspect the use of the same N-terminal capping group in the two components, alongside the relatively hydrophilic amino acids (L and G) in the second component result in these changes. I confirmed that 2NapLG forms physical interactions with the structures formed by 2NapFF using nuclear Overhauser effect NMR experiments (performed and analysed by Matthew Wallace, University of East Anglia).[2]

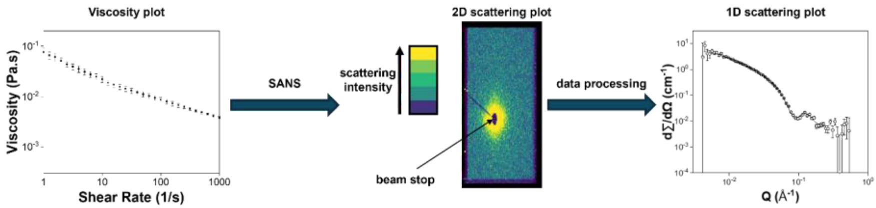


Figure 2. Schematic showing the viscosity and SANS data collected during rheoSANS measurements of a system composed of long, 1D structures that undergo shear-thinning. The 2D scattering pattern collected during SANS is prolate rather than circularly symmetrical, showing the presence of aligned structures within the sample. This alignment occurs due to shear being applied to the long, 1D structures within the sample during the SANS measurement. The 2D scattering data is processed to give the 1D scattering plot which can be fitted to an appropriate model to provide information on the morphology of the structures (1-100 nm) within the sample. The 1D scattering plot shown here fits best to a hollow cylinder model.

2NapFF can be used to form supramolecular gel noodles by extruding a pre-gel solution at high pH into a salt bath containing excess Ca^{2+} ions (Figure 3). Based on the increased viscosity observed in the 2NapLG/2NapFF multicomponent system, I expected this system to form more mechanically robust supramolecular gel noodles than 2NapFF alone. This hypothesis was confirmed using nanoindentation (performed and analysed by Giuseppe Ciccone, University of Glasgow).[3] By exploiting the crystal-forming behaviour of 2NapLG and the ability of the multicomponent system to co-assemble at high pH and self-assemble at low pH, I formed crystals within the gel noodles. This was the first reporting, to our knowledge, of such behaviour. Nanoindentation showed that these composite gel noodles contained defined regions of solid-like behaviour (on the crystals) within the viscoelastic gel noodles.[1] Such a composite system has potential applications in tissue engineering, for example, electromechanical neuromimicry.

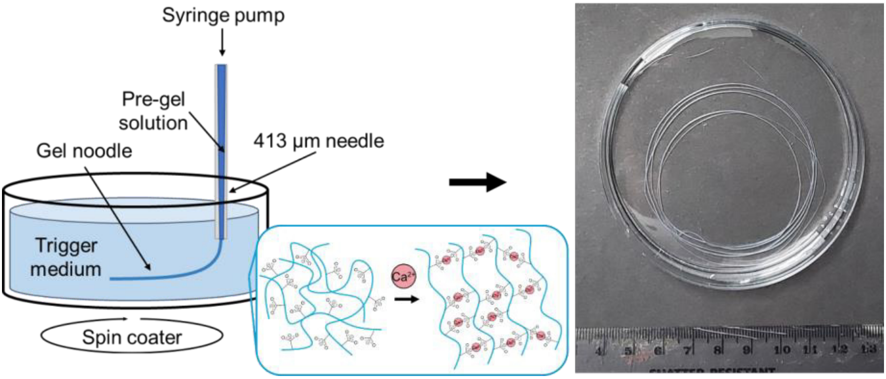


Figure 3. Schematic showing the preparation of gel noodles, and photograph of gel noodles.

Chapter 2. Using rheology to characterise multicomponent gels

In the second chapter of my thesis, I prepared a variety of multicomponent systems where both components were *N*-functionalised dipeptide-based LMWGs that would either co-assemble or self-sort, Figure 1(ii). Using strain and frequency sweeps, as well as a variety of other techniques, I showed that varying the concentration ratio of the two components can be used to tune the properties of the multicomponent system. I also investigated the effect of changing the chirality of a single component on the assembly of the systems. While predicting the outcome of multigelator assembly is a significant challenge, the preparation of a variety of systems allows us to probe the factors affecting their design.[4]

Chapter 3. Using rheology to design a cross-linking toolkit for fine-tuning the properties of peptide-based supramolecular gels

In the third chapter of my thesis, I used strain and frequency sweeps to show that preparing multicomponent systems from a lysine (K)-containing peptide-based LMWG and the cross-linking agent glutaraldehyde allows tuning of the mechanical properties of the final gel depending on the position of the K residue in the peptide chain, whether the cross-linking agent is added to the system before or after gelation and whether gelation is triggered by a reduction in pH or by physical cross-linking with Ca^{2+} ions. All these parameters can be exploited to fine-tune the properties of the system to meet the requirements of the chosen application (Figure 4). Collection of both strain and frequency sweeps was important as chemical cross-linking decreased any frequency-dependence sometimes observed in supramolecular gels at high frequencies. Strain sweeps provided much greater insights into the mechanical properties of the gels. As well as describing the stiffness and reproducibility of my gels, the strain sweeps allowed me to determine the length of the linear viscoelastic region (the strain at which the gel network begins to break down) as well as the point at which G′ and G″ crossover, which shows the strain value at which the gel fully breaks and transitions to a liquid. These parameters amount to gel strength. Using this data, I was able to show that varying the parameters already described allowed me to either (i) increase gel stiffness only, (ii) increase gel stiffness and gel strength, or (iii) to decrease gel stiffness and increase gel strength. This allows almost complete control and fairly predictable outcomes of cross-linking depending on gelator design and gel preparation. These findings were exciting as it is rare to see cases of cross-linking in supramolecular gels that increase gel strength as well as stiffness.[5]

The examples shown in Figure 4 highlight how the position of the cross-linkable K residue in the peptide chain, the concentration of gelator and the method of gelation, as well as whether cross-linking is performed before or after gel formation can all be used to fine-tune the rheological properties of these peptide-based LMWGs.

Acknowledgments

I would like to thank the British Society of Rheology for awarding me the BSR Vernon Harrison Award for my PhD thesis. It was such an honour to accept this prize at the BSR Annual Mid-winter meeting 2023 and to present my work to a room full of rheology experts and enthusiasts! I would also like to thank my PhD supervisor, Professor Dave Adams, for nominating me for the prize and for his unwavering support. Finally, I would like to thank the Leverhulme Trust for funding my PhD.

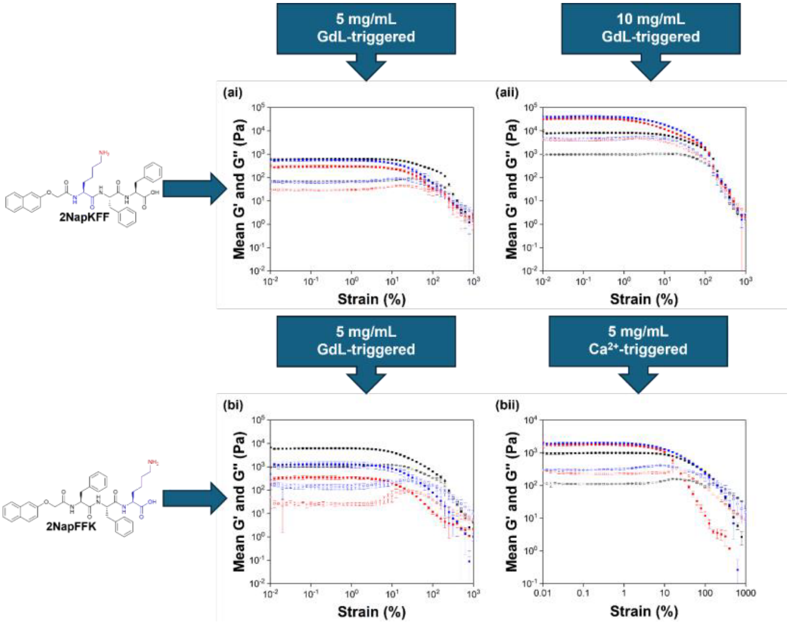


Figure 4. Rheology data collected from gels composed of (a) 2NapKFF at a concentration of (i) 5 mg/mL and (ii) 10 mg/mL triggered *via* pH-reduction using GdL[6] and (b) 2NapFFK at a concentration of 5 mg/mL triggered *via* (i) a pH-reduction using GdL and (ii) physical cross-linking using Ca^{2+} ions.[7] The red data shows the G′ (filled squares) and G″ (hollow squares) of non-cross-linked gels, the black data shows the moduli of gels cross-linked pre-gelation and the blue data shows the moduli of gels cross-linked post-gelation.

References

1. Marshall, L.J., Wallace, M., Mahmoudi, N., Ciccone, G., Wilson, C., Vassalli, M. and Adams, D.J., “Hierarchical Composite Self-Sorted Supramolecular Gel Noodles”, *Advanced Materials*, vol. 35, no. 17, pp.2211277, 2023.
2. Fernández-García, R., Muñoz-García, J.C., Wallace, M., Fabian, L., González-Burgos, E., Gómez-Serranillos, M.P., Raposo, R., Bolás-Fernández, F., Ballesteros, M.P., Healy, A.M. and Khimyak, Y.Z., “Self-assembling, supramolecular chemistry and pharmacology of amphotericin B: Poly-aggregates, oligomers and monomers”, *Journal of Controlled Release*, vol. 341, pp.716-732, 2022.

3. Ciccone, G., Oliva, M.A.G., Antonovaite, N., Lüchtefeld, I., Salmeron-Sanchez, M. and Vassalli, M., “Experimental and data analysis workflow for soft matter nanoindentation”, *JoVE (Journal of Visualized Experiments)*, vol. 179, e63401, 2022.
4. Marshall, L.J., Bianco, S., Ginesi, R.E., Doutch, J., Draper, E.R. and Adams, D.J., “Investigating multigelator systems across multiple length scales”, *Soft Matter*, vol., 19, no. 26, pp.4972-4981, 2023.
5. Marshall, L.J., Matsarskaia, O., Schweins, R. and Adams, D.J., “Enhancement of the mechanical properties of lysine-containing peptide-based supramolecular hydrogels by chemical cross-linking”, *Soft Matter*, vol. 17, no. 37, pp.8459-8464, 2021.
6. Adams, D.J., Butler, M.F., Frith, W.J., Kirkland, M., Mullen, L. and Sanderson, P., “A new method for maintaining homogeneity during liquid–hydrogel transitions using low molecular weight hydrogelators”, *Soft Matter*, vol. *5*, no. 9, pp.1856-1862, 2009.
7. Chen, L., McDonald, T.O. and Adams, D.J., “Salt-induced hydrogels from functionalised-dipeptides”, *RSC Advances*, vol., *3*, no. 23, pp.8714-8720, 2013.

Extensibility governs the flow-induced alignment of polymers and rod-like colloids: A summary

Vincenzo Calabrese[1*], Tatiana Porto Santos[1], Carlos G. Lopez[2], Minne Paul Lettinga[3,4], Simon J. Haward[1], and Amy Q. Shen[1]

(1) Micro/Bio/Nanofluidics Unit Okinawa Institute of Science and Technology Graduate University Okinawa 904-0495, Japan
(2) RWTH Aachen University, Institute of Physical Chemistry, Landoltweg 2, 52074 Aachen, Germany
(3) Laboratory for Soft Matter and Biophysics, KU Leuven, Celestijnenlaan 200D, B-3001 Leuven, Belgium
(4) ICS-3, Institut für Weiche Materie, Forschungszentrum Jülich, D-52425 Jülich, Germany

*email address: Vincenzo.calabrese@oist.jp

This article summarises our recent findings regarding the flow-induced alignment of polymers and rod-like colloids (PaRC) under model flow conditions, namely shear and extensional flow[1]. We summarise our results and posit fundamental questions to address in future research.

PaRC adopt a favourable orientation under sufficiently strong flows. However, how the flow kinematics affect the alignment of such nanostructures according to their extensibility remains unclear. By analysing the shear- and extension-induced alignment of chemically and structurally different PaRC, we show that extensibility is a key determinant of the structural response to the imposed kinematics.

1. Background

Polymers and rod-like colloids (PaRC) are ubiquitous in biological fluids (e.g., mucus, saliva), food and industrial formulations (e.g., gels, paints), imparting specific properties and functionalities. When solubilized or dispersed in a solvent, (PaRC) adopt an equilibrium conformation (e.g., rod-like, worm-like, coil-like) that depends on a multitude of factors including surface chemistry, contour length, and backbone rigidity, affecting the PaRC extensibility and flexibility [2]. The PaRC extensibility (L_e) describes the ratio between the contour length of the fully extended structure (l_c) and the respective size at equilibrium ($\sqrt{\langle R^2 \rangle}$) [3]. The PaRC flexibility (N_p) represents the number of persistence length (l_p) segments composing the PaRC contour length [2,3]. For rigid colloidal rods $L_e \to 1$ and $N_p \ll 1$, whilst for flexible polymers that adopt a coil-like conformation at equilibrium, $L_e \gg 1$ and $N_p \gg 1$. Under sufficiently strong imposed flows, PaRC are driven out of equilibrium and towards a state of alignment induced by velocity gradients in the flow field. The link between the PaRC conformation and the bulk fluid properties at the equilibrium, such as the zero-shear viscosity and the macromolecular time scales of diffusion and relaxation, are well understood and described by generalized scaling theories [2–4]. Nonetheless, how the dynamics of PaRC under flow depend on their equilibrium conformation remains elusive.

We investigate the PaRC with varying extensibility, including rod-like colloids (e.g. filamentous viruses) and significantly more flexible polyelectrolytes in solution under steady shear rate ($\dot{\gamma}$) and extension rate ($\dot{\varepsilon}$) generated via microfluidics [5,6]. Employing quantitative flow-induced birefringence (FIB) imaging in a specific microfluidic device (Fig. 1), where constant shear and extension rates can be approximated, we show that different deformation rates are required for the onset of PaRC alignment in shear and extension, and that this difference is correlated with the PaRC extensibility.

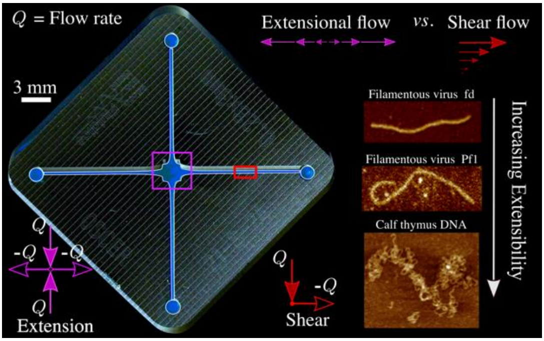


Figure 1. Photograph of the microfluidic platform with the colored boxes indicating the region of interest to probe shear (red box) and extensional flows (magenta box). Details of the microfluidic device are given by Haward et al. [5,6]. On the right side, microscopy images of representative PaRC.

2. Results

In Fig. 2 we plot the normalized birefringence, $\langle\Delta n\rangle/\phi$, with ϕ the mass fraction of the PaRC, as a function of $|\dot{\gamma}|$ (filled symbols) and $|\dot{\varepsilon}|$ (empty symbols) for two representative PaRC with significantly distinct extensibility L_e. The birefringence intensity describes the extent of segmental orientation of the PaRC. For the relatively rigid filamentous virus fd ($L_e \sim 1$), the onset of birefringence occurs at lower values of $|\dot{\varepsilon}|$ than $|\dot{\gamma}|$, indicating that fd virus alignment is induced more readily by extension than by shear (Fig. 2(a)). We introduce a non-dimensional scaling factor (SF) to the extension rate as $SF|\dot{\varepsilon}|$ to match the onset of birefringence in extension with that in shear. Practically, SF provides an estimate of the ratio between the critical shear rate ($|\dot{\gamma}^*|$) and the critical extension rate ($|\dot{\varepsilon}^*|$) at the onset of PaRC alignment ($SF = |\dot{\gamma}^*|/|\dot{\varepsilon}^*|$). For fd virus, $SF = 2.3$ captures the difference between extension- and shear-induced alignment at low deformation rates (Fig. 2(b)). The scaling procedure highlights the difference at high deformation rates where the birefringence in extension reaches a greater plateau value than observed in shear. Using the known dimensions of the fd virus, we compare our experimental results with the revised Doi-Edwards theory for ideal, rigid and monodisperse rods proposed by Lang et al.[7,8]. The theoretical projected order parameter $\langle P_2\rangle$ is compared with the experimentally measured birefringence as $\langle P_2\rangle\Delta n_0 = \langle\Delta n\rangle/\phi$, where Δn_0 is the birefringence of perfectly aligned PaRC at $\phi = 1$ [9,10]. The theory confirms that (i) a lower extension rate is required to induce fd alignment compared to the shear rate, and that (ii) at high deformation rates the greatest extent of alignment occurs in extensional flow. Both (i) and (ii) are consistent with the absence of tumbling events in extension, enhancing the overall extent of alignment. For the theoretical curves, $SF = 2$ (i.e., comparing equal flow strength) enables superimposition of the birefringence curves at low deformation rates in a similar fashion as for the fd dispersion (Fig. 2(b)). Thus, on the basis of theory $SF = 2$ is expected in the limiting case of rigid rod-like PaRC (i.e., $Le = 1$).

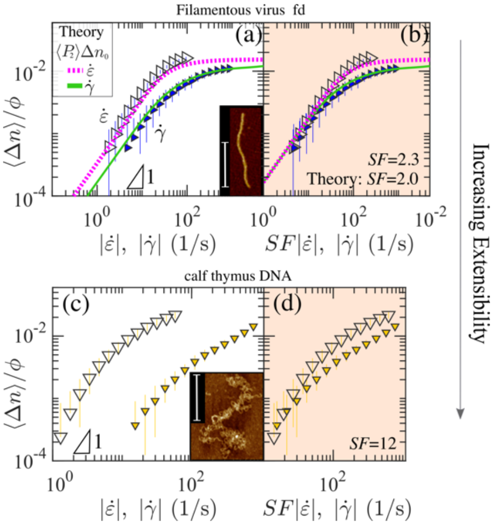


Figure 2. Averaged birefringence $\langle\Delta n\rangle$ normalized by the mass fraction of the PaRC (ϕ) as a function of the extension rate $|\dot{\varepsilon}|$ (empty symbols) and shear rate $|\dot{\gamma}|$ (filled symbols). (a, b) Filamentous virus fd dispersion at 0.2 mg/mL. (c, d) calf thymus DNA solution at 0.19 mg/mL. In (b) and (d) the $\langle\Delta n\rangle/\phi$ as a function of $|\dot{\varepsilon}|$ is re-scaled as $SF|\dot{\varepsilon}|$. In (a) we provide direct comparison with the order parameter, $\langle P_2\rangle$, vs. $|\dot{\gamma}|$ and $|\dot{\varepsilon}|$ from the rigid rod theory[7] where $\langle P_2\rangle$ is scaled as $\langle P_2\rangle\Delta n_0$. The insets in (a), and (b) are representative AFM images of the filamentous virus fd, Pf1, and calf thymus DNA with a scale bar of 500 nm.

With increasing extensibility, the difference between $|\dot{\varepsilon}^*|$ and $|\dot{\gamma}^*|$ becomes more pronounced, as shown for the more extensible calf thymus DNA ($L_e \approx 10$, Fig. 2(c, d)). In this case, a scaling factor of $SF = 12$ is required to match the onset of birefringence. These results suggest that with increasing PaRC extensibility, extensional deformations become progressively more effective at inducing the onset of PaRC alignment than shear deformations. Since the effectiveness of the extensional deformations relative to shear deformations at inducing PaRC alignment is captured by SF, we compare the SF for a library of polyelectrolytes and rod-like colloids with distinct L_e (Fig. 3(a)). Although the different chemical structures and architectures of the PaRC investigated lead to scattering of the data, a general trend of SF as a function of L_e emerges. To provide an empirical guideline for future reference, we approximate the SF increase with L_e as $SF = 2L_e^{\beta}$, where $\beta = 2/3$ is a dimensionless parameter [blue line, Fig. 3(a)]. Given the mutual relationship between L_e and N_p, the function $SF = 2L_e^{\beta}$ also captures the main features for the SF as a function of the PaRC flexibility (N_p) shown in Fig. 3(b) (see main paper for details [1]). The trend of SF as a function of N_p shows a plateau for $N_p < 1$ and a transition towards $SF \propto N_p^{1/3}$ at $N_p \gtrsim 10$ [Fig. 3(b)].

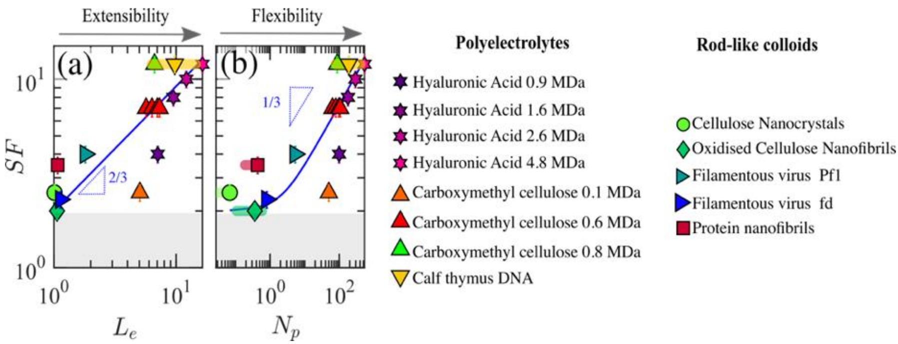


Figure 3. SF as a function of (a) extensibility L_e, and (b) N_p, for a range of polymers (specifically polyelectrolytes) and rod-like colloids. The grey area sets the threshold $SF = 2$ for $L_e = 1$ based on rigid rod theory.

In shear flows intricate conformations and dynamics can occur due to the vorticity component, minimizing the overall degree of backbone orientation. This is supported by single-polymer studies in shear flows, reporting chain extension fluctuation for DNA with $N_p > 1$, phenomena not observed in extensional flows [11,13]. Additionally, shear flow has been found to stabilize hairpin conformations for actin filaments with $N_p \sim 1$ whilst extended conformations have been reported in extensional flows [12,14]. As such, for PaRC with $N_p \gtrsim 1$, the enhanced efficacy of extensional deformations at inducing fluid anisotropy, captured by $SF > 2$, stems from a more extended conformation occurring in extensional flows compared to shear flows.

3. Conclusions and personal reflections of V. Calabrese

Given the key role that PaRC play in many biological and industrial processes (e.g., mucus flow, inkjet printing), there is growing research devoted to studying their dynamics in shear and extensional flows. Comparisons of PaRC dynamics in shear vs. extensional flows have often been inferred from steady shear and/or oscillatory rheology against capillary-driven extensional flow techniques (i.e., experiments based on the capillary-driven thinning of a fluid filament, such as CaBER [15], SRM [16], DoS [17]) (see Ref. [18–20]). While in classic shear rheometry the shear rate can be finely controlled, in capillary thinning experiments the extension rate is self-selected by the fluid. Additionally, in capillary thinning experiments, the extrapolation of material properties is retrieved indirectly from the profile of the filament thinning over time using similarity solutions, or constitutive models with underlying assumptions regarding the polymer response [21]. Because these difficulties, a direct comparison of the effect of shear vs. extensional flows on polymer dynamics has been challenging and limited to single molecule imaging (mainly λ-DNA) [11,22,23].

In this work, we overcome these hurdles by providing a fair comparison of steady shear flow and steady extensional flow as generated in a purpose-built microfluidic device [5]. In combination with flow-induced birefringence we provide a statistically relevant understanding of the polymer response to the flow type. Our results show that the disparity between the critical deformation rates required for the onset of PaRC alignment in shear and extension is related to PaRC extensibility.

We have shown experimentally that interparticle interactions in the semi-dilute regime only change the onset of flow-induced PaRC orientation while retaining the general trend of the birefringence as a function of the deformation rate (i.e., $\dot{\gamma}$ and $\dot{\varepsilon}$). As such, the difference between the critical deformation rates required for the onset of PaRC alignment in shear and extension appears constant for concentrations within the dilute and semi-dilute regimes. As a natural next step, it is interesting to understand how much differently shear and extensional flows affect the polymer dynamics at high PaRC concentrations when confinement effects become significant (e.g., in the presence of entanglements). We leave this as an open question for future research.

References

[1] V. Calabrese, T. Porto Santos, C.G. Lopez, M.P. Lettinga, S.J. Haward, A.Q. Shen, Extensibility governs the flow-induced alignment of polymers and rod-like colloids, Phys. Rev. Res. 6 (2024) 4–9.

[2] M. Rubinstein, Ralph H. Colby, - Polymer Physics (2003).

[3] M. Doi, The Theory of Polymer Dynamics, Oxford University Press, London, UK, 1988.

[4] R.H. Colby, Structure and linear viscoelasticity of flexible polymer solutions: Comparison of polyelectrolyte and neutral polymer solutions, Rheol. Acta. 49 (2010) 425–442.

[5] S.J. Haward, M.S.N. Oliveira, M.A. Alves, G.H. McKinley, Optimized Cross-Slot Flow Geometry for Microfluidic Extensional Rheometry, Phys. Rev. Lett. 109 (2012) 128301.

[6] S.J. Haward, G.H. McKinley, A.Q. Shen, Elastic instabilities in planar elongational flow of monodisperse polymer solutions, Sci. Rep. 6 (2016) 33029.

[7] C. Lang, J. Kohlbrecher, L. Porcar, A. Radulescu, K. Sellinghoff, J.K.G. Dhont, M.P. Lettinga, Microstructural understanding of the length- and stiffness-dependent shear thinning in semidilute colloidal rods, Macromolecules. 52 (2019) 9604–9612.

[8] M. Doi, S.F. Edwards, Dynamics of rod-like macromolecules in concentrated solution. Part 2, J. Chem. Soc. Faraday Trans. 2. 74 (1978) 918.

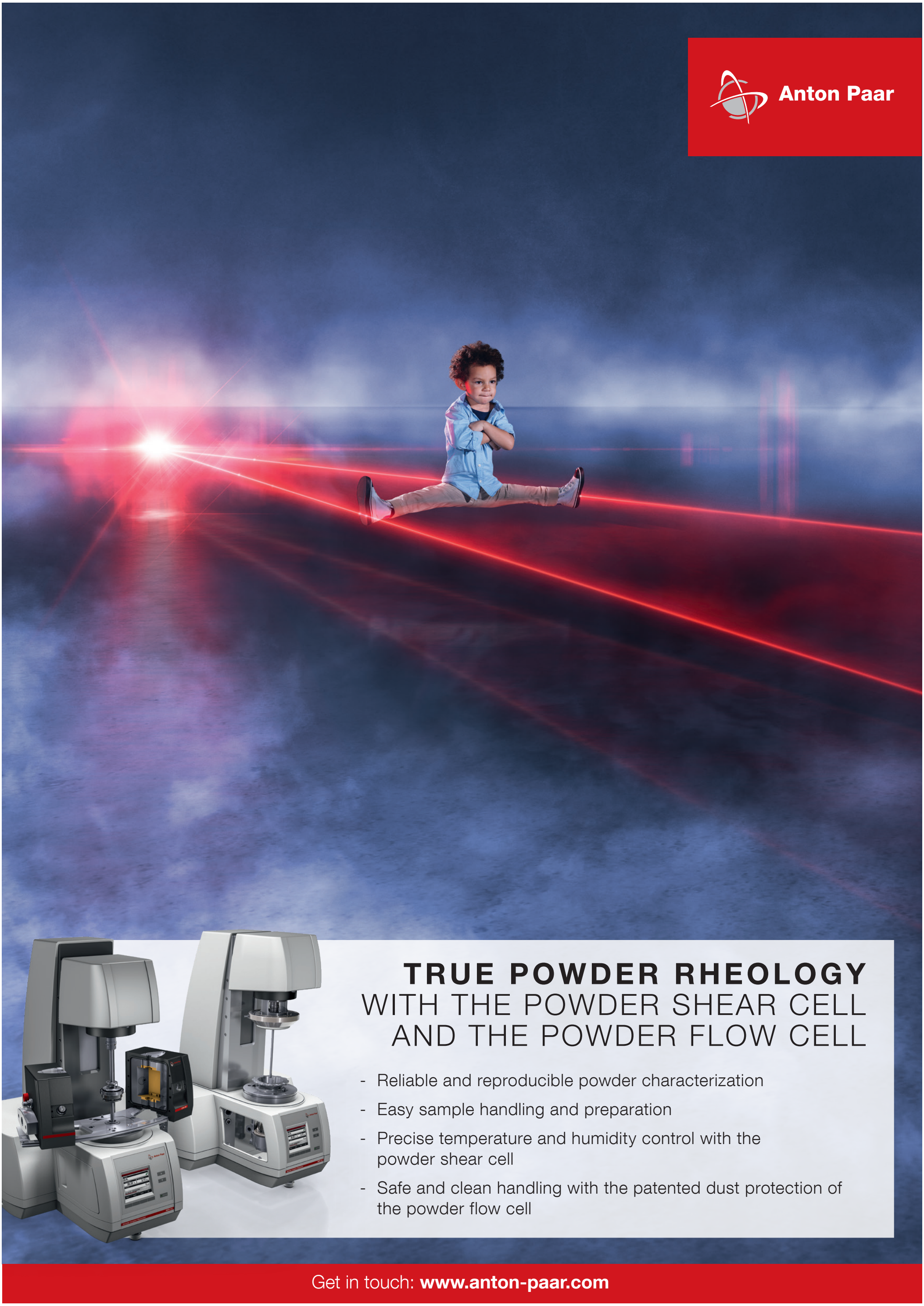
[9] K.R. Purdy, Z. Dogic, S. Fraden, A. Rühm, L. Lurio, S.G.J. Mochrie, Measuring the nematic order of suspensions of colloidal fd virus by x-ray diffraction and optical birefringence., Phys. Rev. E. Stat. Nonlin. Soft Matter Phys. 67 (2003) 031708.

[10] K. Uetani, H. Koga, M. Nogi, Estimation of the Intrinsic Birefringence of Cellulose Using Bacterial Cellulose Nanofiber Films, ACS Macro Lett. 8 (2019) 250–254.

[11] D.E. Smith, H.P. Babcock, S. Chu, Single-polymer dynamics in steady shear flow, Science (80-.). 283 (1999) 1724–1727.

[12] I. Kirchenbuechler, D. Guu, N.A. Kurniawan, G.H. Koenderink, M.P. Lettinga, Direct

visualization of flow-induced conformational transitions of single actin filaments in entangled solutions, Nat. Commun. 5 (2014).
[13] C.M. Schroeder, R.E. Teixeira, E.S.G. Shaqfeh, S. Chu, Characteristic periodic motion of polymers in shear flow, Phys. Rev. Lett. 95 (2005) 1–4.
[14] Y. Liu, K. Zografos, J. Fidalgo, C. Duchêne, C. Quintard, T. Darnige, V. Filipe, S. Huille, O. Du Roure, M.S.N. Oliveira, A. Lindner, Optimised hyperbolic microchannels for the mechanical characterisation of bio-particles, Soft Matter. 16 (2020) 9844–9856.
[15] G.H. McKinley, Visco-elasto-capillary thinning and break-up of complex fluids, Rheol. Rev. 3 (2005) 1–48.
[16] L. Campo-Deaño, C. Clasen, The slow retraction method (SRM) for the determination of ultra-short relaxation times in capillary breakup extensional rheometry experiments, J. Nonnewton. Fluid Mech. 165 (2010) 1688–1699.
[17] J. Dinic, Y. Zhang, L.N. Jimenez, V. Sharma, Extensional Relaxation Times of Dilute, Aqueous Polymer Solutions, ACS Macro Lett. 4 (2015) 804–808.
[18] C. Lang, J. Hendricks, Z. Zhang, N.K. Reddy, J.P. Rothstein, M.P. Lettinga, J. Vermant, C. Clasen, Effects of particle stiffness on the extensional rheology of model rod-like nanoparticle suspensions, Soft Matter. 15 (2019) 833–841.
[19] L.N. Jimenez, J. Dinic, N. Parsi, V. Sharma, Extensional Relaxation Time, Pinch-Off Dynamics, and Printability of Semidilute Polyelectrolyte Solutions, Macromolecules. 51 (2018) 5191–5208.
[20] O. Arnolds, H. Buggisch, D. Sachsenheimer, N. Willenbacher, Capillary breakup extensional rheometry (CaBER) on semi-dilute and concentrated polyethyleneoxide (PEO) solutions, Rheol. Acta. 49 (2010) 1207–1217.
[21] V. Calabrese, A.Q. Shen, S.J. Haward, How do polymers stretch in capillary-driven extensional flows?, ArXiv. (2024), https://arxiv.org/pdf/2403.04103.pdf
[22] C.M. Schroeder, Single polymer dynamics for molecular rheology, J. Rheol. 62 (2018) 371–403.
[23] J.S. Hur, E.S.G. Shaqfeh, H.P. Babcock, S. Chu, Dynamics and configurational fluctuations of single DNA molecules in linear mixed flows, Phys. Rev. E. 66 (2002) 011915.

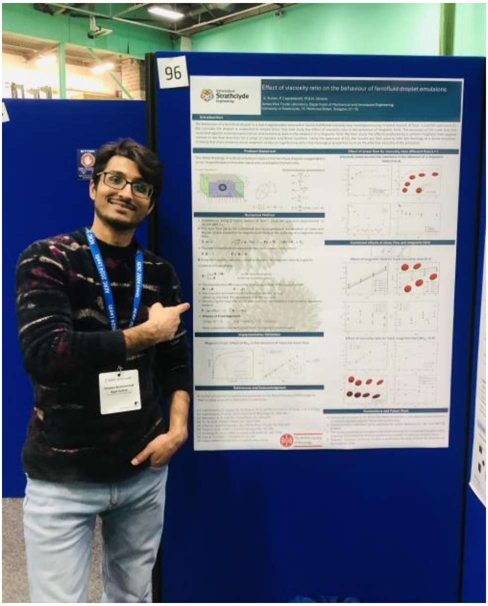


Anton Paar
TRUE POWDER RHEOLOGY
WITH THE POWDER SHEAR CELL
AND THE POWDER FLOW CELL
- Reliable and reproducible powder characterization
- Easy sample handling and preparation
- Precise temperature and humidity control with the powder shear cell
- Safe and clean handling with the patented dust protection of the powder flow cell
Get in touch: www.anton-paar.com


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
NETZSCH
WARNING
NETZSCH

Conference Reports: AERC-2024 Leeds

BSR Student Travel Grant Report
Ghulam Muhammad Ayaz Sultan



I would like to say thanks to the British Society of Rheology for their support and for providing me the chance to participate and present my research at the AERC conference that was held in Leeds. It was a great experience with the opportunity to socialize, listen, and share ideas with researchers from worldwide.

The conference consisted of eight parallel sessions, spanning over three days. The sessions were filled with a diverse range of fascinating presentations and posters. I presented a poster titled "Effect of viscosity ratio on the behaviour of ferrofluid droplet emulsions". The poster covered the latest numerical investigation using a Hybrid Volume of fluid – Level Set approach. The study focused on the behaviour of a ferrofluid droplet in a non-magnetizable immiscible liquid of different viscosity under simple shear flow, and the impact of viscosity ratio in the presence of a magnetic field applied normally to the flow direction for a range of capillary and Bond numbers.

During the conference, I had the privilege of listening to some fascinating lectures. Linder, A. gave a plenary lecture on "From individual trajectories to collective motion in suspensions of E-coli bacteria," where she presented some experimental and numerical studies about the motion of bacteria and their flagella in a flow. Wagner, C shared some interesting data regarding the "margination of red blood cells," and Prezios, V. presented some numerical results indicating that the inertial forces have a significant effect on droplet orientation. Esteban. A gave a presentation on the use of RheoFoam for interfacial rheology simulations, which was quite insteresting. Ellero, M shared some thought-provoking studies about coffee extraction, and Rodrigues, R. discussed the exploration of Magnetorheological cell design and suggested that a slight inclination of the magnetic plate is reasonable.

Cumming, J. L. shared his recent numerical findings on the flow of viscoelastic fluids. He discussed the impact of expansion ratios on viscoelastic flow. Castillo, H.A. presented his own numerical studies on computational rheology, in which he used HiGFlow software to compare with other CFD software options. Cook, E. presented her work on tensorial viscosity numerical models for non-Newtonian fluids. I was particularly interested in her explanation of the model for normal stress calculations and had the opportunity to have a detailed discussion with her about the possibility of using the model to calculate normal stress on fluids with different viscosity ratios. Ji, X discussed her theoretical analysis of viscous and viscoelastic flow through a cross slot.

To summarize, I had the good fortune of interacting with some incredibly talented and passionate individuals in this area. These interactions led to some insightful and productive conversations regarding my work, and I received encouraging feedback that motivated me to continue improving. Moreover, I also enjoyed the social event which was the drink and dinner at "Royal Armouries" where I had the opportunity to connect with the people on a personal level and learn more about their diverse cultures, traditions, languages, and ways of life, which was a truly enriching experience. Overall, it was an enriching experience that left me feeling energized and motivated to continue learning and growing.

University of Strathclyde

BSR Student Travel Grant Report - Nemi Walding

The AERC (Annual European Rheology Conference) brings together worldwide academics and industry partners, from a range of disciplines to discuss everything rheology. This year the AERC conference was held at the University of Leeds and with the support of the BSR Student Travel Grant I was able to attend.

The contribution from the BSR allowed me to travel to the conference and take part in presenting my own work in the geo-rheology session. I presented my talk titled "Unravelling the internal dynamics of low-temperature, wet pyroclastic density currents" in a 15 minute slot. I discussed my ongoing work in my PhD and drew on this work to talk about my future goals and interests.

My ongoing PhD research looks at capillary cohesional behaviours of pyroclastic material and its implications for Pyroclastic Density Currents (PDC) flow dynamics and deposits. My research begins to understand how moisture alters the properties of pyroclastic material and I have identified key gaps for knowledge in understanding the dynamics of wet PDCs which would allow for exciting and novel future research.

This was my first time attending a rheology-based conference. My ongoing PhD work does not take a granular rheology approach, but by listening and attending a variety of talks I was able to begin to explore using a more rheological-based approach in informing my data analysis and interpretation. My talk promoted informative discussions and insightful questions surrounding my work and will hopefully lead to future collaborative opportunities.

I am immensely grateful to the BSR for their support, which made this informative and beneficial experience possible. Thank you.

Editor's note: There are many pictures from the AERC at Leeds available on the conference website: https://rheology-esr.org/aerc-2024/welcome/

Carer's grant awardee

Esther García-Tuñón
School of Engineering and Materials
Innovation Factory,
University of Liverpool

As the first ever Carer's grant awardee, it is a pleasure to write this report for the BSR bulletin and to express my gratitude to the council for their support. I am an UKRI Future Leaders Fellow and Senior Lecturer at the University of Liverpool. I am also a mother of three children with ages 9, 3 and 1. I applied for the BSR Carer's grant to cover part of the expenses to attend the AERC2024 conference in Leeds. This has been my first in person event at the European Rheology Conference. The grant will cover part of the additional costs I incurred during the conference, as my family was travelling and staying in Leeds with me. This is what worked best for us, but the grant could be used in different ways depending on your own circumstances and preferences.

During the Weissenberg Lecture, the awardee Olivier Pouliquen, referred to *science* as a *collective* effort. Conferences, workshops, seminars, and other events are essential for us to feel part of a wider network, to make contributions, and to learn from others in different fields. These interactions facilitate a sense of belonging to the scientific community.

Having a young family and a career in academia are both fulfilling and rewarding but also relentless and hectic. There are often overwhelming moments that lead to feelings of isolation, which is accentuated when attending to any event becomes almost impossible. I started my independent career in 2017, and since then I have attended less than a handful of national and international events due to the pandemic and two maternity leaves quite close together in 2020-21 and 2023. These years have been filled with joy, however the impact in career progression and international visibility are tangible. Although I am in a position of privilege as a fellow, there are limits to the expenses and costs we can claim depending on local policies. Travelling as a family of five is expensive, and my children are still too young for me to travel solo for long periods of time. I must carefully prioritise and plan the events I attend in person, also making sure we can afford it as a family. The BSR carer's grant has helped me to attend AERC 2024, thus facilitating plenty of networking opportunities, establishing new connections, and sparking new ideas. Although the grant does not cover all the costs we incurred (some of which are difficult to quantify), the award and the opportunity to write this report, make me feel seen and supported. I am hopeful that sharing my experience can help other carers in the British Society of Rheology. I would like to encourage them to apply for the grant, and to share their experiences.

I thoroughly enjoyed attending AERC2024. The short course in Rheo-tool was a useful and hands on introduction to computational rheology. The plenary speakers were all excellent and their talks inspiring, it was hard to choose which talks to attend with so many interesting parallel sessions. I am looking forward to participating in the next event and to hear from other carers in the rheology community.

Annual European Rheology Conference 2024
Leeds, UK
9th-12- April 2024
(short course 8th-9th April)

Commentary on the 369th BSR Council Meeting, Chris Ness

The Council held its 369th Meeting online from 10am on Monday 11th September.

After agreeing the identity of the commentary writer and noting apologies from Francesco Del Giudice, Joey Hodges and Richard Watson, we approved the Minutes of the previous Council Meeting. We are indebted to Simon Cox for pointing out that the 2025 AERC will be held in Lyon, not Leon as was written in the minutes.

There followed a detailed discussion about the Society's privacy policy, during which Council proved to be united in their conscientiousness. Contributions from Richard Graham and Simon Cox were particularly helpful, while comments from the entire Council were considered. The Treasurer advised the Council about what financial information is stored and how it is kept secure, while the Web Editor led the discussion about what information is collected when new members are registered. Appropriate changes were proposed to the draft privacy policy to ensure that we are aligned with best practice in all respects.

The next discussion focussed on the idea of producing a UK Rheology Report, inspired in part by an earlier one published in Nature [R. Roscoe. Rheological Research in Britain. *Nature* **204**, 733–734 (1964)] and the article "Our Fluid Nation" prepared by the UK Fluids Network. As an aside there was some suggestion about reproducing archival material in a forthcoming Bulletin (perhaps one of Tom McLeish's previous contributions or indeed the 1964 Nature article itself), before the focus returned to the Report. Council agreed that it would be useful to have a UK Rheology Report, as a means for demonstrating to policy makers and funders that rheology is a crucial UK research area. It was noted in passing that the Fluids report may have played a role in the establishment of the NNFDy scheme. We discussed the practicalities of surveying UK rheologists and the importance of designing such a survey with due care, and concluded by agreeing to form a subgroup comprising the President together with Chris Ness, Richard Thompson, Andrew Clarke and Monica Oliveira. This group will consider the matter further and report back to Council.

Council discussed increasing its Undergraduate bursary amount from the current level so that it is in line (at least) with the minimum wage. Richard Graham raised the important point that setting the bursary so low presents an EDI challenge, as it is likely that doing so would prejudice applications in favour of those with independent financial means. We agreed that this is an important matter to take forward.

The Officers' reports were covered rather quickly. The President's report was noted by Council. The Treasurer reported that finances are healthy, and there are some implications for BSR finances as a result of our involvement with AERC 2024. The Secretary reported a healthy number of travel grant applications, while the Membership secretary reported seven new sign ups. There were no major items to report from the Bulletin editor or the Publications Manager, while the Web editor reminded Council that job adverts are now listed on the website.

The Secretary reported that the next MWM will take place in Lincoln, with a modelling theme and a likely date of 18-19th December 2023. These will be confirmed shortly. Later Richard Hodgkinson proposed that BSR should have a heightened presence at AERC 2024 in Leeds, perhaps with new banners and an opportunity for conference delegates to meet with BSR Council members. This was met with approval.

Council members were pleased that the Annual Award had recently been given to Alexander Morosov of the University of Edinburgh, and the President noted that Prof Morosov has been invited to speak at the MWM in Lincoln. The Gold Award was discussed, and Council members agreed that it would be desirable to be able to award one at AERC in Leeds should there be a suitable nomination in due course. Meanwhile nominations were sought for a future President-elect of the Council. Four names were suggested, at least one of whom was based in industry. It was also noted that the Secretary, Web Editor and Bulletin Editor are approaching these ends of their terms and that new Officers will need to be found imminently.

We finally discussed whether any changes should be made to the policy for awarding travel grants. Some felt that travel grants should be available only to travelling BSR members whose origin or destination is within the UK (with exceptions perhaps for ICR), whereas others were of the opinion they should be open to all with each application being judged on its merits. It was agreed that Council should vote on this matter.

The next meeting will be held during the forthcoming MWM in Lincoln.

CJ Ness, September 2023

BSR AWARDS

2022 Annual Award and Vernon Harrison Award recipients, Prof Stephen Wilson (L) and Dr Joseph Cousins (R) with Dr Mónica Oliveira, University of Strathclyde.

BSR Annual Award

The Annual Award is intended to recognise a significant contribution to rheology, either through a single paper (in which case a group of co-authors can receive the award) or more sustained activity of a single individual. The Award is decided based on scientific merit. Long service is not a factor, and nominations of early career scientists / research workers are welcomed. The final decision is taken by the Council of the British Society of Rheology. If, in a given year, there is no suitable nominee, then the Award will not be given. Deadline: 31st July annually

Vernon Harrison Award

The British Society of Rheology welcomes applications for the Vernon Harrison Award for the most distinguished PhD thesis in rheology. The aim of this award is to recognise excellence, creativity and novelty in research. It will be awarded to the postgraduate student who, in the opinion of the adjudicating committee, has made the most original and significant contribution to any branch of rheological research (experimental, computational or theoretical) leading to the award of a PhD degree in a given academic year. This prize is partly supported by the Vernon Harrison Bequest. Deadline for receipt of applications is 30th September annually.

BSR Student Travel Awards

The British Society of Rheology seeks applications for travel awards from its student membership, with the objective of encouraging students to disseminate their research. Travel awards are available to student members of the Society to present their research by paper or poster at a conference that contains a strong rheological element. The awards are expected to supplement existing sources of funding that would not cover the whole cost of attending the conference on their own. Suitable meetings include the Non-Newtonian Club in September and the Mid-Winter Meeting in December.

Applications for a travel award should be sent to the Secretary (secretary@bsr.org.uk). Submissions should include the name and location of the conference, the title, authors and abstract of the paper submitted to the conference, a breakdown of the projected costs of attending the meeting and a brief supporting letter from the research supervisor. The support of the British Society of Rheology should be mentioned in the conference presentation, and the Society's logo may be used for this purpose. Payment of the bursary will be made on receipt of a conference report suitable for publication in the Bulletin of the Society.

BSR Early Career Travel Award

The purpose of the BSR Early Career Travel Award is to assist early-career researchers with disseminating rheological research and building their research network by either supplementing travel to a national/international conference, or supplementing funding for a short research visit. Research visits that connect academia and industry are especially encouraged.

BSR will award up to £200 for UK-based and £500 for European-based conference travel, and up to £750 for conference travel in the rest of the world. In the case of research visits (or combined conference and research visit), BSR will award up to £500 for UK-based and £1000 for non-UK-based research activity.

Eligibility

Applicants must be a BSR member of at least 9 months standing. This travel award is intended to assist those in the "early stage" of their careers; that is an academic post-doctorate position, transitioning to an established independent researcher, or new to an industrial role. (PhD students, please see student travel award.)

There are no eligibility rules based on years of post-doctoral experience or whether the applicant holds a permanent position. Consideration will be given to applicants who have taken a non-standard career path after their primary degree. Applications are also welcomed from candidates who wish to re-establish themselves after a career break or any other period of absence from active research.

Please note applicants may only apply for one travel award in any 12 month period. Individuals may receive no more than one award within a 3-year period.

Application

In the case of conference travel, submissions should include the name and location of the conference, the title, authors and abstract of the paper submitted to the conference. The support of the British Society of Rheology should be mentioned in the conference presentation, and the Society's logo may be used for this purpose.

In the case of a short research visit, submissions should include the name and location of the host institution/company, and a short synopsis of the intended research.

Applicants should justify why they consider themselves an "early-career" researcher in their submission. A breakdown of the projected costs and a brief supporting letter from the head of school/line manager (and the host institution/company in the case of a research visit) should also be included.

Applications will be judged on the following criteria:
1. Scientific excellence in the area of rheology, including theory and application.
2. Benefits to applicant's career progression.

Applications should be sent to the Secretary (secretary@bsr.org.uk). Applications must be received at least 1 month prior to conference travel and 3 months prior to a research visit. Up to a maximum of 4 awards will be granted per annum.

Payment of the award will be made on receipt of a report suitable for publication in the Bulletin of the Society.

Rheology Engagement Fund (RhEF)

Purpose

The purpose of the BSR Rheology Engagement Fund is to facilitate rheologists in the UK to engage the general public and community, to promote rheology and non-Newtonian fluid mechanics to a broader audience. Funding could, for example, cover expenses for exhibits at science fairs or the preparation of video content for wide dissemination. The BSR will award up to £500.

Eligibility
Applicants must be a member of 9 months standing and may only apply to the RhEF once in any 12-month period.

Application
Submissions should include your name, position and organisation, and a one-page summary of the activity to be supported. Please explain how this activity will engage the public and include a break-down of the projected costs.

Applications should be submitted below and must be received at least 1 month prior to the activity. Up to a maximum of 4 grants will be made each year.

Payment of the award will be made on the receipt of a report suitable for the Bulletin of the Society. Advance payment may be made in certain circumstances; please send enquiries to the Secretary.

BSR Carer Grant

Purpose
The purpose of the BSR Carer's Grant is to enable parents and carers to attend conferences and other research schools, meetings or visits by making a supplementary contribution towards caring costs. The BSR will award up to £250.

Eligibility
Applicants must be a member of 9 months standing and may only apply for one carer's grant in any 12-month period. You may apply for a travel grant simultaneously.

Application
Submissions should include your name, position and organisation, and a short summary of the activity to be supported. Please explain how this activity will support your research and include a break-down of the projected costs.

Applications should be sent to the Secretary (secretay@bsr.org) and must be received at least 1 month prior to the activity. Up to a maximum of 4 grants will be granted per annum. Payment of the award will be made on the receipt of a short report suitable for the Bulletin of the Society. Advance payment may be made in certain circumstances; please send enquiries to the Secretary.

Undergraduate Summer Research Bursaries

The purpose of the awards is to give experience of research to undergraduate students to explore the potential of becoming a researcher and to encourage them to consider a career in rheology. Two such awards are usually granted each year.

The awards provide support of up to £3.5k for a period of up to 8 weeks if full time, of which up to £500 may be for consumable, subject to the condition that the student is paid at least the minimum living wage. Applications from students wishing to work part–time will also be considered. The awards will be transferred to the successful applicant's Institution; *it is the responsibility of the applicants to inform their respective administrative departments of the award.*

The closing date for applications is in February before the summer of the proposed project. Successful candidates will be informed by end of March.

Claire McIlroy
BSR Honorary Secretary

AIMS OF THE SOCIETY

The way liquids flow and solids deform affects all aspects of life.

Extraction and processing of crude oil, moulding of plastics, use of toothpaste, spreading of margarine, painting and the lubrication of joints in the human body are all examples of processes depending upon rheological behaviour. Rheology is defined as the science of the deformation and flow of matter.

If your work is concerned with rheology in any way, then you have much to gain by joining the British Society of Rheology, including

- advance your knowledge by attending our conferences
- receive publications including Rheology Abstracts, Bulletin and Rheology Reviews
- learn of current instrumentation and accessories plus new developments.
- access to non-Newtonian Club linking industry and academia
- travel Grants, Poster Prizes, Career Opportunities
- network with fellow members who, while working in a different discipline or industry, may be facing similar problems to yours

The Society is non-profit making and is registered as a charity. For the details, you are warmly welcome to visit our web site http://www.bsr.org.uk/, and to apply for membership on-line.

CONFERENCE DIARY

	CONFERENCES & MEETINGS
2024	
29^{th} -31^{st} May	**Nordic Rheology Conference, Stavanger, Norway**
28^{th}-29^{th} June	**ICRFDP. International Conference on Rheology in Food Product Design, London**
29^{th} July – 2^{nd} August	**8^{th} International Soft Matter Conference, NC, USA**
25^{th} – 30^{th} August	**26^{th} International Congress on Theoretical and Applied Mechanics, ICTAM. S.Korea**
9^{th}-12^{th} September	**UK Fluids 2024 + NNC Complex Fluids in Industry and Healthcare, Swansea**
12th-14th September	**XVIII Italian Society of Rheology Conference, Capri Island, Naples, Italy**
13^{th}-17^{th} October	**Society of Rheology 95^{th} Annual Meeting, Austin, TX, USA.**
December	**BSR Mid-Winter meeting, Sheffield**
2025	
20^{th}-25^{th} July	**9^{th} Pacific Rim Conference on Rheology, Kobe, Japan**
t.b.c.	**Joint meeting of BSR and Nordic Rheology Society, Aberdeen**
t.b.c.	**Annual European Rheology Conference (AERC), Lyon**
December	**BSR Mid-Winter meeting, Edinburgh**

Regular online webinars:

https://thehitchhikersguidetorheology.com/

https://www.rheologylab.com/webinar/