Fundamental Mechanics for Future Microfluidics

16–18 June 2025
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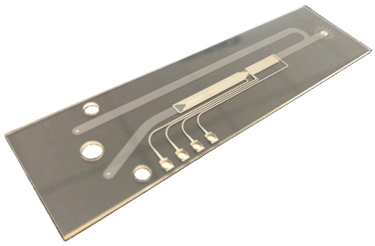

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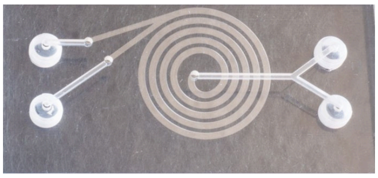

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Exhibitors

Dolomite Microfluidics (Unchained Labs)
www.unchainedlabs.com/dolomite-microfluidics-systems/
www.linkedin.com/company/dolomite-microfluidics?originalSubdomain=uk

Dolomite Microfluidics is a pioneer and well-known leader in the microfluidic industry. We not only provide cutting-edge microfluidic products but also drive innovation in the technology, offering advanced solutions to meet the requirements of our clients. Our state-of-the-art systems are at the forefront of innovation, providing precise control over fluid dynamics to create monodisperse particles, droplets, bubbles, foams, and emulsions.

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Epigem Limited is a UK-based microengineering company specialising in the bespoke design and manufacture of microfluidic chips, fine-line microcircuitry, and hybrid devices for the life sciences, diagnostics, and electronics sectors. Epigem offers flexible, well-characterised fabrication processes suitable for both low and high-volume production. Our team can create fully customizable microfluidic devices consisting of fluidic channels, with inbuilt filters and mixer elements, as an example. Device manufacture is carried out in a cleanroom environment and is ISO9001:2015 quality assured. With decades of experience, the company supports clients from concept through to product realisation. Epigem's innovative micro-gasket system allows seamless integration of microfluidic chips with silicon, glass, or quartz components, enabling complex and modular system design. Additionally, the company can integrate electrical circuitry into microfluidic devices, supporting active fluid manipulation.

Notes

Viscoelastic Instabilities in Microfluidics: Pathways to Elastic Turbulence and Beyond

Amy Shen[1]
[1]Okinawa Institute of Science and Technology, Japan

Microfluidics has revolutionized the investigation of small-scale fluid dynamics, enabling precise control and deep insights into complex flow behaviors with broad implications for biophysics, biotechnology, and engineering. This talk presents experimental and computational results on viscoelastic instabilities and their pathways to elastic turbulence, focusing on microfluidic architectures such as cross slots, micropost arrays, and porous media. By employing selective laser-induced etching (SLE) to create robust glass microfluidic devices capable of sustaining high flow rates, we have uncovered synchronized motions, metachronal waves, and chaotic transitions in viscoelastic flows. Additionally, the impact of geometric disorder on flow behavior is examined, offering new strategies for optimizing mixing efficiency, improving particle separation, and enhancing the design of energy-efficient microfluidic systems.

Flexible filaments in microfluidic flows, from fundamental physics to separation

Olivia Du Roure[1]
[1]ESPCI & Université PSL, France

The dynamics of individual flexible filaments in viscous flows is key to deciphering the rheological behavior of many complex fluids and soft materials. It also underlies a wealth of biophysical processes from flagellar propulsion to intracellular streaming and is key to develop new separation strategies of elongated objects of different properties in a suspension. The interaction between a flexible filament and a given flow depends strongly on the properties of the object - flexibility, aspect ratio and dimensions - and the flow geometry. This interaction is governed by the elasto-viscous number comparing elastic and viscous forces. During the last years, we have studied different configurations of this problem by combining microfluidics, microfabrication and microscopy. I will present recent work on the dynamics of actin filament, used here as a model filament, in different flow geometries and will describe the different morphologies the filament adopts when the elasto-viscous number varies [1, 2]. In particular we observed and elucidated the formation of an helical structure in pure straining flows [2] and discovered that introducing a tilted pillar array in a microfluidic chip allows for length-dependent separation [3].

[1] Liu et al. PNAS 2018, [2] Chakrabarti et al. Nature Physics 2021, [3] Li, Bielinski, et al. In preparation

Droplets flowing in capillary tubes and microfluidic channels

François Gallaire[1]
[1]EPFL, Switzerland

We will first discuss the motion of buoyant Bretherton bubbles stuck in sealed vertical tubes when the inner tube radius is below a critical value near the capillary length. This critical threshold for steady ascent is determined by geometric constraints related to the matching of the upper cap shape with the lubricating film surrounding the elongated part of the bubble. Developing strategies to overcome this threshold and release stuck bubbles is essential for applications involving narrow liquid channels. We investigate the mobility of elongated bubbles leveraging variations in axial and transversal accelerations: tube rotation around its axis and tube inclination relative to gravity. The study predicts novel inner tube radius thresholds based on rotational speed and tilt angle, respectively, providing forecasts for the bubble rising velocity under modified apparent gravity. Experimental measurements of motion threshold and rising velocity compare well with theoretical developments.

We then discuss the motion of droplets confined in microchannels, sometimes referred to as pancake droplets. We show that their structure can be understood as the “tensorial product” of a mildly deformed in-plane geometry and a more convoluted transverse shape across the gap, which is precisely reminiscent of Bretherton bubbles. We finally discuss their mobility, i.e. their relative translation velocity with respect to the surrounding flow, as a function of the capillary number.

Dynamical elasto-capillary self-assembly

Matthieu Labousse[1]
[1]ESPCI & Université PSL, France

Elasto-capillarity is a powerful strategy of self-assembly, not only for your hair morphology after a shower but also to design critical industrial components at the microscale. While static elasto-capillary structures have been experimentally and theoretically well studied, the path towards equilibrium is less well understood and represent, in practice, a major stumbling block for complex self-assembly process. Yet a better understanding of the self-assembling dynamics of such structures could help modelling more complex industry-oriented systems such as the rheology of reinforced materials or biology-oriented like the self-assembly of the mitotic spindle. In this talk, I will rationalize a simple case of dynamical self-assembly and will show that it leads to a rich variety of controlled morphologies.

Stabilization and controlled motion of arbitrarily large Leidenfrost puddles

Samuel Hidalgo-Caballero[1], Matthieu Labousse[1], and Emmanuel Fort[2]
[1]Gulliver, CNRS UMR 7083, ESPCI Paris and PSL University, France, [2]Institut Langevin, ESPCI Paris and PSL University, France

The size of Leidenfrost droplets on flat surfaces is typically limited by the capillary length. As droplets grow larger, gravitational forces flatten them into puddle-like shapes, and beyond a critical radius, they become unstable due to the inverse Rayleigh-Taylor instability, leading to bubble formation. In this study, we introduce a method to suppress this "chimney" instability by selectively removing a portion of the insulating vapor layer beneath the liquid. This approach allows for the stable levitation of arbitrarily large liquid puddles in a quasi-steady evaporation regime. Furthermore, we demonstrate that by directing the escaping vapor, we can achieve controlled motion of these large liquid volumes.

Non-linearities and the emergence of complexity in flow networks

Eleni Katifori[1]
[1]University of Pennsylvania, USA

Microfluidic flow networks are conventionally modeled as linear systems. This talk investigates the impact of integrating nonlinear resistive elements, such as flow-rectifying diodes and bistable valves, into these networks. We will demonstrate how bistable resistive components can induce hysteresis, enabling the system to generate complex global memory states in the form of pressure patterns. Additionally, we will examine non-reciprocal behaviors in peristalsis-driven flow networks equipped with simple fluidic diodes, which allow fluid to flow preferentially in one direction. We will show two fluidic systems that experimentally reproduce the theoretically predicted phenomenology and discuss implications for the design of microfluidic systems with exotic behaviors.

Fluid-structure interactions in a self-intersecting flexible channel

Kaare H. Jensen[1], Benjamin Dollet[2], Philippe Marmottant[2], and Magnus V. Paludan[1]
[1]Department of Physics, Technical University of Denmark, Denmark, [2]University Grenoble Alpes, CNRS, LIPhy, France

Soft, interwoven vessels that carry fluids are commonly encountered in biofluid mechanics. The geometry of these channels can deform under fluid flow, leading to deviations from the linear Hagen–Poiseuille law, which relates flow rate to pressure drop. While the fluid-structure interactions of single deformable channels have been thoroughly investigated, such as in Starling's resistor and its variants, the flow capacity of intertwined channels with multiple self-intersections, known as 'hydraulic knots, ' remains largely unexplored. In this presentation, we provide both experimental and theoretical insights into soft hydraulic knots formed by interconnected microfluidic devices consisting of two intersecting channels separated by a thin elastomeric membrane. Our experiments reveal flow–pressure relationships akin to flow limitation, indicating that the limiting flow rate is contingent upon the configuration of the knot. To rationalize our findings, we develop a mathematical model grounded in lubrication theory, integrated with tension-dominated membrane deflections, which aligns well with our experimental results. Lastly, we explore two potential applications of hydraulic knots in microfluidic flow rectification and attenuation.

Solving the mystery of embolism repair in plants after a period of drought using biomimetic leaves

Philippe Marmottant[1]
[1]Université Grenoble, France

If plants do not have a heart to pump water from the soil, they have the ability to strongly decrease their internal water pressure in the leaves. There, evaporation results in very reduced pressures, down to -190 bars during dry weather! However, under those negative pressures, water can produce cavitation with the sudden nucleation of bubbles. The growth of those bubbles induces a gaseous embolism, progressively filling the hydraulic networks with air. This stops the water circulation and eventually leads to the death of trees. Observations on real leaves showed that the embolism advances by a succession of long stops and sudden jumps.

To understand the nature of jumps, we propose an experimental model using biomimetic leaves in silicone (PDMS), made of thin water-permeable membranes. The veins of these artificial leaves are channels filled with water, and here we have introduced constrictions to mimic the pit in between real leaf channels.

It is not really understood how a plant can recover after such an event, some studies calling for a "miracle", and other some studies suggesting its impossibility and the need for the growth of new tissue.   The final objective of this research is to understand the physics of the refilling of embolised conduits filled with air, when the humidity level increases again.

Soft hydraulics: Basic laws for steady, oscillatory, and complex fluid flows through compliant conduits

Ivan Christov[1]
[1]Purdue University, West Lafayette, USA

Microfluidic devices manufactured from soft polymeric materials have emerged as a paradigm for cheap, disposable, and easy-to-prototype fluidic platforms for integrating chemical and biological assays and analyses. It is now understood that the interplay between the flow forces and the inherently compliant conduits within such devices requires careful consideration. At the same time, the mechanical compliance of these devices enables new approaches to "reconfigurable" microfluidic platforms for microrheometry, sieving of micro- and nano-particles, and development of biomimetic organs-on-a-chip, as well as new modalities of micromixing. In this talk, I will discuss our research program on the basic laws of soft hydraulics. Starting with steady flow through a rectangular microchannel, I will show how a complete understanding of the flow and deformation can be developed from scratch, rationalizing previous experiments. Next, I will show how our approach can be extended to capture non-Newtonian rheology and different conduit geometries' mechanical responses, leading to new experimental collaborations on shear-thinning fluids and Boger fluids in weakly viscoelastic flows. Next, I will describe how our theoretical building blocks can be used to piece together a theory for oscillatory flows through deformable microchannels, demonstrating a novel "elastoinertial" rectification mechanism (a type of self-induced streaming) in these flows. Time permitting, I will explain how our basic laws of soft hydraulics can enable a new understanding of why laminar flows in compliant microchannels become unstable at a low Reynolds number of 200 to 300 (instead of 2000 to 3000!).

Passive viscous flow selection via fluid-induced buckling and snapping

Matteo Pezzulla[1]
[1]Aarhus University, Denmark

The efficient redistribution and control of flow is essential in many biological and engineered systems, from our cardiovascular system to plants and soft robotics. Inspired by Nature, microfluidic devices with passive valves have been developed to perform a variety of tasks, from cell manipulation to fluid mixing and reaction control, giving rise to the field of soft hydraulics. In this talk, I will present two prototypes of passive valves: one harnessing buckling in slender beams and another leveraging snapping in spherical shells, where fluid-induced elastic instabilities are tamed to achieve function. Through a combination of precision desktop-scale experiments, numerical simulations, and theoretical analysis, I will rationalize these behaviors and provide design rules based on scaling relationships among material, geometric, and fluid parameters.

Microfluidic model of haemodynamics in complex media

Qi Chen[1], Valeria Ciccone[1], Eleanor Doman[1], Oliver E Jensen[1], Igor L Chernyavsky[1], and **Anne Juel**[1]
[1]University of Manchester, UK

The flow of red blood cells (RBCs) in heterogeneous biological porous tissues such as the human placenta, remains poorly understood despite the essential role the microvasculature plays in maintaining overall health and functionality of tissues, blood flow and transport mechanisms. This is because the usual description of blood as a simple fluid breaks down when the size of RBCs is similar to that of the vessel. In this study, we use a bespoke suspension of ultra-soft microcapsules with a poroelastic membrane, which have been previously shown to mimic the motion and large deformations of RBCs in simple conduits, in order to explore soft suspension flows in planar porous media. We perform experiments that relate the global resistance of the suspension flow through the porous media to the local distributions of capsule concentration and velocity as a function of volume fraction, capillary number Ca, the ratio of viscous to elastic forces, and geometry. We find that the flow patterns in Hele-Shaw channels and ordered porous media differ significantly from those in disordered porous media, where the presence of capsules promotes preferential paths and supports anomalous capsule dispersion. Despite the complex microscopic dynamics of the suspension flow, we observe the emergence of similar scaling laws for the global flow resistance in both regular and disordered porous media as a function of Ca. We find that the scaling exponent decreases with increasing volume fraction because of cooperative capsule mechanisms, which yield relative stiffening of the system for increasing Ca.

Multistable Metafluids

Amir Gat[1]
[1]Technion, Israel

The thermodynamic properties of fluids play a crucial role in many engineering applications, particularly in the context of energy. In this work, we suggest creating fluids with multistable thermodynamic properties in order to offer new paths for harvesting and storing energy via transitions between equilibria states. Such artificial multistable fluids can be created using the approach employed in metamaterials, which controls macro-properties through micro-structure composition. In this work, the dynamics of such `metafluids' is examined for a configuration of calorically-perfect compressible gas contained within multistable elastic capsules flowing in a fluid-filled tube. We study both analytically and experimentally the velocity-, pressure-, and temperature-fields of multistable compressible metafluids, focusing on transitions between different equilibria. We first examine the dynamics of a single capsule, which may move or change equilibrium state, due to fluidic forces. We then study the interaction and motion of multiple capsules within a fluid-filled tube. We show that such a system can be used to harvest energy from external temperature variations in either time or space. Thus, fluidic multistability allows specific quanta of energy to be captured and stored indefinitely as well as transported as a fluid, via tubes, at standard atmospheric conditions without the need for thermal isolation.

Embedded 3D Printing in Silicone: Fabrication of Milifluidic Circuits for Soft Sensing and Actuation

Alejandro Ibarra[1]
[1]Esmp - IAS - Luxembourg University, Luxembourg

The fabrication of soft, complex structures remains a significant challenge. A common technique is lithography, which can create intricate structures across various scales; however, these structures must be either 2D or constructed layer by layer. This is where 3D printing presents an interesting alternative, offering the flexibility to build complex structures. However, it comes with a loss of resolution compared to lithography. One notable 3D printing technique is direct ink writing (DIW), which involves constructing structures by depositing material with an extruder that moves in three-dimensional space. A compelling variant of this approach is embedded 3D printing, where the extruder adds material within a bath or matrix of liquid silicone. Subsequently, the silicone is cured, and the added material retains its shape within the silicone rubber. Through this method, we can create intricate milifluidic structures that can function as electrical and pneumatic circuits. In this presentation, we discuss the implementation of this 3D printing technique, covering everything from the design of the extruder to the development of tools for path design and planning, as well as how to apply this technique to construct piezoresistive sensors and pneumatic actuators.

Follow the dotted lines

Pierre-Thomas Brun[1]
[1]Ku Leuven, Belgium

We will discuss how interfacial flows can be used to form regular and organized assemblies in microfluidic settings. We will primarily focus on the pattern-forming ability of the Rayleigh-Plateau instability and the shaping ability of drainage flows. In both cases, we will investigate the propensity of these processes to either accumulate memory or, conversely, forget and yield universal solutions.

Electrokinetics with bubbles and drops: wetting films, confined bubbles and impacting drops

Anne-Laure Biance[1]
[1]Université Lyon, France

Water and salt transports through nanoporous membranes are encountered in many applications, from desalination, filtration or energy harvesting membranes. In this talk, we will investigate the particular nature of ionic and liquid transports at the nanoscale, focusing in particular on interactions with surfaces. To get versatile liquid systems, easy to make and to tune, we use "soft matter".

We first consider a pure water film, condensed at the surface of a hydrophilic substrate, whose thickness can be tuned continuously from one water to a few water layers. Despite this very huge confinement, our results can be accounted for by a simple continuous approach.

We then switch to microfluidics and consider a bubble confined in a cylindrical tube filled with a surfactant solution. When the bubble is trapped, we show that this configuration can be used for filtration or desalination. But when the bubble is free, the electric field induces its motion. Surprising bubble motion reversal and non-linearities have been observed and characterized in details.

Finally, we will show how this charge/flow coupling effects can be encountered in other situations, such as during drop impact on a superhydrophobic substrate.

P1. Microparticle collection in millifluidic systems using low frequency vibrations

Joseph Meredith[1], Ansu Sun[1], and Prashant Agrawal[1]
[1]Northumbria University, UK

Efficient manipulation and collection of particles in microfluidic systems is crucial for applications in biomedical assays and manufacturing processes. A key challenge in developing micro-nano particle manipulation strategies is balancing process throughput (or scalability with smaller particle sizes) with precision.

In this work, we have developed millimetre-scale close channel systems to collect microparticles using low frequency liquid oscillations. Particle movement in these devices is driven by spatial gradients in the flow field and an inertial migration to regions of low velocity magnitude. The design strategy used in our work allows us to decouple the frequency of oscillation with spatial gradients to control the stability and speed of particle collection. We further support our experimental observations with numerical simulations.

Our findings demonstrate the capability to collect particles within the micro-devices. This work advances the understanding of particle behaviour in microfluidic systems and opens new avenues for efficient particle manipulation.

P2. Bubbling up in a Lab-on-a-Chip: A gravity-driven approach to the formation of polyelectrolyte multilayer capsules and foams

Stéphane Pivard[1], Guillaume Cotte-Carluer[1], Luca Fiorucci[1], François Schosseler[1], Wiebke Drenckhan[1], and **Aurélie Hourlier-Fargette**[1]
[1]CNRS Institut Charles Sadron, Strasbourg, France

The generation of multi-functional capsules often requires the sequential deposition of different components on the surface of bubbles or drops. To tackle this challenge and avoid the drawbacks of batch-based methods, we developed an approach that takes advantage of gravity in millifluidic channels, allowing bubbles to rise between horizontally stacked chips containing each a controlled flow of a specific fluid [1]. Exploiting gravity in this original Lab-on-a-Chip device permits the sequential deposition of oppositely charged polyelectrolytes layers, resulting in multilayer capsules. We show how the flow resistance of each chip can be adapted such that bubbles move smoothly between them while avoiding undesired mixing of the solutions. We present first examples of obtained multilayer capsules of PSS/PAH, this choice being inspired by an in-depth interfacial rheology study showing that it transitions from liquid-like viscoelastic to solid-like viscoelastic behavior after the deposition of a sufficient number of layers [2].

We also control the bubble/capsule size independently from the inter-bubble distance in the chip, exploiting the adjustable position of a small gas-dispensing tip within the cross-flow generated by the foaming solution in the millifluidic channel. We provide a detailed exploration of the bubbling parameters together with physical justification of the observations.

While our methods use polyelectrolyte assembly on bubbles, they can be readily transferred to other types of solutions or even to drops and particles.

[1] Pivard et al. Colloids and Surfaces A 700 (2024): 134608.
[2] Pivard et al. Soft Matter 20.6 (2024): 1347-1360.

P3. Flow and entanglement of dense suspensions of soft fibers

<u>Catalin Vlad</u>[1], Manon L'Estimé[1], Caroline Frot[1], and Camille Duprat[1]
[1]LadhyX, École Polytechnique, France

Suspensions of soft fibres are involved in a large range of processes, such as the manufacturing of paper or biomedical scaffolds. In particular, dense suspensions of microfibres can entangle to form viscoelastic gels, for example when extruded. The structure of these suspensions, especially the entanglements and deformation of the fibres, directly impacts the resulting elasticity of the fibrous network. Understanding the parameters that play a role in the creation of these fibre entanglements and the resulting mechanical strength of the network is essential. Here, we produce uniform suspensions of soft hydrogel fibres with a control over the characteristics of the fibres and the density of the suspension, using the JAWS method. In order to probe the presence of entanglements, we develop few experiments. In a first experiment a dilute suspension is placed in a container with an opening of controlled size. As we open the hole, the suspension drains under the action of gravity and may flow out of the container. Depending on the pressure gradient and the fibre characteristics, the suspension either flows as a dilute suspension or concentrates to form a gel-like elastic network. Entanglements can either accelerate the extrusion as the fibres are pulled together as an elastic network or hinder the flow through the constriction (jamming). In a second experiment, as the suspension settles in the container, we pull one fibre from it, measure the force needed to extract it from the stack and observe the pulling dynamics.

P4. Diffusioosmotic flow drives fluid-structure interaction and instability in microfluidic configurations

Nataly Maroundik[1], Dotan Ilssar[2], Evgeniy Boyko[1]
[1]Technion - Israel Institute of Technology, Israel, [2]ETH Zurich, Switzerland

Fluid-structure interactions involving electrokinetic phenomena are increasingly relevant in microfluidics, biomedical systems, and soft robotics. One notable electrokinetic phenomenon is diffusioosmotic flow—the spontaneous movement of fluid along a stationary surface driven by a solute concentration gradient. In electrolyte solutions, diffusioosmotic flow arises from two effects: chemiosmosis, driven by osmotic pressure gradients within the electric double layer, and electroosmosis, which can be induced by a spontaneously generated electric field due to unequal ion diffusivities.

In this theoretical study, we analyze the fluid-structure interaction between diffusioosmotic flow and a deformable microfluidic channel. We provide insight into the system's physical behavior by developing a simplified 1D model, in which a viscous film is confined between a rigid lower surface and an elastic upper substrate, modeled as a rigid plate connected to a linear spring. Diffusioosmotic flow, driven by solute concentration differences at the edges, generates fluidic pressure acting on the plate, leading to fluid-structure interaction. We show that above a critical concentration gradient threshold, negative pressures induced by diffusioosmotic flow cause the elastic channel wall to collapse onto the lower surface. We employ theoretical analysis to elucidate the underlying physical mechanisms for the onset of fluid-structure instability and identify three dynamic modes: (i) a stable steady state, (ii) a bottleneck, and (iii) an immediate collapse. We validate our theoretical results with finite-element simulations and find excellent agreement. The understanding of this instability is important for the design of electrokinetic systems containing soft elements.

P5. Flow homogenisation in adaptive microfluidic networks

Julien Bouvard[1], Swarnavo Basu[2], Charlott Leu[3], Onurcan Bektas[2], Joachim Rädler[3], Karen Alim[2], and Gabriel Amselem[1]
[1]LadHyX, Institut Polytechnique De Paris, France, [2]Technische Universität München, Germany, [3]Ludwig-Maximilians-Universität München, Germany

From the vasculature of animals to the porous media making up batteries, the core task of flow networks is to transport solutes and perfuse all cells or media equally with resources. Yet, living flow networks have a key advantage over porous media: they are adaptive and self-organise their geometry for homogeneous perfusion throughout the network. Here, we show that artificial flow networks with an initial random geometry and inhomogeneous perfusion profile can be re-organised towards more homogeneous perfusion by flowing through them a reactive chemical that erodes the network walls. Flowing a pulse of cleaving enzyme through a network patterned into an erodible hydrogel, with initial channels disparate in width, we observe a homogenisation in channel resistances. Experimental observations are matched with numerical simulations of the diffusion-advection-sorption dynamics of an eroding enzyme within a network. Analysing transport dynamics theoretically, we show that homogenisation only occurs if the pulse of the eroding enzyme lasts longer than the time it takes any channel to equilibrate to the pulse concentration. The equilibration time scale derived analytically is in agreement with simulations. Last, we show both numerically and experimentally that erosion leads to the homogenisation of complex networks containing loops. Erosion being an omnipresent reaction, our results pave the way for a very versatile self-organised increase in the performance of porous media.

P6. Dynamic Properties of the Oil-Water Interface in the Presence of Suspended Sucrose Particles

<u>Zohreh Honarvar</u>[1], Beth Green[2], Thomas Curwen[2], Brent Murray[1], Anwesha Sarkar[1], and Gleb Yakubov[1]
[1]School of Food Science and Nutrition, University of Leeds, UK [2]Mondelez UK R&D Limited, UK

Understanding the oral processing of fat-based products, such as chocolate, requires deeper insights into the product-saliva interface. The complexity of this interface arises from several factors, including the presence of surface-active compounds and particulates. One key component, sucrose crystals, stands out because it changes its state from a solid suspended in the oil phase to a dissolved form as it transitions to the aqueous phase. This process imparts a dynamic character to the product-saliva interface, where mass transfer driven by solubilisation and interfacial phenomena become coupled and intertwined.

We have developed a simple microfluidic setup to monitor the structural behaviour of the oil-water interface in the presence of sucrose crystals suspended in the oil phase. Our findings suggest the formation of a complex interfacial layer with structural characteristics governed by the interplay between interfacial tension, fluid viscosity, and the rate of sucrose solubility. Using fluorescent labelling allows for the analysis of the structural morphology of this interfacial layer through image analysis tools. The results provide new insights into the complex behaviour of sucrose-laden fat-based suspensions and emulsions when in contact with aqueous media, such as saliva.

These findings highlight the significance of controlling the dynamics of the interfacial transition zone, which facilitates a deeper understanding of the underlying mechanisms involved in the oral processing of fat-based foods.

P7. A Scalable Capillary-Driven Artificial Tree Design for Passive Dewatering

Linfeng Piao[1], and Jongho Lee[1]
[1]The University of British Columbia, Canada

Inspired by capillary-driven water transport in plants, biomimetic devices for passive fluid transport and dewatering have attracted significant attention over the past decade. We present a scalable capillary-driven artificial tree model, a 3D platform with triple-layered structures, demonstrating its potential for stable and efficient dewatering.

The dewatering performance is evaluated through evaporation tests under a range of simulated weather conditions, where temperature (T), relative humidity (RH), and ambient airflow (U) are independently controlled within the ranges of 20–40 °C, 40–92%, and 0.05–0.90 m/s, respectively. Our results show that the dewatering rate increases with rising T and U, but decreases with increasing RH, with the measured data showing good agreement with predictions from the convective mass transfer model.

We also find that both artificial tree models, with stem heights of 3.5 mm and 105 mm, exhibit consistent dewatering performance in the absence of bubble formation (cavitation), enabling stable operation for over 48 hours. However, the taller tree model shows a higher likelihood of cavitation within the stem structures when processing saline feed solutions (0.1 M NaCl) under conditions of T=30°C, RH=50%, and U=0.9 m/s.

These findings suggest that the artificial tree model holds promise for achieving sustainable, large-scale dewatering applications when combined with anti-cavitation designs, such as hygroscopic materials and hydrogel-based stems or leaves. Alternatively, this model may serve as a viable platform for studying cavitation, bubble dynamics, and their impact on fluid transport, offering new insights into hydraulic dysfunction caused by embolism in vascular plants.

P8. Effect of geometry and operating conditions on the dynamics and focussing behaviour of rigid particles in inertial microfluidics

Fatemehsadat Mirghaderi[1], Rabia Mercimek[2], Ezgi Kestek[2], İsmail Bütün[2], Morteza Ghorbani[2], Ali Kosar[2], and **Timm Krueger**[1]
[1]University of Edinburgh, UK, [2]Sabanci University, Türkiye

Inertial particle microfluidics (IPMF) has gained considerable attention over the past few decades. IPMF is commonly used for particle and cell manipulation, applied to cell focusing and isolation of blood cells for disease diagnostics. As a passive technique, IPMF functionality strongly relies on intrinsic hydrodynamic forces, which are influenced by device geometry, flow conditions, and particle properties. Various analytical, numerical, and experimental studies have been conducted to enhance the understanding of fluid-solid interactions in IPMF. However, it is still challenging to predict the particle behaviour in IPMF devices, hence device design is still largely based on trial and error. In this work, we investigate, via simulations using an in-house immersed-boundary-lattice-Boltzmann code, the effect of geometry and operating conditions on particle dynamics in straight channels with rectangular cross-sections. Our findings are in good agreement with published data. They further identify bifurcation points in the equilibrium positions within rectangular channels. The results demonstrate that the number, location, and stability of equilibrium positions are highly sensitive to the channel aspect ratio, particle size, and Reynolds number. Moreover, force analysis suggests a connection between local lift force distributions and global particle behaviour, offering a potential pathway for faster prediction of equilibrium positions and their stability. Our work enables more predictable design decisions of inertial microfluidic devices for particle focussing and separation.

P9. Control over pattern formation in lifted Hele-Shaw cells with a single hole

David Roughton-Reay[1], Prashant Agrawal[1], and Vincent Barrioz
[1]Northumbria University, UK

Lifted Hele-Shaw cells consist of a liquid sandwiched between two parallel plates at a fixed separation distance. One plate is lifted from the other forming a pressure differential which drives air to displace the liquid. Saffman-Taylor instability develops at the liquid-air interface, which evolves into branching fingers as the liquid recedes [1]. Control over the branching pattern can be achieved by introducing asymmetry in one plate, for example, the addition of holes. By tailoring the path of air in Hele-Shaw cells, the patterns formed can be controlled.

This work investigates methods of control over pattern formation in single hole lifted Hele-Shaw cells. Addition of a central air hole introduces a second liquid-air interface which initiates air fingers from the central hole outwards. The two air fingers displace the liquid creating a ring pattern sat between the liquid spread radius and the central hole. Height, width, inner and outer radii of the ring are characterised for different hole sizes, separation distances, lift speeds and spread radii.

Understanding the conditions under which these patterns form, builds a formation catalogue, providing a strategy for precise control over pattern formation in lifted Hele-Shaw cells using asymmetry. These strategies hold significant potential for biomimicry of multiscale structures, providing the fundamental requirements for more efficient transport networks.

[1] P. Saffman and F. Sir G. Taylor, “The penetration of a fluid into a porous medium or Hele-Shaw cell containing a more viscous liquid,” p. 20, 1958.

P11/V1: Using sub-sonic vibrating flow fields for micro particle collection and sorting (poster and video)

Ansu Sun[1]
[1]Northumbria University, UK

Particle enrichment and sorting are critical in industries such as healthcare, food, and energy, where precise control over particle size is essential for product efficacy and safety. Current technologies, like filtration and centrifugation, often lack precision, while microscale methods, though highly accurate, are expensive and limited in throughput. Achieving a balance between efficiency, scalability, and precision in particle enrichment processes remains a significant challenge, particularly for soft and hard microparticles used in diverse industrial and biomedical applications.

In this work, we introduce a new mechanism utilising fluid flow gradients induced by low-frequency oscillations to collect microparticles. We introduce different strategies through which control the spatial and temporal flow field gradients in a liquid to drive particles to regions of low velocity field magnitudes. This control of flow field gradients also allows the control of second order flow fields, that aids in stabilising the motion of particles towards the collection region. We further support our experimental observations using finite element numerical simulations.

This low-energy, scalable approach has transformative potential for advancing particle enrichment technologies across multiple industries while opening new avenues in bio-medical diagnostics and therapeutic development.

P12/V2. Non-Reciprocal Transport in Contracting Vessels (poster and video)

Justine Parmentier[1], Aaron Will[2], Eleni Katifori[2], Martin Brandenbourger[1]
[1]Institut de Recherche sur les Phénomènes Hors Équilibre, Marseille, France, [2]Department of Physics and Astronomy, University of Pennsylvania, Philadelphia, USA

When external excitations are applied to non-symmetrical crystalline structures, unidirectional or non-reciprocal transport can be observed in electrons, photons or phonons. This phenomenon enables robust, scalable transport of particles and information. However, due to the microscopic nature of these systems, finely controlling the amplitude of unidirectional transport remains challenging. We extend this concept to fluid transport in vessels and demonstrate how the coupling between external excitations and nonlinearities governs fluid transport.

Inspired by the lymphatic system, we study fluid transport in a vessel containing a series of valves acting as nonlinearities, allowing preferential flow through a specific direction. Externally-induced mechanical contractions between the valves generate directional peristaltic-like waves, propagating either forward or backward relative to valve orientation. We characterize the valve contraction mechanisms and the unidirectional fluid transport resulting from the contraction waves. By enabling variable valve opening times, the waves modulate the amplitude of the flow rate leaving the vessel.

Our findings reveal that, regardless of wave direction, valves consistently induce forward-flow transport, thus acting as continuous rectifiers robust against any pressure gradient or contraction mode. Additionally, the direct coupling between contractions and nonlinearities enables unexpected regimes in which backward-oriented waves maximize forward flow, even sustaining negative pressure gradients. These results are supported by theoretical computations of the flow in a vessel subject to nonlinear resistances and peristaltic waves. These insights into valve dynamics and fluid transport mechanisms advance our understanding of non-reciprocal mechanical transport and offer new ways to tune non-reciprocal transport by coupling nonlinearities with external excitations.

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