UNIVERSITY OF LINCOLN

The British Society of Rheology

Mid-Winter Meeting

18-20th December 2023

Modelling & Measurement of Complex Materials: what works, what doesn't, and what's needed?

Programme

Monday 18th December		
11.30am-1pm	**Registration and Lunch (INB Atrium)**	
1.00-1.10pm	Opening remarks	
1.10-1.55pm	**Invited Talk** Hugh Barlow (Unilever)	Interfacial rheology of lung surfactant: experiments and modelling to explore disruption of breathing by aerosolised compounds
1.55-2.20pm	Stephen Flores (University of Manchester)	Structure-property and thermodynamic characterization of wormlike micelles from ionic polydisperse surfactant solutions
2.20.2.45pm	Vinay Kopnar (University of Durham)	How do inter-network crosslinks affect the failure mechanism of double-network hydrogel?
2.45-3.15pm	**Coffee Break (INB Atrium)**	
3.15-3.40pm	Dan Curtis (Swansea University)	The effect of instrument inertia on the initiation of oscillatory flows in stress-controlled frequency sweep and chirp based rheometry
3.40-4.05pm	Tom Eaves (University of Dundee)	Compressional rheology of a fibrous porous medium
4.15-5.30pm	**Tour of the Bridge (Meet in INB Atrium)**	
4.30-6.30pm	***BSR Council Meeting (Council Members Only) INB3305***	

* All talks to talk place in the Isaac Newton Building Lecture Theatre INB0114

Tuesday 19th December		
9.00-9.45am	**Invited Talk** Partick Ilg (University of Reading)	Fluids with internal rotations: hybrid simulations of ferrofluid flow
9.45-10.10am	Theofilos Boulafentis (UCL)	Spatio-temporal characteristics of polymeric turbulent Taylor-Couette flows
10.10-10.35am	Emily Cook (UCL)	Tensorial viscosity models for non-Newtonian fluids
10.35-11.10am	**Coffee Break (INB Atrium)**	
11.10-11.35am	Marco Pinna (University of Lincoln)	Mechanisms of alignment of lamellar-forming block copolymer under shear flow
11.35-12noon	Galina Pavlovskaya (University of Nottingham)	A molecular-mechanical link in shear-induced self-assembly of a functionalized biopolymeric fluid
12noon-12.25pm	Mahdi Davoodi (Schlumberger)	Particle Redistribution in Complex Flow of Complex Fluids
12.25-12.30pm	**Remarks on the Centre of Computational Physics @ Lincoln** Andrei Zvelindovsky (University of Lincoln)	
12.30-1.40pm	**Lunch + Posters (INB Atrium)**	
1.40-2.05pm	Esther Garcia-Tunon Blanca (University of Liverpool)	Linking Rheology and Printability in Direct Ink Writing (DIW): advances and opportunities
2.05-2.30pm	Ian Frigaard (UBC Mechanical Engineering)	Bubbles in yield stress fluids
2.00-2.55pm	James Richards (University of Edinburg)	Optimising non-Newtonian fluids for impact protection of laminates
2.55-3.30pm	**Coffee Break (INB Atrium)**	
3.30-4.15pm	**Vernon Harrison Award Lecture** Libby Marshall (University of Glasgow)	Preparation of multicomponent systems as a means of controlling the properties of peptide-based low molecular weight hydrogels
4.15-5pm	**Annual Award Lecture** Alexander Morozov (University of Edinburgh)	Elastic turbulence in parallel shear flows: Recent progress
7pm	**Conference Dinner (Assembly Rooms, 76 Bailgate, Lincoln, LN1 3AR)**	

* All talks to talk place in the Isaac Newton Building Lecture Theatre INB0114

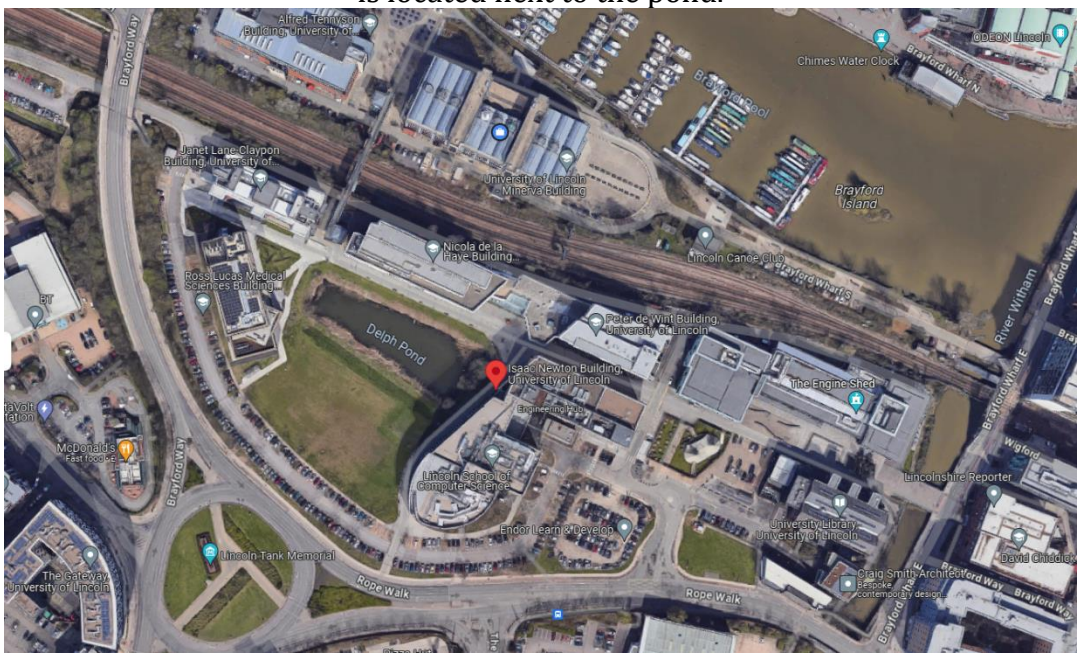
Wednesday 20th December		
9.00-9.40am	**RepTate Demonstration** Jorge Ramirez (UPM, Spain)	
9.40-10.20am	**iRheo Demonstration** Manlio Tassieri (University of Glasgow)	
10.20-10.40am	**Coffee Break (INB Atrium)**	
10.40-11.25am	**Invited Talk** Helen Wilson (UCL)	Building constitutive models for complex suspensions
11.25-11.50am	Tom John (University of Manchester)	Machine learning for viscoelastic constitutive model identification and parameterisation
11.50-12.15pm	John Hinch (University of Cambridge)	Fast flow of an Oldroyd-B fluid through a slowly varying contraction, expansion or constriction in a channel

Useful Information

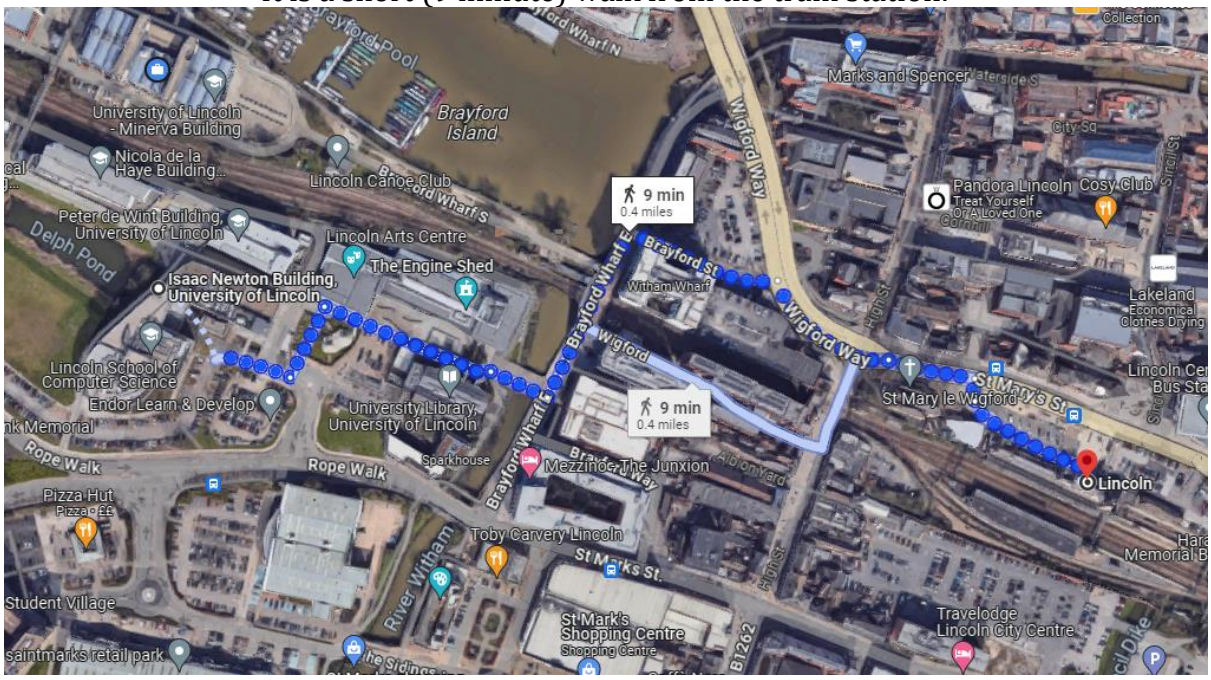
Welcome to the mid-winter meeting. All information can be found on the conference website:

https://www.bsr.org.uk/events/bsr-mid-winter-meeting-non-member

All sessions at this conference will be held in the Isaac Newton building on campus, this is located next to the pond.

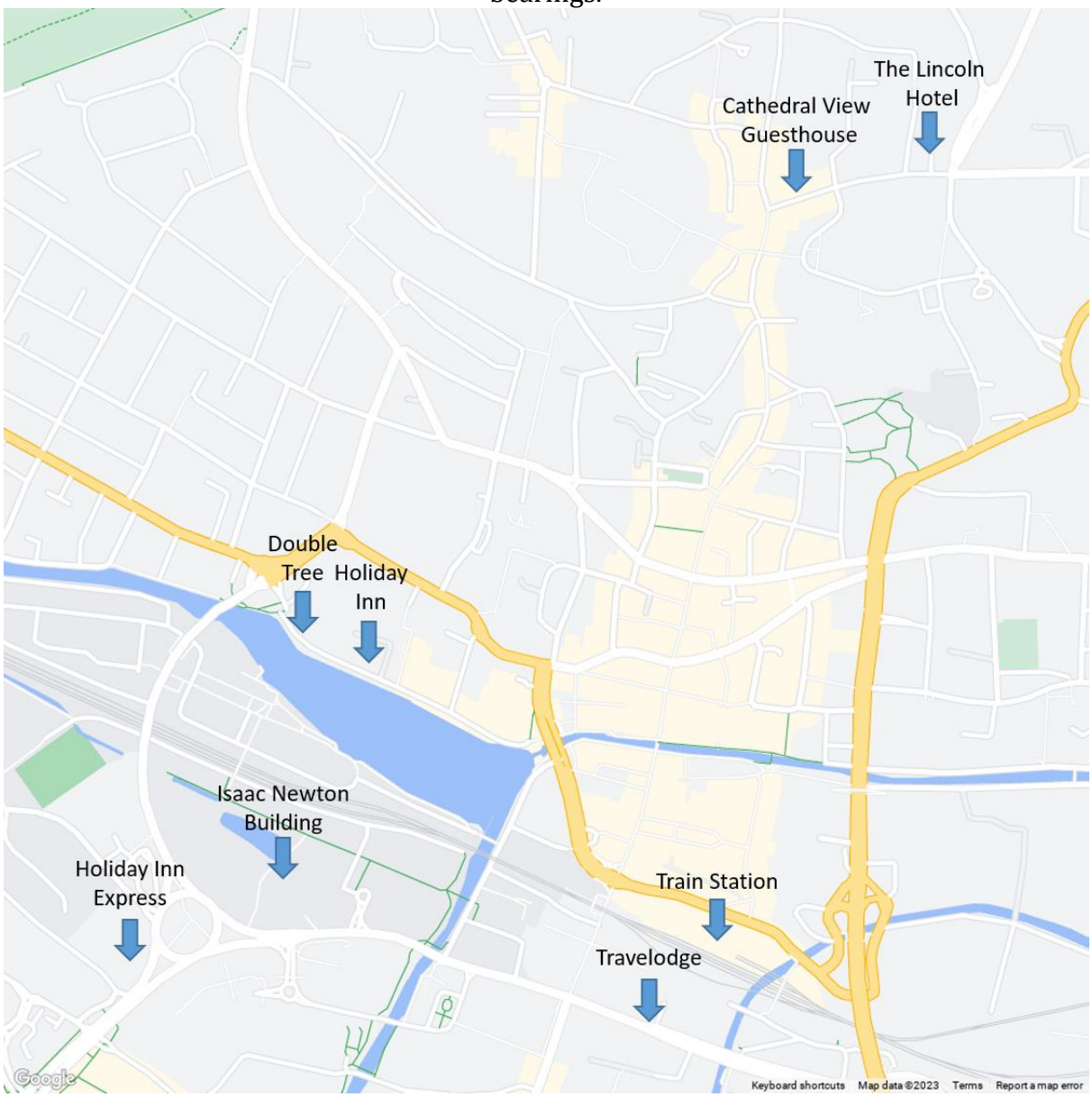


It is a short (9 minute) walk from the train station:



Hotels:

The recommended hotels for the conference can be seen on the below map, along with the main building for the conference and the local train station, to help you get your bearings.



Taxis:

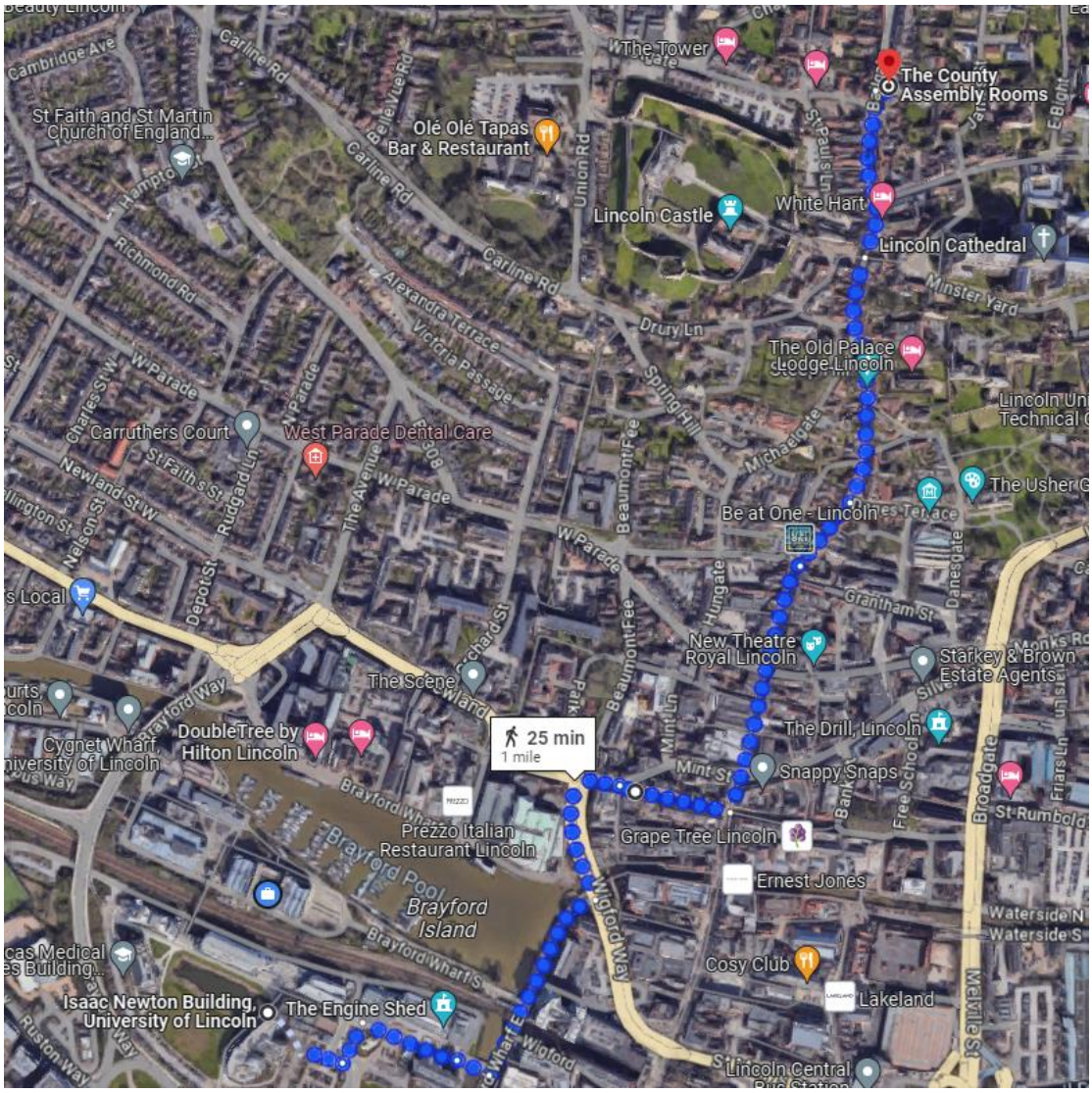
If you require a taxi during your visit we would recommend the below options.
Direct Cars 01522 567567
Handsome Cabs 01522 545352
Uber App

Other Useful Contacts:

Security: 01522 886062
Estates: 01522 886777
ICT: 01522 835857

Conference Dinner:

The conference dinner will be held at the County Assembly Rooms which are reachable with either a short 8 minute taxi ride or a lovely 25 minute walk (~1 Mile) through our historic city, along the high street and up past the castle and cathedral.



Restaurant suggestions:

There are many wonderful restaurants and cafés in our city, here are a selection we think you might like:

Venue	Location	Serving
Café Zoot	Bailgate, Lincoln LN1 3AE	Continental-style cafe/restaurant serving a huge range of dishes from light lunchtime sandwiches to pasta dishes and pizzas.
Castle View Indian Cuisine	Union Rd, Lincoln LN1 3BJ	An Indian restaurant serving a selection of authentic cuisine.
Gino's	7 Gordon Rd, Lincoln LN1 3AJ	An Italian restaurant serving pizzas, pastas and a selection of fish specials
The Botanist Bar & Restaurant	15-17 Cornhill, Lincoln LN5 7ET	Restaurant in the heart of the recently revamped Cornhill Quarter serving hanging kebabs, burgers and brunch.
The Horse and Groom	Carholme Rd, Lincoln LN1 1RH	A traditional pub serving a variety of pub classics.
Turtle Bay	Central Market, Sincil St, Lincoln LN5 7ET	A Caribbean style restaurant serving a wide range of dishes.

Housekeeping:

In the event of the fire alarm sounding please make your way towards the nearest exit, which will be clearly sign posted, and assemble at the fire assembly point behind the Isaac Newton building. If this occurs during a scheduled session please follow the guidance of the conference organisation team. There is a scheduled weekly fire alarm test due to take place at 9am on Wednesday (20th) in this event you do not need to vacate the building.

If you discover a fire in your time here please operate the nearest fire alarm and leave the building calmly via the nearest available exit. Do not attempt to use the lifts, if you require there is fire evacuation call points in each stair well that can be used if you require assistance during evacuation. Once you are outside please proceed to the fire assembly point being Isaac Newton building on the Green outside the performing arts centre.

If you require first aid attention during your visit please make this known to the conference organisation team or contact security on 01522 886062 if no one is immediately accessible.

Abstracts

Invited Speakers

Interfacial rheology of lung surfactant: experiments and modelling to explore disruption of breathing by aerosolised compounds

Hugh Barlow, Sreyoshee Sengupta, Maria Teresa Baltazar and Jorid Sørli.

Abstract. Lung surfactant is a complex mixture of phospholipids and proteins which resides at the fluid-air interface at the surface of our alveoli. Its function is to modify the surface properties of this interface in order to ease breathing and prevent lung collapse [1]. In particular, it increases the elasticity of the alveolar interface to prevent damage to epithelial tissues during breathing. Incidents of hospitalization have occurred when some commercial compounds are inhaled which disrupt the function of lung surfactant [2]. In this study, we explore this effect by combining experimental measurements and theory to understand the impact of a variety of chemical species on the rheology of model lung surfactant.

We examine the change in the dilational elasticity due to the introduction of a variety of compounds. Our experiments show that several chemicals induce changes in the dilational rheology of the lung surfactant monolayers which could lead to lung damage in vivo. Our findings are concordant with the effects observed in humans and in in vivo animal studies such as relative chemical potencies and the dose rate dependency [3]. To understand these effects, we develop a model based on the theory of surfactant adsorption kinetics which effectively reproduces the results seen in the experiments for all compounds studied.

References

[1] Veldhuizen et al. Role of pulmonary surfactant components in surface film formation and dynamics, Biochimica et Biophysica Acta (BBA) - Biomembranes, 1467, 2, (2000)

[2] Scheepers, P.T.J., Masen-Poos, L., van Rooy, F.G.B.G.J. et al. Pulmonary injury associated with spray of a water-based nano-sized waterproofing product: a case study. J Occup Med Toxicol ,12, 33, (2017)

[3] Duch P, Nørgaard AW, Hansen JS, Sørli JB, Jacobsen P, Lynggard F, Levin M, Nielsen GD, Wolkoff P, Ebbehøj NE, Larsen ST. Pulmonary toxicity following exposure to a tile coating product containing alkylsiloxanes. A clinical and toxicological evaluation. Clin Toxicol (Phila). Clinical Toxicology, 52, 5, (2014)

Fluids with internal rotations: hybrid simulations of ferrofluid flow

Patrick Ilg.

Abstract. Ferrofluid flow is fascinating since its flow properties can conveniently be manipulated by external magnetic fields. Novel applications in micro- and nanofluidics as well as in biomedicine have renewed the interest in the flow of colloidal magnetic nanoparticles with a focus on small-scale behavior. Traditional flow simulations of ferrofluids, however, often use simplified constitutive models and do not include fluctuations that are relevant at small scales. Here we address these challenges by proposing a hybrid scheme that combines the multiparticle collision dynamics method for modeling hydrodynamics with Brownian dynamics simulations of a reliable kinetic model describing the microstructure, magnetization dynamics, and resulting stresses. Since both, multiparticle collision dynamics and Brownian dynamics are mesoscopic methods that naturally include fluctuations, this hybrid scheme presents a promising alternative to more traditional approaches, also because of the flexibility to model different geometries and modifying the constitutive model.
In this talk, example flow situations are shown to validate the model and its implementation in Poiseuille flow. Moreover, we also provide numerical predictions for Stokes' second flow problem for ferrofluids as well as field-dependent drag coefficients that are determined from the flow past a square cylinder. Finally, applications of the method to describe flow through porous media is discussed.

Building constitutive models for complex suspensions

Helen Wilson.

Abstract. I'll talk about two different constructions of new constitutive models.
The first study is of shear-thickening fluids, such as a dense cornstarch in water suspension. We have used the dynamics of particle pairs to break a deadlock in the understanding of these systems. By considering the creation, evolution and destruction of contacts, we can create a governing equation for stress which is suitable for general flows and captures many of the phenomena seen in simulations.
In the second case the suspending fluid is itself complex, and we consider weakly deformable inclusions - elastic solid spheres or high-surface-tension droplets - which do not interact directly with one another. Using a mean-field approximation in the form of a cell model, we can calculate homogenised parameters to treat the whole suspension as a second-order fluid. We also gained a surprisingly elegant result about the orientation of deformable particles in shear flow.

Preparation of multicomponent systems as a means of controlling the properties of peptide-based low molecular weight hydrogels

Libby Marshall.

Abstract. Multicomponent systems can be used to achieve different properties and behaviors 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 LMWG and a structurally similar non-gelator, (ii) mixing two structurally similar LMWGs, and (iii) mixing a LMWG and a cross-linking agent. 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. Throughout my PhD I have been fortunate enough to have regular access to rheometers as well as the opportunity to perform RheoSANS at ISIS Neutron and Muon Source. During my talk I will describe the work from my thesis, highlighting the importance of rheology for each project.

RepTate Demonstration

Jorge Ramirez.

Abstract. RepTate (Rheology of Entangled Polymers: Toolkit for Analysis of Theory & Experiment) is a free and open-source software package for viewing, exchanging, and analysing rheological data. It includes several classical and latest theories of polymer dynamics, so they can be tested and fitted to experimental data. This hands-on demonstration will cover the installation and basic use of RepTate, using sample data included with the application. We will focus on key functionalities commonly employed by users, providing a quick yet comprehensive overview. Additionally, we will share insights on how users can actively contribute to the ongoing development of RepTate.

iRheo Demonstration

Manlio Tassieri, Marco Laurati, Dan J. Curtis, Dietmar W. Auhl, Salvatore Coppola, Andrea Scalfati, Karl Hawkins, Phylip Rhodri Williams and Jonathan M. Cooper

Abstract. I will present a simple analytical method for educing the materials' linear viscoelastic properties, over the widest range of experimentally accessible frequencies, from a simple step-strain measurement, without the need of preconceived models nor the idealisation of real measurements. This is achieved by evaluating the Fourier transforms of raw experimental data describing both the time-dependent stress and strain functions. The method has been implemented into a LabView based executable "i-Rheo" and recently on a web platform "i-Rheo Web" (https://i-rheo.mib3avenger.com/), enabling its use to a broad scientific community. The effectiveness of the new rheological tool has been corroborated by direct comparison with conventional linear oscillatory measurements for a series of complex materials as diverse as a monodisperse linear polymer melt, a bimodal blend of linear polymer melts, an industrial styrene-butadiene rubber, an aqueous gelatin solution at the gel point and a highly concentrated suspension of colloidal particles. The broadband nature of i-Rheo and its general validity open the route to a deeper understanding of the material's rheological behaviour in a variety of systems.

Contributed Talks

Structure-property and thermodynamic characterization of wormlike micelles from ionic polydisperse surfactant solutions

Stephen Flores, Junju Mu, Christopher Cabry, Joseph Peterson, Ian Stott, Joanne Cook, Andrew Masters, Carlos Avenda, Christopher Hardacre.

Abstract. Self-assembled wormlike micelles are integral in the formulation of various surfactant systems, with applications ranging from consumer products to advanced oil recovery. The chemical formulation of these micellar systems and how it relates to their structure-property relationship and flow behavior is a significant challenge in the framework of achieving transferable results for industrial applications. In this work, we propose a prediction of the thermodynamic characteristics that link the chemical formulation of wormlike micelles to the microstructural characteristics found in bulk rheological data. To support this, linear rheology measurements were taken for 143 samples with a base formulation of commercial sodium lauryl ether sulphate (SLES), cocamidopropyl betaine (CAPB), and salt. Our approach combines a simple constitutive equation with a simple fitting algorithm and yields results that are extremely robust, stable, and fast compared to previously published alternatives. Tools like this can eventually form the basis of a computational and data-driven approach to formulation design.

How do inter-network crosslinks affect the failure mechanism of double-network hydrogel?

Vinay Kopnar, Dr. Anders Aufderhorst-Roberts, Dr. Natasha, Adam O'Connell + Shirshova.

Abstract. There are very few soft materials that are also strong. Double-network (DN) hydrogel is one of the tough soft materials that is built using two polymer networks having contrasting properties, wherein the first network is hard and brittle, while the second network is soft and ductile. As the hydrogel stretches beyond the fracture point of the first network, the first network sacrifices itself by breaking into clusters which end up acting as secondary crosslinks for the second network and thus strengthening it. The second network prevents any visible macroscopic fracture. Some of the hydrogels have been seen to have inter-network crosslinks between the two polymer networks and the role of these crosslinks on stiffness and toughness hasn't been studied in the depth needed to devise a strategy to design a material. Here, I wish to present the study of the effect of these crosslinks on the mechanical properties of one of the hybrid recoverable DN hydrogel systems done using a rheological technique called large amplitude oscillatory shear (LAOS). With the help of LAOS, I determine the fracture strain at which the first network of the double-network hydrogel ruptures and observe how the fracture strain changes when the inter-network crosslinks in the system are disrupted. I also take a closer look at LAOS as a rheological technique to elucidate the behavior of molecular-scale characteristics on the mechanical properties of the material.

The effect of instrument inertia on the initiation of oscillatory flows in stress-controlled frequency sweep and chirp based rheometry

D Curtis, A Ogunkeye, R Hudson.

Abstract. In a recent paper [Hassager, J. Rheol. 64, 545-550 (2020)], Hassager performed an analysis of the start up of stress-controlled oscillatory flow based on the general theory of linear viscoelasticity. The analysis provided a theoretical basis for exploring the establishment of a steady strain offset that is inherent to stress controlled oscillatory rheometric protocols. However, the analysis neglected the impact of instrument inertia on the establishment of the steady periodic response. The inclusion of the inertia term in the framework is important since it (i) gives rise to inertio-elastic ringing and (ii) introduces an additional phase shift in the periodic part of the response. Herein, we modify the expressions to include an appropriate inertial contribution and demonstrate that the presence of the additional terms can have a substantial impact on the time scale required to attain the steady state periodic response. The analysis is then applied to an aqueous solution of wormlike micelles in the context of both single tone small amplitude oscillatory shear experiments (i.e. standard frequency sweeps) and stress controlled chirp based rheometry.

Compressional rheology of a fibrous porous medium

Tom S. Eaves Daniel T. Paterson Duncan R. Hewitt Neil J. Balmforth D. Mark Martinez.

Abstract. Dense particulate suspensions form a porous medium in which a network of contacts between adjacent particles results in an effective solid network stress which may resist deformation; understanding the rheology of such suspensions is essential in a wide variety of industrial and environmental applications. The effective solid stress is most commonly taken to reflect plastic rearrangements of the interconnected particle network. However, such an approach was seen to be incompatible with experimental observations of the compressional behaviour of wood-fibre pulp suspensions (used in the paper-making industry). Over a series of rheological investigations, a poro-elasto-visco-plastic model of the one-dimensional compression of this material has been developed, with each element of the rheology being of crucial importance in different compressional regimes. This talk will describe the sequence of experiments which led to the definition of this rheology and indicate how the microstructure of this material may dictate its behaviour. It will conclude with an outlook of whether or not other related materials are expected to fall within a similar rheological description.

Spatio-temporal characteristics of polymeric turbulent Taylor-Couette flows

Theofilos, Boulafentis Stavroula, Balabani.

Abstract. Polymer solutions are known to introduce instabilities in parallel and shear wall-bounded flows (Morozov, 2022; Yamani et al., 2021), ultimately leading to the onset of a universal, chaotic flow state reminiscent of turbulence, termed Elasto-Inertial Turbulence (EIT). The Taylor-Couette flow, comprising two concentric cylinders with the inner one rotating, serves as a paradigm for viscoelastic shear flows. Previously reported results describe chaotic states leading to EIT, such as the defect-mediated-turbulence (DMT) and the merging and splitting mechanism (MST), associated with the modification of the vortical structures by elasticity. However, to date, no velocity data have been available to elucidate the role of elasticity on these instabilities. We report Particle Image Velocimetry (PIV) measurements for TC flows of polymer solutions with varied elasticity (El=0-0.52) at a fixed Reynolds number (Re=120), obtained in both the meridional and azimuthal plane. The addition of polymers destabilises the Taylor-Vortex flow for El up to 0.185, introducing velocity fluctuations with a characteristic spectral signature. However, the latter disappears when El is increased further, implying a potential relaminarization of the flow, as reported previously by experimental studies in pipe flow (Choueiri et al., 2018). The spatio-temporal nature of this flow is fully characterised by the velocity measurements and compared to numerical findings (Song et al., 2021).

Tensorial viscosity models for non-Newtonian fluids

Emily Cook, Duncan Hewitt and Mahdi Davoodi.

Abstract. Many industrial fluids are engineered to exhibit viscoelastic behaviours which aid in industrial processes. As a result of elasticity, such fluids can exhibit a whole zoo of complex behaviour; in particular, they can experience normal stresses in flows where inelastic fluids would experience none. It is therefore of interest to efficiently capture these viscoelastic effects during modelling and simulation, as they could have a meaningful impact on the industrial application. Relatively ‘simple’ generalised-Newtonian-fluid models are usually considered to be insufficient for modelling viscoelastic phenomena, because they impose an instantaneous relationship in which the stress and strain-rate tensors are always aligned. On the other hand, viscoelastic models, such as the Oldroyd B model, are implicit equations of the stress tensor, and are therefore difficult to analyse and can be computationally expensive or unstable. This talk will outline and explore a class of constitutive equation which relates stress and deformation rate via a viscosity tensor. Such models allow for guaranteed control of normal stresses, without the requirement of implicit derivatives of the stress tensor, improving numerical tractability. The efficacy of such models in emulating some complex viscoelastic behaviour, and their association with traditional viscoelastic models, will be discussed.

Mechanisms of alignment of lamellar-forming block copolymer under shear flow

Marco Pinna, Javier Diaz, Ignacio Pagonabarraga, Christopher Denison and Andrei Zvelindovsky.

Abstract. The potential applications of block copolymer thin films, utilizing their self-assembly capabilities, are greatly promising when achieving long-range ordering. In this talk the alignment of lamellae under shear flow through experimental results will be validated. By classifying the alignment mechanisms based on shear rate and degree of segregation, we uncover significant similarities to the systems subjected to electric fields, suggesting a common orientational pathway of lamellae orienting towards the direction of external fields. However, the utilization of thin films with surface effects introduces distinct features in the lamellae orientation pathway compared to electric fields. Notably, we observe the emergence of a three-dimensional rotation alongside the conventional two-dimensional rotation observed previously. Furthermore, a transient regime has been identified within the melting mechanism which was only depicted by Schneider et al.[Macromolecules 2018, 51,4642]. These findings significantly enhance our understanding of block copolymer alignments and shed light on the intricate interplay between external fields and the lamellar structure.

A molecular-mechanical link in shear-induced self-assembly of a functionalized biopolymeric fluid

Galina Pavlovskaya and Thomas Meersmann.

Abstract. 23Na multiple quantum filtered (MQF) rheo-NMR methods were applied to probe the molecular foundation for flow induced self-assembly in 0.5% *κ*-carrageenan fluid. This method is sensitive enough to utilize an endogenous sodium ion concentration of approximately 0.02%. Rheo-NMR experiments were conducted at different temperatures and shear rates to explore varying molecular dynamics of the biopolymer in the fluid under shear. The temperature in the rheo-NMR experiments was changes from 288 K to 313 K to capture transition of Îº-carrageenan molecules from helices to coils. At each temperature, the fluid was also tested for flow and oscillatory shear behaviour using bulk rheometry methods. It was found that the 23Na MQF signals were observed for the 0.5% *κ*-carrageenan solution only under shear and when the fluid demonstrated yielding and/or shear-thinning behaviour. At temperatures of 303 K and above, no 23Na MQF signals were observed independent of the presence or absence of shear as the molecular phase transition to random coils occurs and the fluid becomes Newtonian.

Particle Redistribution in Complex Flow of Complex Fluids

Mahdi Davoodi and Andrew Clarke.

Abstract. A major part of well-construction practices in SLB is drilling the well which is a process that still experiences significant technical challenges. These industry challenges continue to be highly relevant as SLB extends its, activity in adjacent energy transition technologies that also require deep drilling, that is geothermal, carbon capture & sequestration and sustainable lithium production. Here we focus on the ability of drilling fluids to carry rock cuttings to the surface. Within the industry this particle-carriage problem is, in general, modelled using a generalized Newtonian fluid. Yet there are repeated industry reports comparing fluids where the flow curves are closely similar but where cuttings transport is demonstrably different. To probe this, using a set of numerical and experimental techniques, we compare a Oldroyd-B model as a proxy for a water-based drilling fluid together with a generalized Newtonian fluids as aqueous Bentonite dispersion. The rheological properties of each of the two fluids, are chosen so that their generalized Newtonian properties are closely similar. However, their extended rheological properties, in particular normal stress differences, differ markedly. We examine dense particle motion in a horizontal Couette in the presence of Taylor vortices for each fluid. We find significant effects dependent on fluid type which, we speculatively assign as primarily due to normal forces generated by the background fluid.

Linking Rheology and Printability in Direct Ink Writing (DIW): advances and opportunities

Rishav Agrawal and Esther Garcia-Tunon Blanca.

Abstract. Direct ink writing (DIW) is an expanding multi-disciplinary research field in 3D printing. Its strength is the versatility of materials formulation through careful design of complex fluids. These must be extremely shear-thinning soft solids, able to flow through narrow nozzles, recover their structure upon deposition and retain the predesigned 3D shape. Linking rheology and printability is a growing area of research amongst the DIW and rheology communities.[1-3] We have proposed 'printability' protocols using continuous shear and oscillatory rheology[4] for graphene oxide (GO) formulations. In this talk, I will present our work in complex fluids for DIW using LAOS, FT rheology,[5] Sequence of Physical Processes (SPP) and recovery tests.[6] We adopt the same nomenclature as a recent review[3] to facilitate clear guidance in a multi-disciplinary field. We quantify three rheological stages in the printing process to create Ashby-type[5] maps: 1) flow during extrusion (flowability, T vs FTI-1); 2) recovery stage when exiting the nozzle (recoverability, λ vs. % of recovery); and 3) ability to retain the predesigned shape for optimum shape fidelity (material strength, G' and σf). We demonstrate that the three maps must be considered holistically for a fair assessment of printability. We will discuss specific guidance to improve rheological analysis in DIW and provide comprehensive printability maps.

Bubbles in yield stress fluids

Masoud Daneshi, Marjan Zare, Ali Pourzahedi, Emad Chaparian, Ian Frigaard.

Abstract. Bubbles arise in a variety of contexts interesting for yield stress fluid mechanics. Here we address questions of the static limit for single and multiple bubbles which can be important for applications to greenhouse gas emission mitigation. We examine the interaction of bubbles in clouds and networks, with the aim of understanding these problems.

Optimising non-Newtonian fluids for impact protection of laminates?

James A. Richards, Daniel J. M. Hodgson, Rory E. O'Neill, Michael E. DeRosa, and Wilson C. K. Poon.

Abstract. Non-Newtonian fluids can be used for the protection of flexible laminates. Understanding the coupling between the flow of the protecting fluid and the deformation of the protected solids is necessary in order to optimise this functionality. We present a scaling analysis of the problem based on a single coupling variable, the effective width of a squeeze flow between flat rigid plates, and predict that impact protection for laminates is optimised by using shear-thinning, and not shear-thickening, fluids. The prediction is verified experimentally by measuring the velocity and pressure in impact experiments. Our scaling analysis should be generically applicable for non-Newtonian fluid-solid interactions in diverse applications.

Machine learning for viscoelastic constitutive model identification and parameterisation

Thomas John, Max Mowbray, Michail Vousvoukis, Ahmed Alalwyat, Philip Martin, Dongda Zhang, Adam Kowalski, Claudio Fonte.

Abstract. In order to model a viscoelastic fluid flow, we need to select and parameterise a constitutive model. Currently, there is a plethora of different viscoelastic models to choose from, and choosing the correct model for a given material is no trivial task. Moreover, fitting the parameters of the chosen model to experimental data can be challenging if no analytical solution exists for the constitutive model under the selected flow. In this study, we assess the feasibility of using the Random Forest (RF) machine learning algorithm for selecting and parameterising constitutive models using Large Amplitude Oscillatory Shear (LAOS). We train the RF algorithm using LAOS data for the linear-PTT and exponential-PTT models. For both models, the RF algorithm is easily able to predict the model parameters from the LAOS response. The predictive accuracy is also fairly insensitive to the RF algorithm parameters (the Hyper-parameters), highlighting the robustness of the method for this application. For more complex models, such as the RoLiE-Poly model, challenges can arise due to the fact that multiple different sets of model parameters can give very similar LAOS behaviour. This highlights that the exact methodology used for model fitting may need to be tuned on a per-model basis.

Fast flow of an Oldroyd-B fluid through a slowly varying contraction, expansion or constriction in a channel

E.J.Hinch, E.Boyko and H.A.Stone.

Abstract. Lubrication theory is adapted to incorporate the large normal stresses that occur for order-one Deborah numbers, De, the ratio of the relaxation time to the residence time.
Comparing with the pressure drop for a Newtonian viscous fluid with a viscosity equal to that of an Oldroyd-B fluid in steady simple shear, we find numerically a reduced pressure drop through a contraction and an increased pressure drop through an expansion, both changing linearly with De at high De. For a constriction there is a smaller pressure drop that plateaus at high De. Much of the change in pressure
drop occurs in the stress relaxation in a long exit channel.
An asymptotic analysis for high De, based on the idea that normal stresses are stretched by an accelerating flow in proportion to the square of the velocity, reveals that the large linear changes in pressure drop are due to higher normal stresses pulling the fluid through the narrowest gap. A secondary cause of the reduction is that the elastic shear stresses do not have time to build up to their steady state equilibrium value while they accelerate through a contraction.
Our findings of the change in pressure drop have the opposite sign to most experiments with elastic liquids, so some modification of the Oldroyd-B fluid model is required. The two mechanisms, of larger normal stresses pulling the fluid through the narrowest gap and the elastic shear stresses needing time to achieve their steady values, are however robust and would come with most constitute equations for an elastic liquid. A modification that includes some form of extra dissipative stress may be necessary.