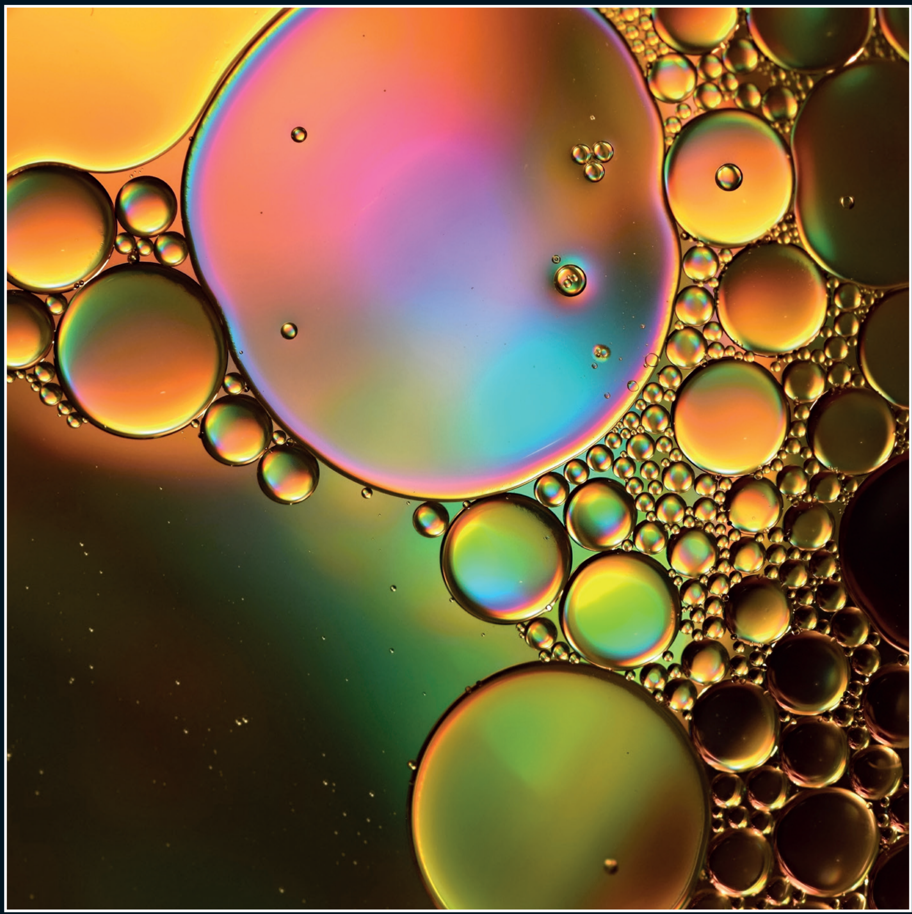
Abstract Book



Physics in Food Manufacturing Conference

10–11 January 2018
The James Clerk Maxwell Building (JCMB)
The University of Edinburgh
Edinburgh, UK

http://pifm2018.iopconfs.org

IOP Institute of Physics

Physics in Food Manufacturing Conference

Welcome

Welcome to the first Physics in Food Manufacturing Group Conference. We hope you enjoy the programme over the next two days and take the chance to meet new people and reconnect with old friends. The conference showcases the wide variety of physics relevant to food manufacturing and addresses the themes where academia-industry collaborations are likely to make the most impact. Please take the time to explore the exhibition and poster session on Tuesday morning. There is also the opportunity to see some of the facilities available at the University of Edinburgh.

Best Wishes,

Anne Pawsey, Tiffany Wood and Wilson Poon.

Programme

Wednesday 11 January

09:30 **Registration**

10:30 **Welcome and Introduction**

Session: Sensing, Imaging and Monitoring

11:00 **(Invited) The physics of optical sorting in the food industry**

Tim Kelf, Buhler Group, UK

11:40 **Managing the food chain: sensors, reassurance and block chain technology**

Malcolm Povey, University of Leeds, UK

11:55 **Advances in low powered ultrasound characterisation of food**

Zachary Glover, University of Southern Denmark, Denmark, University of Leeds, UK

12:10 **Hyper- and Multi-Spectral Imaging in Food Manufacturing**

Andrew Strong, Cambridge Consultants Ltd., UK

12:30 **Lunch**

Session: Facilities and Manufacturing

13:30 **(Invited) The physics of chocolate**

Beccy Smith, Modelez, USA (UK branch)

14:10 **In-situ single mode dielectric measurements of microwaveable snack pellets**

Erik Esveld, Wageningen Food and Biobased Research, Netherlands

14:25 **Depth-resolved monitoring of fluidic flows at m/s velocities and micrometre resolution using Optical Coherence Tomography via a single optical fibre access port** Jonathan Mark Hallam, Cranfield University, UK

14:40 **Neutron imaging in agriculture and food science**

Genoveva Burca, Science and Technology Facilities Council, Rutherford Appleton Laboratory, UK

15:00 **Coffee Break**

Session: Ingredients and Processing

15:30 **(Invited) Ingredient functionalities and how they are defined by, or define process steps in food production**

Tim Foster, University of Nottingham, UK

16:10 **The structure and physical properties of edible organogels based on phytosterols**

Andrew Matheson, University of Edinburgh, UK

16:25 **Mycoprotein fractions from the Quorn fermentation co-product as novel foaming, emulsifying and gelling agents**

Julien Lonchamp, Queen Margaret University, UK

16:40 **The Application of Additive Manufacture in Food Manufacturing**

Richard Claridge, PA Consulting, UK

17:00 **Close**

19:00 **Conference Dinner**

Thursday 12 January

08:30 **Registration**

Session: Structure and Function

09:30 **(Invited talk) A physicists dream or nightmare? A brief overview of the microstructure of ice-cream, and how it is influenced by processing and storage**

Bill Frith, Unilever, UK

10:10 **Interfacial behaviour of plant based proteins**

Amélie Banc, University of Montpelier, France

10:25 **Soft meets hard - a microscopic view of the freeze-thaw stability of Pickering emulsions**

Katy Dickinson, University of Edinburgh, UK

10:40 **Model Gluten Gels**

Laurence Ramos, French National Centre for Scientific Research, University of Montpelier, France

11:30 **Coffee Break, Posters and University of Edinburgh Facilities Tour(s)**

13:00 **Lunch**

Session: Theory and Simulation

14:00 (Invited talk) **Improving flowability of dense suspensions**

Mike Cates, University of Cambridge, UK

14:40 **Simulating the manufacturing of porous foods at multiple scales**

Ruud van der Sman, Wageningenen Food and Biobased Research, Netherlands

14:55 **Initiation, growth and morphological change of fibres, ribbons and tubules**

Doug Cleaver, Sheffield Hallam University, UK

15:10 **The physics of extraction from beds**

John Melrose, Jacobs Douwe Egberts, UK

15:30 **Closing Remarks**

15:45 **Refreshments and Close**

Physics in Food Manufacturing Conference

Poster Programme

P:1	**General principles of efficient counter-current heat exchangers** R Farr, Jacobs Douwe Egberts, UK
P:2	**Optical emission spectroscopy of an atmospheric pressure plasma jet and resulting anti-microbial properties** L Free, Dublin City University, Ireland
P:3	**PROSPECT CL - Liquid scale up facility for process development and metrological studies** K Roettger, Centre for Process Innovation, UK
P:4	**Stabilizing and interfacial properties of the WPI and WPI-MD19 conjugates mixtures in oil-in-water emulsion system** R Ding, University of Leeds, UK
P:5	**Nanobubbles on mineral surfaces** C Owens, University of Exeter, UK
P:6	**Process analytics in food manufacture** J Dimakou, PA Consulting, UK
P:7	**Intense pulsed electric fields generated by a prolate spheroid reflector in water** P Senior, Loughborough University, UK
P:8	**Non-invasive PEF technology for industrial pre-packed food processing** P Senir, Loughborough University, UK
P:9	**Modelling of water transport and swelling during rice cooking: assessing the Free Volume and Flory-Huggins theories** Lopez-Quiroga, University of Birmingham, UK
P:10	**Cocoa butter crystallisation as affected by pressure pulses** M L Parada, University of Leeds, UK
P:11	**Cocoa butter crystallisation as affected by pressure pulses** M Povey, University of Leeds, UK

Session - Sensing, Imaging and Monitoring

(Invited) The physics of optical sorting in the food industry

T Kelf

Buhler Group, UK

For 70 years sorting machines have been working quietly to clean and protect our food. All bulk food, be it wheat, nuts, fruit etc., will have passed through at least one optical sorter before it reaches our homes, and this ensures that we don't find stones in our rice or snails in our peas.

A typical system, the size of a washing machine, is able to image over 50 million grains per hour whilst ensuring that grains with spots of size 0.5mm or larger are effectively removed. To achieve such performance requires the input from a many of fields of research: The flow of the product needs to be well understood and optimised to pass cleanly over the view. The lighting and detection needs to be optimised for subtle colours. Real time computation is required to process the gigabytes of data continuously generated by the cameras and to assess the colours and shapes of the grains; finally tiny air ejector need to precisely open and close at milli-second timescales to remove any objects assessed to be undesirable.

This talk will cover these core aspects of the sorting machine and describe of the physics involved in achieving the impressive performances we see today.

Managing the food chain: sensors, reassurance and block chain technology

M Povey

University of Leeds, UK

Together with our colleagues at Jiangsu University, Zhenjiang, China we are planning the deployment of multiple sensors integrated into a mass-produced platform integrating measurement, data analytics, artificial intelligence and capable of monitoring all stages in food distribution from the factory gate to the consumer. Multiple non-invasive modalities; optical, microwave, ultrasound with in-package biosensors capable of monitoring product freshness and interrogate-ability by the consumer's mobile phone will be integrated with capability from factory based sensors, in-package and in-container sensors throughout the packaged food supply chain. Data security is ensured by Block Chain technology in which data is distributed over a number of independent nodes.

All elements of the platform are at least TRL (Technology Readiness Level) 5 and many elements are commercially available.

The mass production of high quality and economic food is a great achievement of industrial society which has made possible significant increases in life expectancy and quality of life globally. However, by no means all the world's population has benefitted from this achievement, whilst climate change and population dietary change are existential threats to the benefits so far achieved by the industrial production of food.

By food quality, we do not mean haute cuisine or highly expensive meals. We mean an economic and ready supply of food enabling a healthy, long and productive life for consumers, with a good variety enhancing the enjoyment of life – neither eating to live or living to eat but a balance in which the consumer is empowered to make informed choice. By quality ingredients we mean that the consumer is entitled to receive ingredients described, e.g., rice means rice largely uncontaminated by herbicide; British beef means specific cattle breeds, born and raised in the UK.

Currently food supply chains are highly susceptible to (a) criminal contamination, (b) accidental contamination and (c) manufacturer obfuscation threatening public health and confidence in food product. These threats are exacerbated by the globalization of supply chains. Another serious issue is the deliberate addition of cheap food ingredients which are public health threats, the most prominent of which is the addition of sugar to numerous food products where it might not be expected such as ready meals and processed fruit and vegetables. Independent monitoring of food supply chains is necessary to reassure the consumer and to provide quality food economically.

A combination of 100% on-line monitoring at the factory gate and wholesale recipient with automated supervision in the distribution system (Container and consumer monitoring intermittently reporting using mobile technologies together with in-package monitoring using colour change dyes and RFC technology) can, together with consumer education, transform our health choices and help eliminate societal diseases such as diabetes. The Technology will also help eliminate food waste, in China currently 30% of processed pork is spoilt in the supply chain and the use of artificial intelligence will allow the optimization of the supply chain, reducing energy usage and waste. Agriculture and food processing are together the biggest contributors to greenhouse gas emissions and optimization of the supply chain is essential if these contributions are to be reduced.

Advances in low powered ultrasound characterisation of food

Z Glover[1], M Francis[2], M Holmes[2] and M Povey[2]

[1]University of Southern Denmark, Denmark, [2]University of Leeds, UK

Low powered ultrasound has been demonstrated to be an important tool for the characterisation of foodstuffs. An advantage of low powered ultrasound is that it is a non-destructive testing method that can measure highly concentrated systems in-situ without dilution. Ultrasonic characterisation systems can also be readily introduced into existing systems and offer increased penetration depth for in-line industrial monitoring. The speed of sound and acoustic attenuation through a material are dependent on physical properties, such as density, compressibility and bulk viscosity. Therefore, acoustic based techniques can provide more information on dynamic changes in materials than comparable optical methods.

The novel methods presented here are the Crystal Stik and the Acoustic Diffractometer. The Crystal Stik uses broad band Ultrasound Reflection Spectroscopy (URS) and the Acoustic Diffractometer is a method for determining the angular dependency of acoustic scattering. Higher temporal resolution is achieved with these new techniques as they do not require averaging as with previous ultrasonic measurements. Temperature control is important for all ultrasonic methods due to the temperature dependency of the speed of sound. These new techniques offer much better temperature offset than previous methods due to high precision temperature measurement inherent in the technique. As spatial resolution is frequency dependent the high frequency Crystal Stik offers a system with increased resolution. Combining these advantages, these techniques have demonstrated an unprecedented degree of precision and accuracy. This presentation will demonstrate how these recent advances in the field of the ultrasonic characterisation have been applied to dairy products.

Hyper- and multi-spectral imaging in food manufacturing

A Strong and S Jordan

Cambridge Consultants Ltd, UK

Hyperspectral imaging – the ability to record digital images which capture spectral information at each pixel – has long been favoured in the defence world but is being adopted rapidly in the food industry in applications such as on-line inspection of high-value fruit & vegetable crops and products such as seafood. The Agri-Tech industry is also adopting the technology for remote sensing, where its ability to discriminate fruit from leaves, to detect disease, or to enable estimation of size of brassicas (cabbage, broccoli, cauliflower etc.) allows the farmer to understand how different crops are performing and what action to take in any trouble areas. In food manufacturing, detection of anomalies and/or contamination can enable rejection of product early in the process, saving money by avoiding the processing of defective material.

There are numerous approaches to hyperspectral imaging, each having its own merits. Multispectral imaging offers a lower cost alternative which samples the spectra at key wavelengths (rather than capturing a pseudo-continuous spectrum). For specific applications this can be faster and more cost-effective than hyperspectral imaging. This presentation will examine the various techniques available and will discuss ways of selecting the most appropriate approach.

Session – Facilities and Manufacturing

(Invited) The Physics of Chocolate

B Smith

Modelez, UK

The manufacture of chocolate confectionery is a multi-step process and offers a wealth of opportunities for modelling & simulation. In order to create a delicious bar of chocolate, we will need to have fermented, roasted, evaporated, mixed, ground, cooled, deposited, vibrated, crystallised, extruded, cut and more. However models and simulations can only be built when we have understood some of the underlying physics including rheology, structural mechanics, and polymorphism. There is a huge opportunity for physicists to shine in the field of food manufacture!

In-situ single mode dielectric measurements of microwaveable snack pellets

E Esveld[1], J Bows[2], M Vollebregt[1] and R van der Sman[1]

[1]Wageningen Food & Biobased Research, Netherlands, [2]PepsiCo R&D, UK

To capture the fast dynamics of microwave expansion of starch based snack pellets, a single mode shorted waveguide set-up was used. It is equipped with a six-port impedance analyser which measures the complex reflection and absorbed power during heating. The pellet is suspended in the E-field maximum, with a centre inserted optic temperature sensor. Also a video of the moment/progression of snack expansion is recorded. Warm air is passed along the sample to prevent steam condensation.

The dielectric properties of the pellet during heating are obtained via an inverse mapping of the recorded reflection on the expected reflection of the shorted wave guide for the whole possible range of dielectric properties. These were pre-computed by finite elements simulation both for unexpanded and expanded pellet geometry.

The dielectric properties of the starch pellets change significantly during heating, expansion and subsequent drying. The dielectric properties increase with increasing temperature up to a maximum when the pellet expands. During expansion the power absorption shows a sudden decline. This is mainly due to the sudden change in porosity and can be reasonably predicted with the refraction mixing rule. The change of dielectric properties with temperature and different moisture content fit within the dipolar dispersion theory. Addition of salt (2.5%) to the starch pellet composition results in a slight decrease of the dielectric constant and loss factor, as it apparently lowers the effective mobility of the dipoles.

Depth-resolved monitoring of fluidic flows at m/s velocities and micrometre resolution using Optical Coherence Tomography via a single optical fibre access port

J M Hallam, E Rilas, H Ford, T Charret and R Tatam

Cranfield University, UK

Optical Coherence Tomography (OCT) systems can provide 3-dimensional imaging through reasonably-opaque materials with micrometre resolution, coupled to a single optical axis point using optical fibre cables. Developed for imaging the human eye, OCT has been used for the detection of skin cancers and endoscopically in the human body. Industrial applications are growing in popularity including for the monitoring of bond-curing in aerospace, for production-line non-destructive-testing, and for medical device manufacturing and drug encapsulation monitoring.

We report on the progress of OCT development in the Centre for Engineering Photonics at Cranfield University. Notably, a demonstrated, multiplexed beam system for imaging and tracking high-velocity microfluidic flows up to the meter-per-second range with 10-micrometre resolution, directly relevant to nozzle design characterisation for spraying and continuous monitoring of such systems. This system is also applicable to high-speed quality assurance for fast-moving production lines. We also report on a passive OCT sensor head for pipe inspection, capable of imaging both damage, cracking and biofilm growth.

Neutron imaging in agriculture and food science

G Burca

Science and Technology Facilities Council, Rutherford Appleton Laboratory, UK

Neutrons form a highly penetrating radiation passing through matter without damaging or structurally modifying it, a property that makes them the ideal tool for many kinds of complementary material investigations. Neutron imaging is one of the experimental techniques in which captured or scattered neutrons provide important information about the inner structure and indirectly about the composition of a sample considering the fact that different materials attenuate neutrons to a greater or lesser extent. The strong interaction of neutrons with hydrogen and their ability to distinguish between hydrogen and deuterium with no radiation damage make neutrons a good probe for imaging biological specimens.

This talk aims to present possible applications of neutron imaging in agriculture and food manufacturing and preliminary results acquired from the first neutron imaging measurements on different biological samples I have done at the Rutherford Appleton Laboratory during the scientific commissioning of the IMAT beamline [1-3] (e.g. non-invasive imaging of heavy water distribution in organs, plants or soils).

[1] http://www.isis.stfc.ac.uk/instruments/imat/imat8259.html

[2] G. Burca, W. Kockelmann, J.A. James, M.E. Fitzpatrick, Modelling of an imaging beamline at the ISIS pulsed neutron source, Journal of Instrumentation, 8 (2013), no 10, http://dx.doi.org/10.1088/1748-0221/8/10/P10001

[3] W. Kockelmann, G. Burca, J. Kelleher, S. Kabra, et al., Status of the Neutron Imaging and Diffraction Instrument IMAT, Physics Procedia, 69 (2015), 71-78, doi:10.1016/j.phpro.2015.07.010

Session – Ingredients and Processing

(Invited) Ingredient functionalities and how they are defined by, or define process steps in food production

T Foster and S F Holland

University of Nottingham, UK

Food ingredients are traditionally refined into white powders of high functional specification. There is, however, a desire to use less-refined materials. Given these materials are from natural origin, there is variation in material properties at the molecular level, but when we consider less-refined samples, their natural variation will be both at the molecular and supramolecular level.

This talk will cover some molecular thinking around the production of fluid gels, and some of the physics/engineering questions still remaining about the control of their mechanical properties.

When considering the less-refined materials, then processes to 'unpack' the natural functional goodies within the supramolecular cell wall matrices can be considered. Additional concepts of functionalising these materials upon further processing will be introduced, such as control of the amorphous/crystalline ratio through ball milling and fibrillation through homogenisation.

Upon further utilising these materials the use of fluid gels and functionalised natural materials will be processed using High Viscosity Jetting and Ink Jet Printing modes of 'Additive Manufacturing', indicating that new mesoscale structures can be built, by careful design of the input ingredients.

Finally, a thought might be given to the next generation of fluid gels, which may come from the use of less-refined staring materials.

[1] Abbaszadeh A, MacNaughtan W and Foster TJ, 2014. The effect of ball milling and rehydration on powdered mixtures of hydrocolloids, Carbohydrate Polymers, 102, 978-985.
[2] Agarwal D, MacNaughtan WJ and Foster TJ, 2018. Interactions between microfibrillar cellulose and carboxymethyl cellulose in an aqueous suspension, under review.
[3] Ellis AL, Norton AB, Mills TB, Norton IT, 2017. Stabilisation of foams by agar gel particles. Food Hydrocoll. 73, 222–228.
[4] Foster TJ, Natural Structuring with cell wall materials, Food Hydrocolloids, 25(8), 1828-1832, 2011.
[5] Frith WJ, Garijo X, Foster TJ, Norton IT, 2002. Microstructural Origins of the Rheology of Fluid Gels. Gums Stabilisers Food Ind. 11, 95–103.
[6] Gabriele A, Spyropoulos F, Norton IT, 2010. A conceptual model for fluid gel lubrication. Soft Matter 6, 4205.
[7] Holland S, Foster T, MacNaughtan W, Tuck C, 2017. Design and characterisation of food grade powders and inks for microstructure control using 3D printing. J. Food Eng. 4–11.
[8] Matharu AS, Houghton JA, Lucas-Torres C and Moren A, 2016. Acid-free microwave-assisted hydrothermal extraction of pectin and porous cellulose from mango peel waste – towards a zero waste mango biorefinery, Green Chemistry, 18, 5280-5287.
[9] Norton IT, Jarvis DA, Foster TJ, 1999. A molecular model for the formation and properties of fluid gels. International Journal of Biological Macromolecules. 26, 255–261.

The structure and physical properties of edible organogels based on phytosterols

A Matheson[1], G Dalkas[2], H Vass[1], A Gromov[1], V Koutsos[1], S Euston[2] and P Clegg[1]

[1]University of Edinburgh, UK, [2]Heriot Watt University, UK

In many foods, crystallized saturated fats provide texture and mechanical strength, but are linked to an increased risk of heart disease. The replacement of saturated fats with alternative materials which offer the same mechanical properties but without the associated health risks is therefore a topic of much research. Phytosterols and phytosterol-esters such as β-sitosterol and γ-oryzanol have been shown to self-assemble into mechanically robust gel networks in common cooking oils, and have also been shown to significantly lower blood cholesterol levels. Therefore phytosterol based organogels represent a very attractive option for the replacement of saturated fats. However, understanding the structure of how these gels and the kinetics of their formation are key to successfully incorporating organogels into food.

To this end, we have investigated phytosterol organogels over a range of length scales. A combination of spectroscopy, atomic force microscopy (AFM) and molecular dynamics simulations give insight into the structure of individual self-assembled fibrils and the driving force behind their formation. Using the same range of experimental techniques we also investigate the interactions between fibrils to form larger, fibrous bundles.

These gels have previously been shown to be sensitive to the presence of water. We show that by replacing water with glycerol, we may disperse droplets through the organogel matrix whilst retaining excellent structural stability.

[1] Matheson et al, Langmuir, 2017, 33, 4537–4542

Mycoprotein fractions from the quorn fermentation co-product as novel foaming, emulsifying and gelling agents

J Lonchamp[1], P Clegg[2] and S Euston[3]

[1]Queen Margaret University, UK, [2]University of Edinburgh, UK, [3]Heriot-Watt University, UK

The food industry is looking for sustainable alternatives to functional proteins of animal origin due to their high costs, market volatility and environmental footprint. In this context the production of fungal proteins by Marlow Foods for use in their meat-replacer product Quorn offers a potential sustainable, environmentally-friendly and cost-effective option.

This study assessed the functional profile (foaming, emulsifying and rheological properties) and composition of an unexploited liquid co-product (centrate) from the Quorn fermentation process. A range of protein fractions were generated from the centrate via successive ultrafiltration steps and their functional and proteomic profiles were characterised in comparison with a commercial whey protein concentrate (WPC).

The high-molecular weight (HMW) fraction obtained displayed outstanding foaming stability, emulsifying and rheological properties. Foams prepared from HMW solutions proved more stable than with WPC. Oil emulsions prepared with the HMW fraction showed a smaller oil droplet size distribution than with WPC and proved more stable, while the HMW fraction displayed interfacial properties at the oil/water interface, forming a rigid film at the interface. HMW solutions and oil emulsions showed high viscosities in comparison with WPC. HMW solutions and hydrogels displayed higher viscoelasticities than the WPC ones.

Large mycelium structures were observed in the HMW extract by confocal microscopy as a result of the ultrafiltration process and could be responsible for its rheological properties. A protein from the surface-active cerato-platanin family was reported in higher proportions in HMW than in the other fractions and could have contributed to its higher functionality. The higher foaming and emulsifying stability of the HMW fraction could result from the release of surface-active moieties, protein aggregates and cell debris and/or from the presence of the dense mycelial network.

This study highlighted the potential of functional fungal proteins from the Quorn fermentation process as novel sustainable ingredients for the food industry.

The application of additive manufacture in food manufacturing

R Claridge

PA Consulting, UK

Additive manufacture is the process of constructing objects by putting down material only where it is required. This includes printing approaches but has been popularised in FMCG applications through 3D printing.

Over the last three years, PA have spent considerable time developing 3D printing for food applications. This is seen as a potential area for new and disruptive products, and presents the simultaneous opportunity for waste reduction, rapid product customisation and product functionalisation.

In this talk we will discuss the opportunities, implementation and scale-up challenges of additive approaches in food.

A key challenge when it comes to developing printing applications in food is that of the materials characteristics of the substance to be printed with. The second key challenge is then one of throughputs; whist one can print foodstuffs, doing this at an industrial rate is a non-trivial material and mechanical engineering challenge.

We discuss a ‘process window’ in which these technologies are viable, and strategies to bring materials into this window. This includes temperature and rheology control, surface energy modification and varying material deposition strategies.

As food has particular temperature sensitivities, this approach means that although many materials can be used with an additive approach, the full range is limited.

We will demonstrate that additive manufacture of food is feasible and has real commercial benefit, and that the best near term uses are in concert with existing with current approaches, rather than as a replacement for them.

Session – Structure and Function

(Invited) A physicist’s dream or nightmare? A brief overview of the microstructure of ice-cream, and how it is influenced by processing and storage

W J Frith

Unilever R&D, UK

Ice cream is an immensely complex material that presents unique challenges in terms of manufacturing and distribution. It comprises many phases in varying degrees of disequilibrium, the main ones being ice, air, oil/fat and aqueous solution(s). The texture, flavour and quality of the ice-cream is critically dependent on the microstructure of these phases, most of which will evolve over time during manufacture and storage. In particular, the ice and air phases will ripen and disproportionate, leading to poor texture, and ultimately separation/collapse of the product. The process of microstructural evolution can be slowed by addition of stabilisers that structure the unfrozen phase, but a crucial role is also played by network formation of the fat and protein in solution. Networks are also crucial in the determination of the texture of the product, with the ice-crystal network being most prominent, providing the initial firmness, whilst the fat droplet network contributes to aspects such as a creamy mouth-feel.

In this talk I will give a brief overview of the microstructure of ice-cream and the various aspects that affect stability. I will then focus on the properties of the network forming components, in particular how fat and protein networks can form, and the roles they play.

Interfacial behavior of plant based proteins

A Banc, A Poirier, A Stocco, M In and L Ramos

[1]University of Montpellier, France

With the demography growth, there is a huge pressure on protein demand, and the development of plant based proteins is required for a future sustainable food production. Plant proteins are efficient to stabilize interfaces in foams or emulsions, and the understanding of physical mechanisms at the origin of their interfacial behavior is important to develop new products. We investigate the adsorption of wheat grains (gliadin) and sunflower seeds (helianthinin) proteins, at air-water and oil-water interfaces, respectively. A combination of tensiometry, dilatational viscoelasticity and ellipsometry measurements is used to determine the adsorption mechanisms, and characterize the structure and properties of the interfacial protein films formed with different bulk protein concentrations. We demonstrate that a diffusion-controlled adsorption occurs at low bulk protein concentration for helianthinin whereas this mechanism occurs whatever the bulk concentration for gliadins. Surface pressure-induced film relaxation through conformation changes of proteins at the air-water interface is identified for gliadin whereas surface aggregation is observed at high helianthinin concentration. Overall, our experimental results highlight that structural flexibility of proteins appears as a key factor for their interfacial activity.

Soft meets hard - a microscopic view of the freeze-thaw stability of pickering emulsions

K L Dickinson and J Thijssen

University of Edinburgh, UK

Particle-stabilised or Pickering emulsions are widely used in the food and personal care industries and are present in common household products such as homogenised milk and food spreads [1]. In addition, Pickering stabilisation has been suggested as a method of increasing product shelf life over surfactant stabilisation [2]. It is therefore important to characterise the behaviour and stability of these composites under the influence of processes used both in industry and in daily life, such as freezing and thawing. These processes have the potential to alter the taste of food products or the effectiveness of personal care or pharmaceutical products [3].

Using confocal microscopy, we investigate the microscopic changes in structure of water-in-oil Pickering emulsions undergoing freeze-thaw cycles. We explore the effects of uniform and non-uniform freezing on both the behaviour of the emulsions during the freeze-thaw cycle and on the post-thaw structure. In particular, we observe biliquid foam patches form during non-uniform freezing which are absent from uniformly frozen samples. We also consider the consequences of varying droplet size and freeze rate for uniform freeze-thaw cycles. Our results suggest that particles at the interface become unjammed during the freeze-thaw cycle and later re-jam at a different packing fraction. Apart from elucidating the stability of particle-stabilised emulsions under industrially relevant processes, our results also help us to understand how hard materials (the ice crystals that form upon freezing) interact with soft materials at the microscopic level.

[1] T.N. Hunter, R.J. Pugh, G.V. Franks and G.J. Jameson, Adv. Colloid Interface Sci, 137, 57 (2008).
[2] L. Alison, P Rühs, E. Tervoort et al. Langmuir, 32, 50, (2016).
[3] S. Ghosh and D. Rousseau, Journal of Colloid and Interface Science, 339, 91 (2009).

Model gluten gels

L Ramos, A Banc, M Dahesh, C Charbonneau, J Pincemaille, P Menut, and M H Morel

[1]University of Montpellier, France

The origin of the unique rheological properties of wheat gluten, the water-insoluble protein fraction of wheat grain, is crucial in bread-making processes and questions scientists since the 18th century. Gluten is a mixture of two types of proteins, monomeric gliadins and polymeric glutenins, formed by subunits linked via disulfide bonds. To better understand the respective role of gliadins (Gli) and glutenins (Glu) in the supramolecular structure of gluten and its link to rheology, we have developed a model gluten system using a food-grade solvent, which allows quantitative comparisons with theoretical models for synthetic polymers [1].

Thanks to an experimental protocol based on a liquid-liquid phase separation, we can extract, from industrial gluten, gluten protein fractions with contrasted mass ratios Glu/Gli (from 0.04 to 2). Stable gluten protein suspensions in a water/ethanol mixture solvent over a wide range of concentrations can be produced. Using scattering techniques, we demonstrate that blends of Gli and Glu exhibit features characteristic of branched flexible polymer chains in a good solvent, and form in a dilute regime large Glu-rich protein assemblies [2]. In the semi-dilute regime, we evidence the existence of large zones (of typical size 60 nm) rich in hydrogen bonds [3]. We show that hydrogen bonds are responsible for the spontaneous sample gelation, whose concentration dependence can be quantitatively accounted using percolation theories developed for polymer gels [4].

Overall, our experimental results illustrate the relevance of model gluten gels to unravel the unique and complex behavior of gluten.

[1] Banc, Dahesh, Wolf, Morel, Ramos. Journal of Cereal Science 75, 175 (2017).
[2] Dahesh, Banc, Duri, Morel, Ramos. J Phys Chem B 118, 11065 (2014).
[3] Banc, Charbonneau, Dahesh, Appavou, Fu, Morel, Ramos. Soft Matter 12, 5340 (2016).
[4] Dahesh, Banc, Duri, Morel, Ramos. Food Hydrocolloids, 52, 1 (2016).

Session 5 – Theory and Simulation

(Invited) Improving flowability of dense suspensions

M Cates

University of Cambridge, UK

The flow of very dense suspensions shows problematic features such as discontinous shear-thickening which can clog processing equipment. Such features are increasingly understood in terms of a stress-dependent contact friction between particles. This understanding explains the success of a common strategy for increasing flowability of suspensions at high solid content, which is to add ingredients (often listed misleadingly as 'emulsifiers') whose role is to reduce the friction by absorption onto the solid particles. It also suggests a second strategy that avoids such additives. This is to modify the process flow with a vibrational component that stops frictional contacts from building up.

Numerical simulations show this to be effective only if the vibration is transverse to the main flow rather than along it.

Simulating the manufacturing of porous foods at multiple scales

R van der Sman

Wageningen Food and Biobased Research, Netherlands

Many foods are liked because of their crispy and porous structure, like expanded snacks and bakery products. These solid foams are created via intensive heating of a starchy dough with a limited amount of water. At sufficiently high temperature the water will start to boil, and steam bubbles are formed – which will expand during continued heating. At a certain moment the expanding bubbles will open, due to fillers added to the dough [1], and steam can escape. During further heating, there is so much moisture lost that the starchy dough is brought to the glassy state. The porous structure is now fixated – rendering the product its crispy and porous texture.

We have developed multiscale simulation models describing these kinds of food structuring processes [2,3]. One of the objective of these models is to investigate the effect of dough reformulation on the structure formation.
The model describes phenomena at two scales: at the bubble scale we solve the momentum equation describing the bubble expansion, while at the product scale we solve for the heat and mass transfer to the environment. For the bubble scale we use the Amon-Denson cell model. At the product scale we solve the volume-averaged Fourier and Fick equations for the heat and mass transfer, assuming the food to be a porous medium.

Results will be presented for starchy snacks expanding in frying oil, and biscuits baking in hot air ovens. For the former we have particularly investigated the effect of salt reduction on solid foam formation [3]. For the latter case, we have extended the product scale model with model for viscoelastic, large deformation mechanics to describe the spreading of the dough. Eventually, we strive for a multiscale model for biscuit baking, investigating the effect of sucrose replacement by other carbohydrates.

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Initiation, growth and morphological change of fibres, ribbons and tubules

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Highly anisotropic, self assembled structures are utilised in a wealth of food and personal care systems. However, the means by which these form and develop is far from straightforward. Here, we use molecular dynamics simulation of a series of simple coarse-grained mesogenic systems to examine the self-assembly of such supramolecular structures. The simulated systems, which are bipartite mixtures of disc-shaped and spherical particles, combine the thread-like aggregation of chromonics with the frustrations and incommensurabilities of amphiphilicity.

A veritable zoo of structures, many of which possess emergent supramolecular chirality, are reproducibly obtained. These including fibres, double helices, twisted bilayer ribbons, multi-strand ropes and tubules. By assessing the sensitivity of these final structures to the underpinning particle-scale interactions, insight is gained into how emergent length-scales can develop in grown structures. Further, from time-lines of the associated hierarchical self-assembly processes, the importance of mesogenic intermediates and size-dependent morphological changes in the development of complex aggregates is evidenced.

This is indicative of more generic behaviour in anisotropic, self-assembling systems. As such aggregates grow, the balance between their controlling effects crosses over from being dominated by particle-scale behaviours (e.g. packing) to continuum issues (e.g. elastic stresses).

The physics of extraction from beds

J Melrose

Jacobs Douwe Egberts, UK

The release of molecules thru beds of particles under flow is a common problem. The talk will review recent work on modelling this problem - the main application being coffee brewing. It will be shown how best to approximate a double lognormal distribution of particles by a few representative particles for use as source terms in finite volume elements. Measurements and modelling on the dynamic flow permeability of beds, will be used to couple the release model with models of pumps to simulate coffee brewing systems. Open problems on particle packing and flow permeability of beds will be introduced.

Poster Session

General principles of efficient counter-current heat exchangers

R Farr

Jacobs Douwe Egberts, UK

Heat exchange is an important unit operation, and for foods may involve viscous liquids, so that minimising the pressure drop is a useful design criterion. Here, we present a general analysis of counter-current exchange devices linking their efficiency to the geometry of the exchange surface and supply network. For certain parameter ranges, we show that the optimal exchanger consists of densely packed pipes which can span a thin sheet of large area (an ‘active layer’), which may be crumpled into a fractal surface and supplied with a fractal network of pipes. We derive the efficiencies of such exchangers, showing the potential for significant gains compared to regular exchangers (where the active layer is flat), using parameters relevant for biological systems.

Optical emission spectroscopy of an atmospheric pressure plasma jet and resulting anti-microbial properties

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Atmospheric Pressure Plasma Jets (APPJs) have a growing role in the agricultural and food industries. Through the creation of reactive Nitrogen species (RNS) and reactive Oxygen species (ROS, collectively RONS). APPJs are increasingly being investigated as an alternative method for the inactivation of micro-organisms, decontamination, enhanced germination and plant growth. Optical emission spectroscopy preformed on the plasma jet revealed the generation of atomic and molecular Oxygen and atomic and molecular Nitrogen species, the precursors for RONS, in addition to hydroxyl radicals (OH). The generation of these species were found to be related to the operating parameters of the plasma jet, e.g. voltage, frequency, duty cycle and electrode position. Black pepper grains inoculated with *Bacillus subtilis* were treated with the plasma jet under various operating conditions. Using the plate count method, the number of colony-forming units (CFU) were measured at one hour, 24 hours and 48 hours after treatment. It was found that longer treatment times and higher voltages resulted in a greater log reduction in CFUs. A temporal behaviour was also observed, as log reductions increased after treatment with 48 hours having the largest log reduction. Possible explanations are surface modification of the pepper grain reducing the ability for cells to attach to the surface, or cell damage eventually leading to cell death.

PROSPECT CL - Liquid scale up facility for process development and metrological studies

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[1]University of Edinburgh, UK, [2]University of Leeds, UK, [3]University of Nottingham, UK, [4]University of Birmingham, UK, [1]Centre for Process Innovation, UK

The abstract describes a pilot scale research facility for liquid scale up established by the Centre for Process Innovation (CPI) as part of the National Formulation Centre (NFC) in a joint project with the universities of Birmingham, Edinburgh and Leeds. The state-of-the-art facilities will enable us to develop, prove, prototype and scale up the next generation of products and processes. This will enable us to accelerate and de-risk the translation of laboratory innovations into new and improved processes for commercial companies of all sizes. We will present the first results on scaling up a high internal phase emulsion (HIPE) stabilised with the emulsifier Polyglyercerol Polyricinoleate (PGPR) which has demonstrated benefits across the food sector, including the ability to reduce the amount of cocoa butter in chocolate, leading to more cost effective, lower-fat products.

Scaling up this model system will make use of the two major functions of the new facility:

1. Understanding the universal principles of manufacturing formulations at different scales and enabling the predictive scale-up of batch formulation processes.
2. Developing, validating and utilizing new Process Analytics Technologies (PAT) and process analytics capabilities.

The instrumentation that will produce the data for understanding and predicting processes include focused-beam reflectance measurement (FBRM), an in-line microscope, laser diffraction particle sizing, an in-line rheometer and various sensors for monitoring temperature, pH, conductivity and density. The hardware control and data fusion will be provided by a fully Industry 4.0 enabled software package. This will allow the implementation of advanced process control models for real time prediction of process parameters and the detection of process abnormalities. The University of Leeds will develop the data fusion and process control models. The University of Edinburgh will develop specially designed liquid systems, including the HIPE system we present here, to mimic a range of industrial formulations. The University of Birmingham will utilise their knowledge of formulation processes to scale up these model systems and enable the team to understand the fundamental principles.

Stabilizing and interfacial properties of the WPI and WPI-MD19 conjugates mixtures in oil-in-water emulsion system

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Proteins are surface active polymers due to the amphiphilic structure. They can be used as emulsifiers in food colloids preparation. However, natural food proteins are less soluble in water and quite sensitive to environmental conditions such as pH and ionic strength. In order to improve the physicochemical properties of natural proteins, they can be covalently bonded with reducing polysaccharides via the Maillard reaction (Akhtar and Ding, 2017). First of all, the attachment of hydrophilic sugar moieties can significantly enhance the solubility of proteins. Secondly, the polysaccharide side chains adsorbed on the oil-water interface can provide strong steric effects to prevent the instability of colloidal systems such as flocculation and coalescence (Ding et al., 2017). The primary and secondary structures of native proteins and conjugates are of considerable difference due to the modifications. These structural changes can have a great influence on the interfacial properties of proteins such as kinetic adsorptions and surface denaturation. This project is going to investigate the stabilizing properties of native protein and conjugates mixtures in O/W emulsions and competitive adsorption between the two polymers i.e. protein and protein-polysaccharide conjugates by comparing the alteration of surface tension and theoretical calculations (SCF) (Ettelaie et al., 2008). Both experimental and theoretical results suggest that WPI-MD19 conjugate system can tolerate the existence of native protein till 40 w/w %, and protein-polysaccharide conjugates can compete with unreacted proteins during adsorption and will not be easily displaced by native proteins in the period of observations. This investigation offered another evidence of stabilising properties of protein-polysaccharide conjugates from the viewpoint of interfacial behaviours.

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Nanobubbles on mineral surfaces

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Since nanobubbles were first imaged in 2000 (for a recent review, see Alheshibri *et al*), they have been found to be important in a number of technologies and industries, ranging from mineral processing to cancer research (Seddon *and* Lohse 2011). Nanobubbles can vary from a radius of 50nm to 500nm, and form in liquids, "bulk nanobubbles", and at liquid-solid boundaries, "surface nanobubbles". Surface nanobubbles have been found to exist for up to several days in aqueous solution (Weijs *and* Lohse 2013; Liu *et al.,* 2017), and are widely accepted as explaining the long range attractive force between two hydrophobic surfaces in water. More generally, bubbles are important in a wide range of food processing from the foam in beer, the air bubbles in Danish pastries to the crystallisation and taste of ice cream (Sauret *et al.,* 2015; Campbell 2016; Deligny *et al.,* 2017). Nanobubbles have also been shown to increase the growth rate of animals and plants (Ebina *et al*., 2013).

In this poster, we present a preliminary experimental study of nanobubbles formed on the surface of different minerals, where the bubbles were characterised using atomic force microscopy. We are now developing a simple finite element model so that the observed variation in the size of the nanobubbles can be related to the surface properties of the mineral, with the ultimate aim of being able to control nanobubble formation.

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Process analytics in food manufacture

J Dimakou

PA Consulting, UK

Process analytics implementation can make your production and quality control more efficient in this fast paced digital age. This is a talk about how cutting edge technology helps more and more manufacturing processes to reinvent and save costs through real-time in-line analysis by enhancing consistency, capital savings, footprint, minimizing rejects and product recalls, late-stage customisation, turning batch systems into continuous or even inventing novel processes and machines that currently don't exist. Novel technologies include new chemical sensors, new raman and infra-red spectrometers and improved software for fruit maturity, harvest time optimisation, sugar analysis and 2D/3D imaging.

Intense pulsed electric fields generated by a prolate spheroid reflector in water

P Senior and B Novac

Loughborough University, UK

The efficient treatment of skin cancer, bioelectricity effects and food processing have all been proven in practice using subnanosecond application of intense pulsed electric fields (PEF). However, the technique uses invasive i.e., electrode based technology, and therefore it is not applicable to all applications.

The present work represents a first step towards the development of a non-invasive technique, in which a microwave prolate spheroidal reflector submerged in water generates remotely intense subnanosecond PEF inside a cubic centimetre region. The reflector is powered by a 10 GW pulsed power Tesla-Blumlein pulse forming line generator coupled to a bipolar former capable of producing a 300 ps rise time, 650 kV peak to peak voltage impulse. Technical details will be provided and the predictions from a 3D CST software study will be compared with experimental results.

Non-invasive PEF technology for industrial pre-packed food processing

P Senior and B Novac

Loughborough University, UK

At present, invasive pulsed electric field (PEF) technology is applied on an industrial scale for processing 'pumpable' food e.g., fruit juice. The interaction of the metallic electrodes used for processing with the liquid food is the source of many unwanted phenomena such as an increase in temperature due to the thermal energy deposited by large conductive currents, hydrolysis effects injecting metal particles into the fluid or juice bits clogging the narrow inter-electrode area.

The paper will present results obtained during a preliminary proof-of-concept research programme aimed at advancing a non-invasive PEF technology for use in the industrial pre-packed food processing. The novel technique is capable not only to avoid all the inconveniences of the invasive processing, but may open the way for the treatment of solid pre-packed food, a worldwide premiere.

Modelling of water transport and swelling during rice cooking: assessing the free volume and flory-huggins theories

M Lopez-Quiroga

University of Birmingham, UK

Foods are multicomponent, complex materials usually structured through thermal processes. The interactions between water, oil/fat, proteins and carbohydrates - e.g. water sorption, cross-linking of bio-polymer networks or glass transitions - taking place during processing/cooking lead to changes in the structure and function of foods that could be better understood applying fundamental soft matter physics.

In this framework, this work presents an evaluation of two different approaches (i) the Free-Volume and (ii) the Flory-Huggins theory to describe water transport and volume change in rice grains during cooking. *Ab initio* estimations of the mutual effective diffusivity coefficient have been obtained from the self-diffusivities of water and bio-polymer (starch). The mass transport problem has been formulated and solved considering both water fraction and chemical potential as driving force. To account for grain expansion (i.e. swelling) a moving swelling front dependent, which advance depends on the absorbed water, has been included in the problem formulation.

The studied model formulations have been implemented and solved using the finite differences method in a one-dimensional axi-symmetric geometry using spherical coordinates. In addition, the Landau transform has been applied to solve the moving boundary cases.

Models outputs have been compared to experimental results to assess the validity of the reviewed theories. The findings of this work could be used to support modelling-based design of industrial cooking processes for products such as cereal grains and pulses.

Cocoa butter crystallisation as affected by pressure pulses

M L Parada

University of Leeds, UK

Most work regarding the effect of pressure on fats has been related to the application of over 150 MPa. These studies have concluded that pressure-treated fats crystallise preferentially into the β polymorph, whi is highly desirable in the production of chocolate. However, it is of interest to determine if lower pressures can be used, as they would represent lower safety hazards. Therefore, this research investigated if the application of lower pressures are sufficient to induce a preferential crystallisation in the βV polymorph.

Rheology-structure relations for bakery fats

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University of Guelph, Canada

The rheology of fat crystal networks under linear shear deformations has been extensively studied. However, there has been limited focus on their viscoelastic response under large shear deformations imposed during processing and product use. We probed the nonlinear viscoelastic behavior of bakery fats (roll-in and multi-purpose) displaying mechanics akin to ductile and brittle solids using large amplitude oscillatory shear (LAOS). Using the FT-Chebyshev stress decomposition method, and local measures of nonlinear viscoelasticity, we obtained rheological properties relevant to bulk behavior. We found that ductile fats dissipate more viscous energy than brittle fats and show increased plastic deformation. Structural characterization by ultra-small angle x-ray scattering and electron microscopy revealed the presence of three hierarchy levels and layered microstructures in ductile fats in contrast to only two hierarchies and random microstructures in brittle fats. We suggest that these structural features account for increased viscous dissipation, which contributes to ductile-like macroscopic behavior and material functionality.

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