UNIVERSITY OF CAMBRIDGE

# CEB Focus

Department of Chemical Engineering and Biotechnology

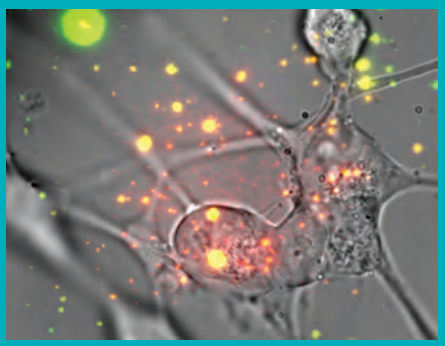
Easter 2011 Issue 3

*Professor Malcolm Mackley retires after 30 years in the Department* *p.3*

## In this issue



*A new CUCES Committee* *p.6*



*Microscopy techniques for Alzheimer's and Parkinson's research* *p.14*

*Remembering the past* *p.17*

# Welcome

## *Message from HoD Professor Nigel Slater*

Welcome again to *CEB Focus*. Spring is here and appropriately this issue is about continuity and rebirth. We focus first on the innovative research work of Professor Malcolm Mackley and we wish him all the very best for a happy, long and well earned retirement in the West Country. We also showcase the research of some of the younger members of the Department and I hope that we have properly conveyed their considerable enthusiasm, energy and talent. Continuity is certainly there as evidenced by the passion for outstanding teaching and research that characterises CEB and rebirth through the talent that is evident in our young researchers. Last week I received a 'Congratulations' email from one of my PhD students who is now working in Singapore and in it I learnt that CEB has been ranked second only to MIT in the 2011 QS World University Chemical Engineering Rankings. A very fitting tribute indeed to Malcolm and all CEB academic staff past and current. But it is one that must also strengthen our resolve to be second to none. CEB is currently reviewing the opportunities that lie open to it and how best we might realise them and I hope to share these thoughts with you in a future issue. What is crystal clear at the outset though, is that tomorrow's academics are well equipped to meet the challenge that lies ahead of them.

**Editorial**

It is important to us to have a newsletter that reflects the identity of the newly-merged Department. We have representatives from Chemical Engineering, Biotechnology and the Magnetic Resonance Research Centre (MRRC) generating ideas, providing input, and liaising with academics, research groups and students in order to make this possible.

Since the last issue, the membership of the editorial team has changed. Amy Chesterton and Fernando Abegao have left the team to concentrate on their studies, whilst Marijke Fagan and Nick Ramskill, both PhD students working at the MRRC, have joined. We thank Amy and Fernando for all their help in establishing the newsletter. And we want to thank everyone who has contributed to this issue of *CEB Focus*. Thank you to the writers for their articles and in particular thank you to Vanessa Blake and Barrie Goddard for their photographs.

*CEB Focus* is an opportunity for you to support and enhance the Chemical Engineering and Biotechnology community at Cambridge. Contributions from Department members, alumni and corporate partners are always welcome. If you have any comments or suggestions for articles to be included in the next issue, please get in touch with the Editorial Team on ceb-focus@ceb.cam.ac.uk.

We look forward to hearing from you in the future!

For those wishing to receive a regular copy of *CEB Focus* electronically please subscribe by sending a message to ceb-news-request@lists.cam.ac.uk with 'Subscribe' as the subject of the message.

*Editorial Team: From left to right Marijke Fagan, Elena Gonzalez and Rashmi Tripathi; back row: Nick Ramskill and Alastair Clarke*

## A Tribute to Professor Malcolm Mackley FREng – Inventor, Scientist and Engineer

*Dr Bart Hallmark*
*Design Lecturer*

Professor Malcolm Mackley needs no introduction to departmental members having taught countless undergraduates and having supervised and mentored many PhD students and postdocs. Malcolm's research interests are incredibly broad, encompassing pure science, pragmatic engineering and innovation; they include, amongst other topics, fluid mechanics, rheology, membranes, microreactors and alternative fuels. His inventions reflect this broad nature, from commercially-available rheological tools to techniques for shape-forming chocolate at room temperature.

Malcolm's career started at the University of Bristol under the guidance of Professors Andrew Keller and Sir Charles Frank; Malcolm's PhD concerned investigating flow induced polymer crystallisation. This research led not only to tantalizing scientific observations related to fibrous crystals (Figure 1) but also to commercially-important discoveries concerning ultra-high-strength polymer fibres.

In 1979, Malcolm joined the Department of Chemical Engineering at Cambridge, having previously held a lectureship in materials science at the University of Sussex. At Cambridge, Malcolm's research flourished and included new interests such as mixing processes, resulting from investigations into wave energy. A key observation concerning the efficiency of wave-energy extraction was a loss of energy due to the formation of vortices. Once understood, Malcolm eliminated vortex formation from his energy capture devices and exploited the phenomenon as a novel mixing technology, shown in Figure 2.

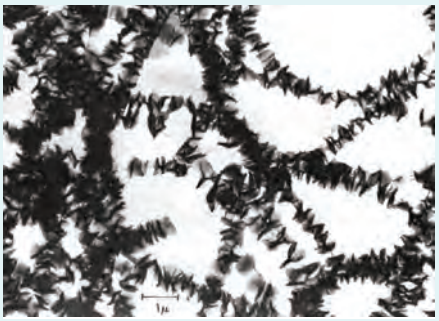


*Figure 1. Transmission electron micrograph of 'shish-kebab' crystal structure of polyethyelene, produced by an elongational flow-field (Mackley and Keller,* ***Pure Appl. Chem.****, 39, 193, 1974)*

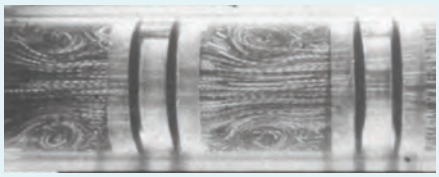


*Figure 2. Photograph of the flow pattern generated by an oscillating flow though a baffled tube. Flow is from right to left. (Brunold, Hunns, Mackley and Thompson,* ***Chem. Eng. Sci.,*** *44(5), 1227, 1989)*

The phenomenon of oscillatory flow mixing led to the development of successive generations of reactor, piloted by ICI and by BP. Today, oscillatory flow mixing can be found in bioreactors and in commercially-available systems from Ni Tech Solutions; a company founded by one of Malcolm's former postdocs.

In recognition of his achievements, Malcolm won the Beilby Medal in 1987; soon afterwards, Malcolm was also the recipient of the Charles Vernon Boys prize. These accolades were also reflected in the Department, with Malcolm's promotion to a readership in 1991.

The 1990s gave rise to two inventions for which Malcolm would be instantly associated; the discovery of the cold extrusion of chocolate and the invention of the Cambridge Multi-Pass Rheometer (MPR). The cold extrusion of chocolate resulted from a previous polymer processing development; surprisingly, the phase-change characteristics of chocolate shared some of the qualitative features that were essential for this new polymer processing technique, albeit at lower temperatures. The first ram extrusion experiments conducted at room temperature proved to be a great success.

Chocolate cold extrusion was able to produce complex prismatic shapes with very well-defined edges, something that was impossible to attain using traditional melt processing. Additionally, chocolate cold extrusion gave rise to a surprising temporary flexibility; this allowed improbable operations with the newly-extruded product, such as being able to tie it in knots! This is illustrated by Malcolm in Figure 3.

*Figure 3. Malcolm demonstrating the flexibility of a filament of newly cold extruded chocolate by tying it in a knot.*

The ability to shape-form chocolate accurately, quickly and inexpensively was of great commercial interest; Nestlé soon adopted the technology and developed it. The first commercial product that used Malcolm's cold extrusion process was Nesquik 'Shake on Shapes', which hit the shelves in 1998.

Aspects of the fundamental physics underlying cold extrusion were explored in another invention, a twin-piston, fully enclosed, capillary rheometer; the MPR. This device eliminated many of the problems associated with traditional capillary rheometers and allowed samples of material to be processed under precisely controlled conditions. The flow could be interrogated either optically, allowing direct observation of stress in optically birefringent materials, or by X-rays, allowing the in-situ quantification of crystallisation phenomena. The exact nature of the boundary conditions within the MPR made for an ideal piece of experimental apparatus with which to validate numerical models, hence testing the accuracy of rheological constitutive equations; an early example is shown in Figure 4.

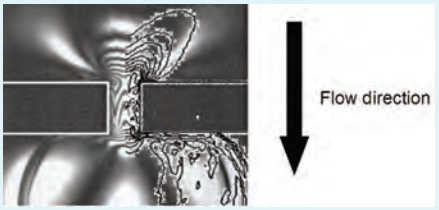



*Figure 4. Early experimental observations and numerical predictions of 'stress fangs' within molten polyethylene; images taken from MPR experiments. (adapted from Lee, Mackley* ***et al., J. Rheol.,*** *45(6), 1261, 2001).*

Malcolm's championing of innovation led to recognition within the University with his promotion to 'Professor of Process Innovation' in 1999 and to his election to Fellow of the Royal Academy of Engineering in 2003. Within the Royal Academy, he was very active as a judge for the MacRobert award, the UK's premier engineering innovation award.

Throughout what can only be described as an illustrious and high-achieving career, Malcolm never lost sight of the important things in life. Family, consisting of Margaret and his two daughters, Emily and Sophie, and friends were top priorities, closely followed by a passionate love of dinghy racing. With the advent of retirement, Malcolm will, no doubt, be busier than ever, either sailing, continuing to champion innovation in engineering or as an author. Malcolm's first work of fiction, 'High Tension', has just been published by Publibook in France.

Malcolm, we wish you all the very best and thank you wholeheartedly for the time, effort and energy that you have put into all aspects of life at the Department. Please keep in touch – you'll be sorely missed. Some of your friends and colleagues overseas have been in contact to say a few words, so I'll leave it to them to conclude this article.

**Professor Jean-François Agassant** (Head of Cemef, Sophia-Antipolis, France)
**Professor Rudy Valette** (Associate Professor, Cemef)
I met Malcolm for the first time seventeen years ago at the 1994 European rheology meeting in Seville, Spain. We decided, with other colleagues from The Netherlands and Germany, amongst other countries, to make a proposal for European funding in the area of rheology. The idea was to use complex flow field measurements, using

techniques such as flow induced birefringence and laser doppler anemometry, together with flow field computations in order to identify nonlinear parameters of viscoelastic constitutive equations.
Malcolm is very efficient when writing collaborative papers: a first draft with an outline, a second draft one week later with the first paragraphs, and so on. After a few weeks the paper is completed and sent to the editor.

Malcolm is a real engineer!

**Dr Rudy Koopmans** (The Dow Chemical Company, Switzerland)
Creativity is probably a word I would associate most with Malcolm. He lived the word in his profession for as long as I knew him, and that is since we met for the first time at the incipient Rolduc Polymer Meeting in The Netherlands in 1985. Ever since, I saw Malcolm explore daring concepts that, in a number of cases, changed materials processing approaches or brought a different perspective on the fundamental understanding of polymer flow.

The degree of freedom given to fail and to work independently without too many constraints, but with guidance to focus on the validation of the final concept, allowed for creativity to foster and for his co-workers and students to give the best they had. On the multiple occasions we worked together, the discussions were a never ending source of imaginative new ideas. Malcolm's preferred location, in the south of France, and his sailing probably provided time to reflect and let the mind explore different perspectives.
Accordingly, next to the professional interaction it was always a pleasure to have a variety of discussion topics that put the order of the day in a different light. Seeing Malcolm about to take leave of Cambridge University is certainly a loss for the academic surroundings. In my opinion, a renaissance man is stepping aside, but hopefully to a place where creativity will continue to be fostered.

**Dr Dean Barker** (Fisher & Paykel Healthcare, New Zealand)
For me, and my family, Malcolm and Margaret were a source of much more than just equations, models, and really excellent lab facilities (thanks Malcolm), they were also a portal to a life lived with generous spirit, with passion for one's values, and recognition of the importance of family, friends, and community.

So how on earth does this profound summary come about at morning tea you may ask? Well, it doesn't. Malcolm was generous in inviting me to go sailing with him on weekends; he said he was 'one short' - I replied, *'I am one, and short,'* and so it happened. Through sailing I learned about the intricacies and importance of pre-race preparation (great starts lead to great finishes), I also experienced great teamwork and the importance of individual responsibility within a team, tempered with tolerance of others, particularly under stress. We shared disappointment, picked through our mistakes, took chances, won some, lost some, enjoyed them all, and shared in the high and low moments with others of similar bent. Then there was the art of a fine after-dinner speech, impromptu of course, that would touch everyone with merriment through a well refined, and cultured wit, reflecting boyish charm, sitting comfortably alongside professorial eloquence.

I could go on, but I won't, in case I embarrass us both, so will finish by saying - Dear Malcolm, to you and Margaret, thank you for your generosity during the time the Barkers were in Cambridge. You both gave us so much, for which we cannot ever repay you, but can only hope to 'pay forward', with an instalment plan. We wish you a most happy retirement, and have the expectation that, even though that was an excellent win on the water that day Malcolm, that you'll have many more opportunities to declare, *'it doesn't come better than that!'*

## CUCES Annual Dinner

*Anna Kvarngren*
*CUCES Events and Careers Officer 2010-11*

*Former CUCES Committee led by Constantinos Pittas*

On the evening of the 11 March, 125 Department staff, members, alumni, guests and friends came together to enjoy the 2011 CUCES Annual Dinner at the University Arms hotel. The evening began with a champagne reception followed by a three-course dinner in one of the beautiful rooms in the old part of the hotel. During the dinner, the guests were treated to speeches from the HoD Professor Nigel Slater, the outgoing CUCES President, Constantinos Pittas and from Department alumnus Dr Neal Morgan, representing the event sponsor, Shell.

For guests choosing to stay around after the dinner, the evening's entertainment was far from over with a DJ playing until midnight and a photographer to snap a photo memory of the evening. Overall the evening was a great success with Part IIB students Ian Tam and Tom Ithell describing it as *'the best night of their lives'.*

The CUCES committee would like to take this opportunity to thank the event sponsor, Shell, since the success of the event would not have been possible without their support. The committee would also like to thank the Department for supporting the event.

## New CUCES Committee takes charge

*Nick Ramskill*
*PhD Student*

The Easter vacation and the Annual Dinner mark the changeover of the committee for the Cambridge University Chemical Engineering Society (CUCES). The new committee is comprised of Akshay Deshmukh (President), Marina Steketee (Secretary), Laurence Tonna (Treasurer), Erica Lee (Events Coordinator), James Perry (Careers Representative), Zsigmond Varga (IT & Publicity ) and Ben Richards (Social Secretary and Frank Morton Representative).

Reflecting on the past year, outgoing president Constantinos Pittas said, *"Our two main goals for the year were to promote interest in Chemical Engineering among our classmates (the raison d'être of the society) and to maintain and empower the spirit of togetherness and inclusiveness that distinguishes our Department."* The introduction of the new position of 'Career Rep' has proven to be a huge success organising more lunch-time/evening career events.

*Akshay Deshmukh CUCES President 2011-12*

Looking to the year ahead, new president Akshay Deshmukh said, *"I feel privileged to be leading an exciting group of engineers as the President of the 2011/12 Committee."*

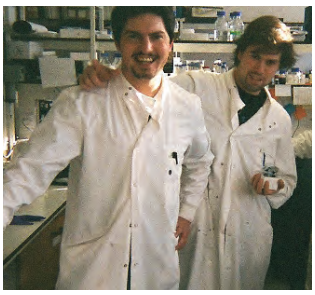
Akshay has also spoken about the committee's plans for the future, *"We will endeavour to replicate the successes of the 2010/2011 Committee from the large Department events to the numerous careers events which form the backbone of the CUCES calendar. We hope to invite more non-traditional companies to deliver careers talks whilst maintaining strong links with the teaching consortium of companies. Socially we intend to inject a range of events into the CUCES calendar in order to improve the social and academic interaction between students."*

For more information on CUCES, please visit the website: www.srcf.ucam.org/cuces

## CEB Students awarded £3500 travel grants

*Leo Martinez-Hurtado and Jamie Walter*
*Biotechnology PhD Students*

Leo and Jamie have been awarded a £3,500 NanoDTC Associate Grant from the Nano Doctoral Training Centre (DTC), Cambridge. Leo is an active member of the Healthcare Biotechnology group developing holographic gas sensor technologies and Jamie is in the Analytical Biotechnology group and develops multifunctional ion-selective delivery vehicles. They have been awarded this grant to promote cross-disciplinary research within the central themes of self-assembling functional nanomaterials and devices. This will entail disseminating their research to larger communities at conferences and tours, establishing and building networks within the field and consulting students on the interface between biology and nanotechnology at the Nano Doctoral Training centre.



*Jamie and Leo*

Along with the award, Jamie has completed study visits to laboratories in Harvard, M.I.T and the Focussed Ultrasound Lab at Harvard Medical School, and both Jamie and Leo have had a paper accepted for the NSTI Nanotech conference and exposition 2011, the world's largest nanotechnology conference. The activities of the NanoDTC associate programme include, among others, lab visits, talks among the students and industry talks. The programme also offers an exceptional networking opportunity. The DTC was established in 2009 to equip the next generation of researchers with the skills and experience to become nanoscience entrepreneurs by turning basic science research into future applications. A directory of the researchers actively involved in the program can be found at http://www.nanodtc.cam.ac.uk/directory/

## The Three Peaks Challenge for KidsCan

*Manny Kemp*
*PhD Student*

This summer, I will be walking up the highest peaks in England, Scotland and Wales, namely Ben Nevis, Scafell Pike and Mount Snowdon. I will be doing this for KidsCan, a small paediatric cancer research charity based in the University of Salford. Their research is directed along two lines: the advancement of treatment for cancers which mainly affect children, such as leukaemia, and the development of treatment methods for cancer of any type which are less damaging to children.

In adults, most non-cancerous cells are not dividing and this provides a basis for discriminating drugs, but in a child, most of the tissues are growing and developing so the ability of conventional cancer drugs to distinguish between tumour and normal tissue is diminished, with increased side-effects.

The hike is organised by a company called Student Adventures in collaboration with Cambridge RAG and is set to take place at the start of May Week, over the weekend of the 18 and 19 June. Together with other students from around the country, I will be starting in Glen Nevis in the mid-afternoon and will finish 24 hours later in North Wales. To date I have raised £1030, and nearly £195 more in Gift Aid, mostly through my web page (www.justgiving.com/kidscan-manny-threepeaks), and have already been sponsored by several members of this Department. I would greatly appreciate any further support from the rest of you.

*Manny collecting for RAG*

## Masters in Bioscience Enterprise Programme

*Editorial Team*

The Masters in Bioscience Enterprise (MBE) programme is aimed towards providing students with hands on experience in starting up biotech companies. Students are trained in all aspects of running a start-up including managing intellectual property and gathering investment. Many life sciences students use this degree as a stepping stone to enter biotech businesses. For example, **Jildou Sterkenburgh,** a current MBE student, did her undergrad degree in Biotechnology from Netherlands. Her main inspiration for taking up the course has been to learn how to commercialize R & D in the biotech industry. She is mainly interested in agrobiotechnology.

MBE students are also encouraged to enter business plan writing competitions in Cambridge. A few of them like **Lindsay Kellar-Parsons** and **Vivian Tan** have managed to secure prizes in the 100 words business idea writing competition in the Michaelmas term.

These students are also given a chance to visit start-up companies and get first hand exposure in learning about the biotech businesses by directly interacting with CEOs. A visit to Boston to understand the biotech entrepreneurial environment across the Atlantic is also on the curriculum.

The general impression one gets is that students find MBE to be useful in acquiring good business skills relevant to the biotech industry. Nice bonding between students outside the classroom adds up to the overall entrepreneurial experience students receive in this much sought after course. MBE student **Mike Freedman** commented *'The MBE course is a rigorous course that provides the breadth and depth to prepare students for the challenging world of bio-entrepreneurship'.*

## Second Year PhD Student Talks

On three afternoons in January and February, the Department's 31 second year PhD students were given the opportunity to showcase their research projects in the form of a poster and a five minute presentation followed by questions. The prizes for each session were awarded to Mariana Garcia Domingos, Meenal Pore and Christine Schmaus, with the runner up prizes going to Alastair Clarke, Wen Liu, Julian Jaros and Kyra Sedransk. *The three winners give brief descriptions of their projects here.*

*Prize winners: Christine Schmaus, Julian Jaros, Meenal Pore, Kyra Sendransk and Mariana Garcia Domingos*

### Turbulent Plumes and Thermals with Internal Buoyancy Change

*Mariana Garcia Domingos*

Whenever a buoyant fluid emerges from a localised source it rises in the form of a plume (for continuous releases) or a thermal (for discrete releases). A deep understanding of the dynamics of these plumes/thermals is essential for the development of appropriate techniques to mitigate the impact of accidents and natural disasters such as the recent BP oil spill in the Gulf of Mexico, the volcanic ash plume in Iceland, or the nuclear gas releases in Japan.

Both external variations in the environmental density and internal buoyancy changes affect the motion of a plume/thermal. If they cause a decrease in the buoyancy flux, the plume/thermal may eventually reach the density of the surrounding fluid, coming to a rest at a finite height where it spreads out radially with zero buoyancy. Internal buoyancy changes in turbulent plumes/thermals can be induced by transitions of phase, dissolution and chemical reaction. The aim of this project is to investigate the effect of internal buoyancy changes in plume/thermal motion. The project uses experimental, analytical and numerical methods, combining chemical engineering knowledge with mathematical techniques.

The BP oil spill plume contained three phases and involved the dissolution of methane and the formation of methane hydrates. Our model suggests that the methane gas was the main component responsible for the mixing of the oil with very large amounts of seawater. This mixing aided dissolution of the oil from the droplets and subsequent dilution in the seawater. External stratification in the Gulf of Mexico was crucial in the formation of intrusions of oil-contaminated water at great depths, as depicted in Figure 1.

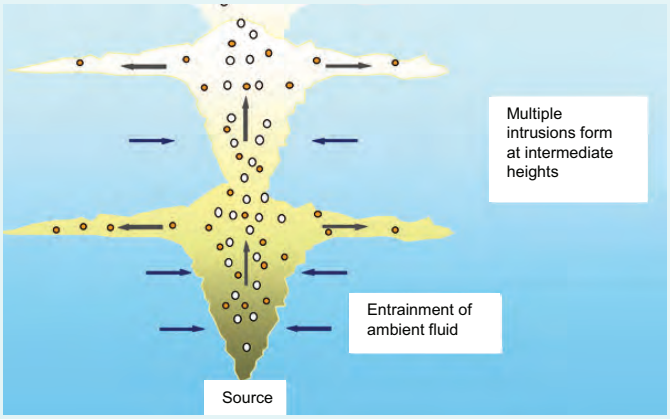



*Figure 1. Spreading of a turbulent plume rising in a density-stratified environment when multiphase and internal processes are important (Cardoso, S. S. S., TCE, 2010, 829/830: 30-33)*

**Investigation of Jet-Jet and Jet-Wall Interactions in Packed Beds Using MRI**

*Meenal Pore*

Despite the widespread use of fluidised beds in industrial processes, various fluidisation phenomena are still poorly understood, making design and scale-up difficult. Fluidised systems are optically opaque so it is difficult to observe the behaviour of particles and gas within the bulk of the bed. Only a few experimental techniques exist to provide non-intrusive measurements in opaque granular systems, one of which is Magnetic Resonance Imaging (MRI). The unique capability of MRI is that it can measure both particle distributions (voidage) and velocities to a high spatial and temporal resolution in single- and two-phase granular systems.

Our research has focused on the formation and evolution of jets of gas injected into a gas-solid fluidised bed, such as those occurring at the holes in a multi-hole distributor plate. Gas jets are of interest as much of the gas-solids contacting occurs in the region directly above the distributor where gas bubbles are still small. Particles entrained into the high velocity jets can have a 'sandblasting' effect on bed internals and walls, causing erosion. It is desirable to have a better understanding of interactions between neighbouring jets and between the jets and the wall, which often dictate such erosive processes.

Magnetic resonance images of poppy seeds were acquired with air jets from multi-orifice distributors at different gas flowrates. These images (Figure 2)

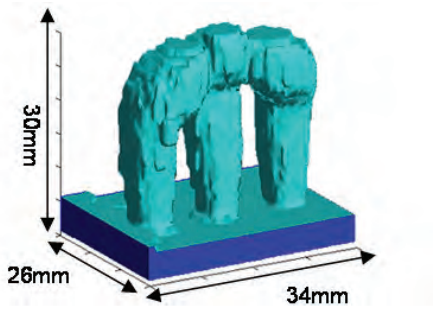



*Figure 2. 3D reconstruction of gas jets formed at a 3 hole co-linear distributor with an in-plane resolution of 0.43 x 0.43 mm and an axial resolution of 1 mm.*

gave information on the geometrical properties of the jets. It was found that jet-jet interactions stabilise jets so jets from multi-orifice distributors are longer than those from a single-orifice distributor. It was also found that jet-wall interactions stabilise a jet when the gas jet is wide enough to touch the bed wall, which leads to a long spout being formed up the bed, causing gas bypassing. Future work will include the study of deadzones (with respect to jet stability) and MRI of the gas phase in fluidised systems.

**Evaluation of CFD Trickle-Bed Reactor Models with Compressed Sensing MRI**

*Christine Schmaus*

Trickle-beds are fixed-bed reactors in which gas and liquid flow downwards co-currently over a catalyst packing. They are widely used in the chemical industry, eg for petrochemical hydrogenations. Traditional reactor models fail to account for local-scale heterogeneities, which have a significant influence on reactor performance. Computational Fluid Dynamics (CFD) is a promising approach for local-scale modelling, but validation and further development are hampered by a lack of equally detailed experimental data. MRI can supply spatially and temporally resolved maps of liquid distribution and velocities, which have contributed much to the understanding of the complex flow patterns in fixed beds. We are now aiming to push the boundaries of sensitivity and temporal and spatial resolution with the help of novel data sampling and image reconstruction techniques.

Our first aim was to measure the gas velocity at the gas-liquid-interface to clarify disputes about the extent of interaction between the phases. As gases yield much lower signal intensity than liquids, the acquisition times are normally too long to achieve good resolutions. Compressed sensing enabled us to reconstruct high quality images from only 20% of the normally required sampling points, reducing the acquisition time by 80%. This enabled us to acquire liquid- and gas-phase velocity maps (Figure 3) with a sufficiently high resolution to clearly identify the gas-liquid interface for the first time. The data shows that the liquid velocity at the interface rises with increasing gas flow rates and the shear stress at the liquid-gas interface is the same order of magnitude as the shear stress at the liquid-solid interface. This confirmed that the shear stress which the gas exerts on the liquid cannot be neglected in phase interaction models. The next challenge will be the monitoring of phenomena on limited time-scales, such as drainage from packed beds and surface waves on liquid films.

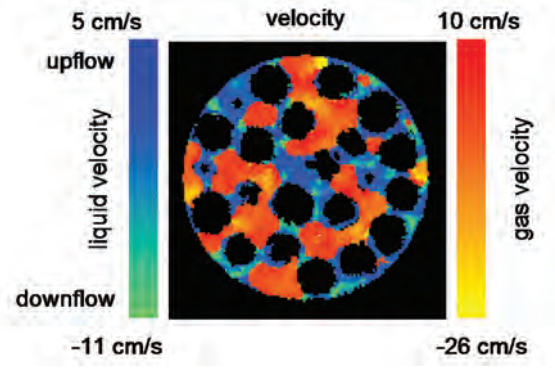



*Figure 3. Velocity map of liquid (water) and gas (SF6) flow through a horizontal slice of a trickle-bed reactor with a resolution of 236 µm*

# Microscopy techniques for the study of disease processes in living cells

*M. Winters, G.S. Kaminski*
*Laser Analytics Group*

Bioimaging, and the emerging field of biophotonics, are essential in enabling contemporary biological and biophysical research. Ever since the demonstration, in Cambridge, of the first practical laser scanning confocal microscope (LSCM) in 1985, the field of fluorescence microscopy has been developing at an explosive rate. The microscopy technique is minimally invasive and it permits the study of biomolecules and their interactions in living cells and organisms. The ability to combine novel optical imaging modalities with the molecular engineering of highly specific fluorescent protein labels has led to a paradigm shift in biological research.

## *'Strong focus on biomedical applications'*

Over the past seven years the Laser Analytics Group has developed a strong focus on biomedical applications of laser-based imaging techniques and variants of optical microscopy such as Fluorescence Lifetime Imaging Microscopy (FLIM) and Förster Resonance Energy Transfer (FRET), which enable us to study molecular mechanisms of disease directly within the cell. A key topic of our research is the development of techniques to study the function and dysfunction of proteins linked to neurodegenerative diseases, such as Alzheimer's and Parkinson's disease. A common feature of these diseases is that certain proteins, for reasons largely unknown, seem to lose their ability to maintain their functional native folding state. Upon misfolding they adopt aberrant shapes and collapse into the form of insoluble deposits, so called amyloids, which are toxic to neurons in the brain. Indeed in the brains of patients suffering from Alzheimer's and Parkinson's such deposits are found in great abundance in the form of long proteinaceous filaments. Unfortunately, the molecular interactions leading to misfolding, aggregation and fibril formation are not yet understood primarily because these processes cannot, with existing techniques, be observed in their physiological environment in living systems.

Whilst standard fluorescence microscopy techniques such as confocal microscopy can provide some information on the localisation and abundance of amyloid deposits in cultured cells, and even in model organisms, their resolution is not good enough to study the aggregation process and ensuing aggregate formations directly. In fact, the lack of 'molecular scale contrast' in biological samples is one of the major problems scientists seek to overcome with the development of novel imaging techniques. Since light consists of electromagnetic waves, it is subject to diffraction and this puts a limit on the ultimate spatial resolution one is able to obtain with light microscopy (of the order of the wavelength of light). This is orders of magnitude larger than the size of, for example, toxic amyloid structures. We are using several novel optical microscopy techniques, so called 'super-resolution' techniques, to overcome these limitations.

## *'FRET enables us to study molecular mechanisms of disease directly in the cell'*

In one technique we exploit our discovery that amyloid structures develop intrinsic energy states that depend on their aggregate size. We can probe these energy states through attachment of fluorescent tags, which interact with the amyloid proteins via a FRET process. We have shown that the strength of FRET occurring between fluorescent label and amyloid protein is a function of aggregate size and can be quantified by measuring the fluorescence lifetime (the average time it takes for

molecules to emit fluorescence upon excitation) of the fluorescent label. As aggregates grow, significant FRET takes place, reducing the measured fluorescence lifetime.

## *'For the first time, we have an optical method to report on the kinetics of protein aggregation in live cells'*

We have correlated the lifetime signatures with aggregate size through *in vitro* experiments and the use of alternative methods that give us structural information, e.g. Electron Microscopy and Nuclear Magnetic Resonance Imaging. The lifetime signatures can thus be calibrated for aggregate size, and for the first time, we have available an optical method to report on the kinetics of protein aggregation in live cells and even organisms (Figure 1). In collaboration with partners in the Department of Chemistry and Medicine we are applying such techniques to monitor the effect of small molecule drugs and their potential to inhibit the aggregation process leading to disease.

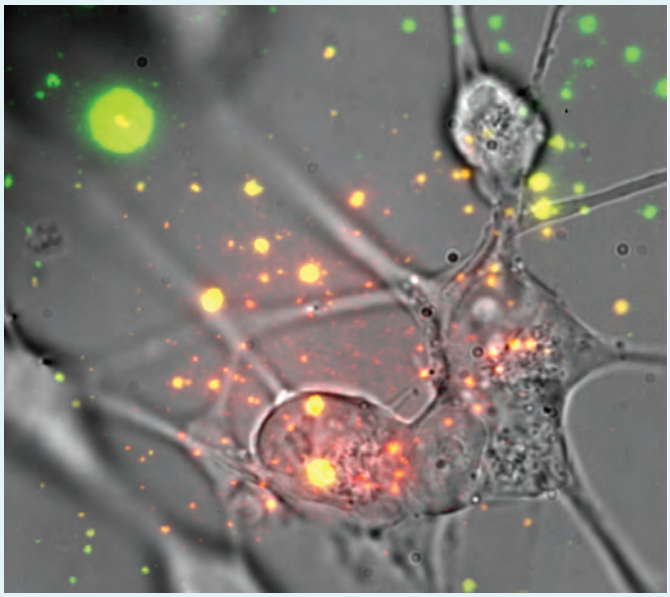


*Figure 1 Image shows the outlines of nerve cells (grey scale image) on which are superimposed marker signals, which show membrane structures in red and the concentration of amyloid beta 40 protein in green. Yellow signals denote regions where signals from the protein and the membrane structures overlap indicating that transport is mediated by cellular vesicles.*

Whilst FRET offers molecular-scale 'super-resolution', it provides information indirectly, i.e. FRET is not capable of informing on the shape and structure of amyloidal aggregates, yet the topology of amyloid structures may be related to toxicity and the propensity for healthy brain cells to become infected. Using a single molecule imaging technique we have set up, in collaboration with partners at the University of Würzburg, Germany, a novel super-resolution technique called dSTORM (direct stochastic optical reconstruction microscopy), which offers true spatial information on a scale of orders of magnitude smaller than the wavelength of light. In traditional light microscopy, diffraction leads to blurring of object information in the image and thus loss of information.

## *'With dSTORM we have been able to resolve structures down to a resolution of 20 nm'*

A point object appears as a blurred spot, described by the so-called point spread function (PSF), when imaged through a microscope and the PSF's minimal width is of the order of a wavelength of light. An object containing many fluorescent molecules will thus lead to an image, which is the sum of all blurred spots, and spatial detail below a wavelength of light is completely lost.

In dSTORM we use lasers to switch fluorescent molecules on and off one by one, so that we image individual PSFs. We then use an algorithm to determine the central position of the PSF, which informs us on the spatial location of the fluorescent molecule to a much greater precision than the wavelength of light (Figure 2).

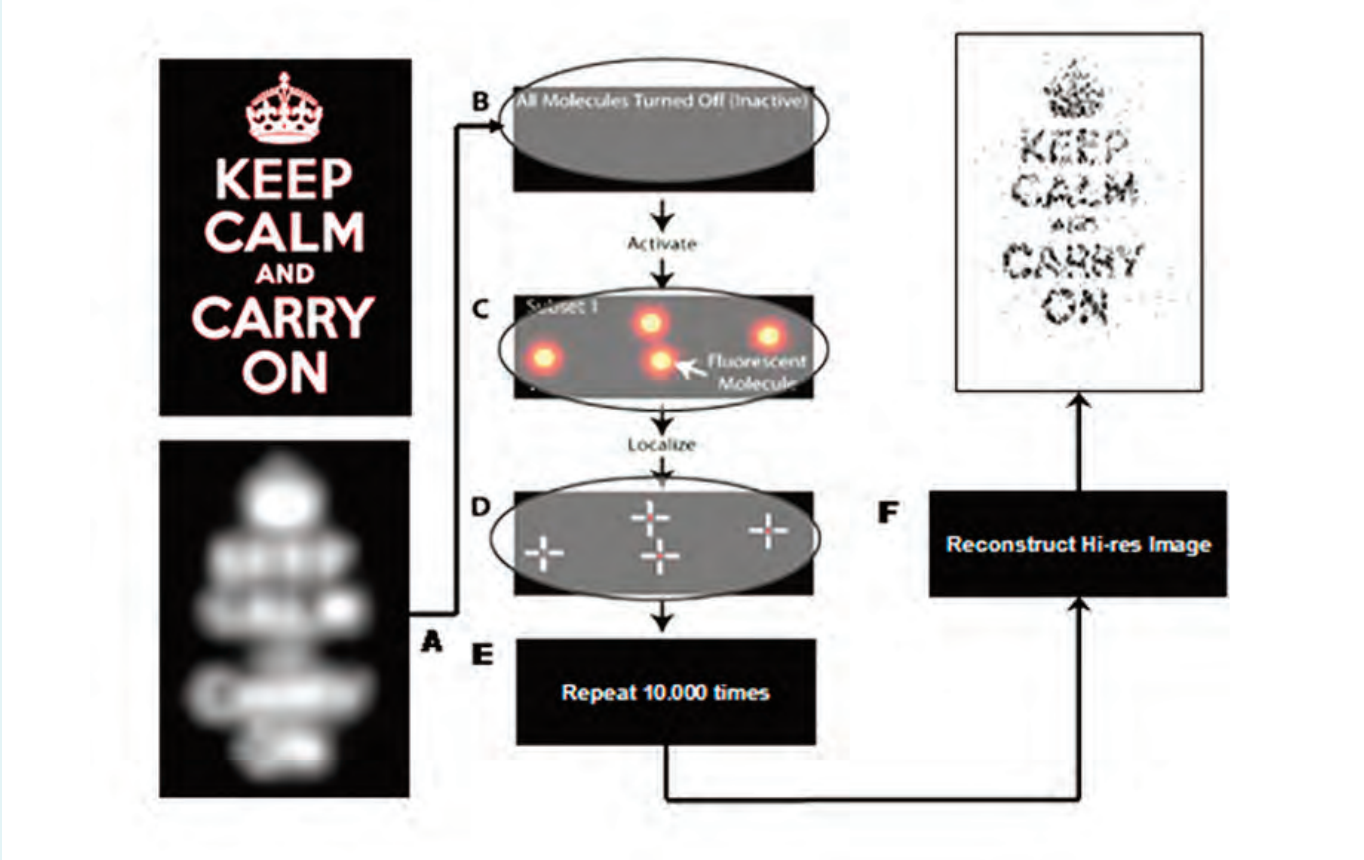



*Figure 2 Illustration of the dSTORM principle. Suppose a popular wartime poster (top left) were printed on a very small scale: only 2 micrometers wide. Although the printing is sharp, the image we see with a light microscope is blurred: because features smaller than the wavelength of light are lost by diffraction limitation (A). In dSTORM, the fluorescent molecules on the object are first chemically quenched (B). A sparse subset is reactivated (C), and the exact position of each molecule is inferred by finding the centroid of its image (D). After repeating steps B-D many times, we can use the exact position of many fluorescent molecules to construct a super-resolution image (F) at a resolution limited only by the number of photons we are able to collect from each fluorophore, in practice about 20 nm.*

In fact, the localisation accuracy is a function of photon number (signal strength) and we have been able to resolve structures down to a resolution of 20 nm with dSTORM. For the first time we are now able to 'see' the structures of aggregates using an all-optical method, at a resolution approaching that of electron microscopy techniques (Figure 3).

More generally, these novel all-optical techniques will open the door for increasingly detailed studies of the structures and pathologies of aggregation-mediated processes, and thus enhance a general understanding of protein misfolding disorders, with evident applications in the search for, and validation of, possible therapeutic agents.

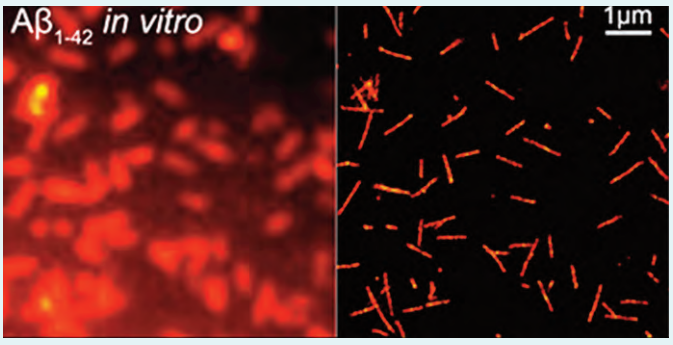



*Figure 3 With dSTORM the nature and morphology of intracellular amyloid beta 42 (Aβ1-42) aggregates can be probed directly at a resolution approaching that of electron microscopy techniques. Left: Normal fluorescence microscopy images of Aß1-42 fibrils formed in vitro on the surface of a microscope glass slide. Right: dSTORM image corresponding to the fluorescence image on the left. Note the vastly improved resolution obtained with dSTORM. Far right: Adjacent fibrils can be resolved well below the diffraction limit.*

## Cambridge Enterprise: Sharing knowledge through consultancy

*Sarah Collins*
*CE Marketing and Events Manager*

When considering commercialising research, often it can be difficult to know where to begin, especially for researchers who are still early in their careers. As well as helping University staff commercialise their ideas, Cambridge Enterprise also provides a managed service to help them apply their knowledge to real-life situations by undertaking consultancy work.

For many University staff, consultancy is often their first connection with industry, and is the quickest and easiest way to build a bridge between the University and the so-called "real world": government, industry and the public sector. University research and expertise is in great demand across many sectors, and consultancy is often the most effective way for this to happen. Consultancy work can take many forms, including providing solutions to specific business problems, the provision of expert reports on technical, economic and commercial issues, expert witness advice, serving on scientific advisory boards and much more.

There are two ways in which University staff may undertake consultancy work: they may undertake a project entirely on their own, or they can work with Cambridge Enterprise, the University's commercialisation group, which manages over 200 consultancy projects per year in subject areas that range from engineering to economics, physics to philosophy and computer sciences to clinical medicine.

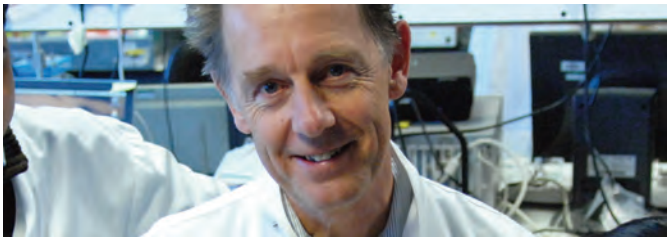
Through its wholly owned subsidiary, Cambridge University Technical Services (CUTS), Cambridge Enterprise facilitates consultancy work for University staff so that they are free to concentrate on the project and the relationship with the client, without distractions or concerns over contractual matters and management of the administrative issues associated with the project.

Cambridge Enterprise can assist staff in the negotiation of contract terms and conditions, provide assistance with costing and pricing, arrange the use of University facilities, invoicing and income distribution. Staff also benefit from the University's insurance cover when undertaking consultancy work through Cambridge Enterprise.
Through consultancy, Cambridge staff perform important work for some of the world's largest companies. During the past year, staff from the Department of Chemical Engineering and Biotechnology have worked with companies such as Mitsubishi, Unilever, Dow Chemical, GlaxoSmithKline and Shire Pharmaceuticals.

The projects can vary widely in type and scope. For example, The Polymer Fluids Group at CEB has used the CE consultancy route on a number of occasions to carry out short exploratory projects using their own specialist equipment and processes. Clients have included Dow Chemicals, BP, Cadbury and various ink jet companies. Dr Mick Mantle completed an in-situ MRI dissolution test of tablet formulations for Shire Pharmaceuticals; and Professor Nigel Slater provided consultancy advice to Biopharma Technology Limited for a TSB funded project on the formulation and processing of cell-containing regenerative medicine products to enable long term storage.

The Consultancy Services team can advise staff on how to share their knowledge and expertise through consultancy work. For more information, contact the team on (0)1223 760339 or cuts@enterprise.cam.ac.uk.

## Professor Chris Lowe awarded OBE



**Professor Christopher Lowe**, serial entrepreneur and Director of CEB's Institute of Biotechnology, was awarded the "Queen's Anniversary Prize for Higher and Further Education" in 2007. He is also one of the six Cambridge academics awarded an OBE in the Queen's New Year Honours List back in January 2011.

Professor Nigel Slater, HoD, commented on 'this very well deserved award' in recognition for Chris' significant achievements in advancing the science and commercialisation of healthcare biotechnology. Professor Lowe has a strong academic and entrepreneurial track record with over 340 publications, 70 or more patents and 10 spin-out companies worth conservatively over £200M and employing 200 people across chemical engineering, biochemistry and related disciplines.

CEB Editorial Team recently met with Chris and caught up with his latest movements and achievements at an interview:

*First of all, congratulations for your recent OBE Award for your services to science! Is this really the culmination of your achievements, what else can we expect from Professor Lowe?*
No, definitely not! This is a very important spur to continue pushing ahead with new science and technology and translating it into products and services for the benefit of the UK. I have a large and very capable multidisciplinary group of co-workers progressing a variety of novel healthcare biotechnology projects which I intend to see through to commercial success.

*How did you find out that you had been given this major award?*
It is common practice to inform the recipient in the middle of November, to check whether they wish to accept the honour and to enquire if they are willing to engage in publicity. This communication is in strict confidence with publicity embargoed until after the awards are formally announced.

*This is not the first award you have received, but what does this particular one mean to you?*
This one means a lot to me since it is recognition by the UK Government that you have achieved something of value to the community and UK as a whole.

You have been actively involved in setting up many collaborations with several Biotechnology companies worldwide. *Could you please tell us a bit more about your recent movements?*
I have over the years visited some 120 countries, but more recently I have concentrated my efforts on the Middle East. Over the last two years I have made contacts in Turkey, Iran, Syria, Lebanon, Egypt, Morocco and Jordan. I now sit on the Board of Directors of a Jordanian company, Monojo, as a Non-Executive Director. We have recently established a new Anglo-Jordanian company, BioJo, which will exploit developments from both countries.

*And finally, what comes next for Professor Lowe?*
I have plans to continue to develop novel technologies in healthcare biotechnology industries; establish several more start-up companies based on developments emanating from my own laboratory; form better links with clinicians and perfect the Research-to-Patient philosophy; expand and evolve the Master's Course in Bioscience Enterprise to create the next generation of entrepreneurial scientists; and assist the UK Government to formulate sensible policies to promote such interests.

*Following this interview, Profesor Chris Lowe also won the BBSRC Commercial Innovator 2011 Award back in March for his work on SMART HOLOGRAMS, a revolutionary intelligent optical sensor technology for a wide range of applications.*

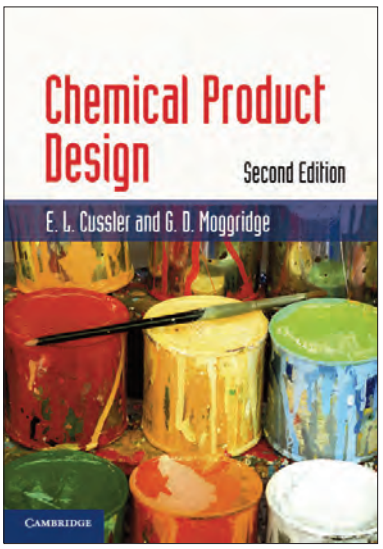
## Dr David Scott awarded a Pilkington Teaching Prize

Some of the University's very best teaching talents are honoured every year at the annual Pilkington Prizes awards ceremony. These prizes go to committed individuals who have pioneered new methods of teaching and learning, those who have done outstanding work on outreach programmes and/or shown an amazing ability to inspire students to achieve. Among the prize winners this year is Dr David Scott, CEB's Director of Teaching. He is delighted by the award and commented:

*'I am flattered and honoured. Teaching is an important activity in the University, and one way the University recognises this is by these prizes. And teaching is not just giving the 9 am lecture on Monday mornings – there's feedback, examining, timetabling, coursework, etc… I've also had the great fortune of learning from a number of colleagues. Their contribution is like an iceberg - much is done below the surface and we couldn't do our job without the superb input from the support staff. I enjoy teaching. One of the joys of working in the University is having contact with clever young people who can – and will - challenge what I say, and point out my mistakes'.*

A prize of £1000 will be deposited in a 'donation account' of his choice and all the winners will receive their awards from the Vice-Chancellor during a reception at Homerton College on 15 June 2011.

## 2nd Edition of 'Chemical Product Design' now out!




We are delighted to announce that the 2nd Edition of this much acclaimed book is now out. Dr Geoff Moggridge, CEB academic and Principal Investigator of the 'Structured Materials' Research Group, wrote it in collaboration with E. L. Cussler from the University of Minnesota. The 2001 edition presented a simple four-step design process that could be applied to a variety of products.

The revised edition is a major re-write, twice as long as the first edition. Now with 496 pages, 76 illustrations, 80 tables and 81 exercises. The features to highlight in the new edition are: a four-step template for the design process, numerous real-world examples and four new chapters dividing products into commodities, devices, molecular products and microstructures.

Dr Moggridge told *CEB Focus* the main reason behind writing a new edition: *'The first edition was popular and was used as the basis for new courses all over the world. In the second edition we have tried to make it easier to teach these courses, by adding a lot more examples and a second way of structuring the material, based on product type. This also naturally leads to the incorporation of more science and engineering appropriate to each product type, which links it in with other parts of the curriculum.'*

# Remembering the past: A history of the Department of Chemical Engineering & Biotechnology 1946–2011

*Emeritus Professor John F. Davidson*
*Former Head of Department*

Some important events in the Department's history are described below under the headings of successive Heads of Department.

### Professor T. R. C. Fox (1946 – 1958)

*Figure 1. Professor Fox, Head of Department from 1946 to 1958*

In 1945, the University received an endowment from Shell for a chemical engineering department and chair. The first Shell Professor was T.R.C. Fox (Figure 1), appointed in 1946. The undergraduate Tripos course began in 1948. This was a highly innovative course in that the teaching was science-based, rather than technology-based.

An important innovation was to recruit staff who knew little or nothing about Chemical Engineering, but had a good background in Science or Engineering. Students read either Natural Sciences (the majority) or Engineering for their first two years and then entered the Department for a two-year course in Chemical Engineering. There were no large teaching experiments, unusual in those days and there was no Design Project, much to the distress of the Institution of Chemical Engineers (IChemE). In their final year, students did a Research Project, innovative at the time, and an industrial report on a specific process.

Professor Fox never published a research paper, but he encouraged research. For example:

(i) The Hydrogen-Oxygen Fuel Cell (F.T. Bacon FRS), which eventually went to the moon.
(ii) Pioneering work by P. V. Danckwerts on residence time distributions, gas absorption and mixing.
(iii) Distillation of liquid hydrogen for tritium separation, relevant to the hydrogen bomb.
(iv) Early work on fluidisation, starting with Tripos research projects.

None of the above had any funding from Research Councils, though there was industrial funding for projects (i) and (iii).

### Professor P. V. Danckwerts (1959 – 1975)

Relations with IChemE improved: Professor Danckwerts (Figure 2) became its President 1965-6 and a Design Project was introduced which became part of the course for every student's third year at the University. In 1967, the Department introduced its own subject, Fluid Mechanics and Transfer Processes, into the Natural Sciences Tripos Part IB. This Tripos includes a wide range of scientific subjects, so the addition of a Chemical Engineering topic was notable.

*Figure 2. Department photo from 1975, with Professor Danckwerts seated front row, centre*

The Department was early in introducing computers: an IBM 1620 machine was bought with

Shell funds (available because the Department had not purchased large teaching equipment, a wise decision of Professor Fox). Thus the Department was early in research on computational flow-sheeting and on computer-controlled experiments.

Dr Davidson (Figure 3), then a Reader, was President of IChemE 1970–71. In 1974 he was a member of the Court of Inquiry for the Flixborough Disaster, in which twenty-eight were killed and a large factory was destroyed.

*Figure 3. Professor Davidson with HRH Prince Philip, Duke of Edinburgh*

### Professor J F Davidson (1975 – 1993)

Biotechnology was launched in the 1980's, first by Dr Chase (Figure 5) and Dr Slater in the Department and then by the arrival of Dr Lowe who started the Institute of Biotechnology. At first the Institute was attached to the Department, but after a few years it became a separate establishment and remained so for many years (see below).

Likewise the Department assisted with initiating a Polymer Chemistry Group in the late 1980's: this Group was fostered as a joint venture by the Departments of Physics, Materials Science and Metallurgy and Chemical Engineering, but later moved to the Department of Chemistry.

The MEng (Master of Engineering), a new degree for the University, was introduced in 1990; in this the Department was the leader. All students completing the four year course are eligible for MEng. This lead has been followed by a number of other departments who have adopted the MEng or similar title for students completing a four year course.

### Professor J. Bridgwater (1993 – 1998)

A major change was the introduction of the three year Chemical Engineering course. Students enter the University to read Natural Sciences or Engineering. After one year, they transfer to Chemical Engineering for the three year course:

(1) Year 2 leads to the Chemical Engineering Tripos (CET) Part I
(2) Year 3 leads to CET Part IIA, including the Design Project
(3) Year 4 leads to CET Part IIB, including the Research Project

An important administrative change was the introduction of the School of Technology comprising, as well as this Department, initially the Departments of Engineering and of Computer Science, the Judge Business School and the Institute of Biotechnology. In 1998, the Shell Fund was returned to the Department for the Department's sole use.
Professor Bridgwater (Figure 4) was President of the IChemE, 1997–98.

*Figure 4. Professor Bridgwater (right) with Professor Gladden (centre) and alumnus Dr Mark Sankey at the Alumni Speaker Series, May 2010*

### Professor H A Chase (1998 – 2006)

*Figure 5. Professor H. A. Chase at Research Open Day 2003*

An important innovation was the introduction of the MPhil course in Advanced Chemical Engineering comprising a six-month course of advanced study plus a six-month research project requiring a dissertation plus an oral examination. The first course began in October 2004, but plans were laid earlier.

### Professor L. F. Gladden (2006 – 2010)

During this period the Department was re-amalgamated with the Institute of Biotechnology which had grown substantially since its inception. Thus was formed the present Department of Chemical Engineering and Biotechnology, which obtained the highest possible rating in the last Research Assessment Exercise.

Professor Gladden (Figure 4) founded the MRI centre and she also pioneered the CEB new building initiative.

The Department now includes three buildings:

(1) The original premises in Pembroke Street
(2) The Institute of Biotechnology in Tennis Court Road
(3) The Magnetic Resonance Research Centre on the West Cambridge Site. This building houses a group working on magnetic resonance imaging applied to Chemical Engineering, a National Centre for the UK, under the leadership of Professor Gladden.

### Professor N. K. H. Slater (2010 – present)

Professor Nigel Slater took over from Professor Lynn Gladden in October 2010 and will continue the pursuit of the vision Professor Gladden championed for the Department to be fully integrated within a single new building that meets the educational needs of our current and future students.



**1st year PhD Student Seminars**

**Wed 11 May** (starting at 2.15pm in LT1, Pembroke Street)

**Wed 18 May** (starting at 2.15pm in LT1, Pembroke Street)

**Thurs 9 June** (starting at 9.00am in Level 3, Tea Room, Tennis Court Road) Two-part talk by Dr Vassilis Vassiliadis on **Friday 6 and 13 May**, 3.30pm: *'Optimisation: Formulations, Algorithms and Applications'*

**Remember CEB Pub Nights** every second Friday of the month! - Next one on Friday 13 May (The Mill pub) - Note that they will still be taking place out of term over the summer break.

Last alumni talk this academic year on **Friday 27 May** - Mark Perrett, Senior Advisor at Morgan Stanley, Lecture Theatre 1, 4.00 pm

**Friday 27 May** Class of 1982-92 Alumni Reunion event in the Department (dinner in Fitzwilliam College)

**June CUCES summer BBQ** sponsored by BP (date/venue to be confirmed)

**Friday 8 July** Class of 1962-72 Alumni Reunion in the Department (lunch in Sidney Sussex College)

**Thomas Pintelon**
*PhD Student*

I joined the department in July 2007 to pursue a PhD on the mathematical modelling of biofilm growth. From the start, I appreciated the ideal combination of flexibility, freedom and supervision (by Dr Mike Johns) that allowed me to dictate the direction of my research. Thanks to the amazing team and facilities available at the MRRC, I was able to test and validate my theoretical findings against experimental results. This collaboration also allowed me to increase the industrial relevance of my work by linking it with microbial-enhanced oil recovery and biofouling of reverse osmosis membranes.

Life in Cambridge has definitely been one of the most remarkable and rewarding experiences in my life! I enjoyed rowing for my college (Selwyn) and took up fencing. After submitting my PhD in June 2010, I took up a job in a Brussels-based company (Callataÿ & Wouters) which is active in the financial consulting sector providing software and services to banks.

**Jing Li**
*PhD Student*

I spent four years in Cambridge studying for my PhD with the Dorothy Hodgkin Postgraduate Award. During my time I investigated the chemistry and biotechnology applications and purification strategies of natural products. My supervisor, Professor Howard Chase, continuously provided me with the right environment to pursue this work – although it was a bit outside the normal realm of his research!

I returned to China after finishing my PhD and currently work in Guiyang. I am the general manager of a small venture fund of 50 million RMB (5 million GBP) mainly interested in the venture capital investment of small high-tech enterprises. I am also a government official responsible for technology transfer and industrialisation. Guiyang is a Tier-2 city which is dedicated to supplying preferential policies for attracting direct foreign investment. Its major industries include pharmaceutical, chemical, machinery and food processing. I warmly welcome colleagues interested in collaboration to contact me (jing.li1982@gmail.com).

## A warm welcome to...

Post-doctoral researchers
Dr Neil R Williamson
Dr Liam McMillan

Visiting Researchers
Antoine Carof
Guillaume Chivot
Jessica Ocampos Colina
Erwin de-Genst
Peter Gyring
Anthony Knobel
Nuria Rodriguez Gomez
Sara Gomez Sanz

## Goodbye to...

Dr Mike Johns, Reader
Luke Miller, PhD Student
Adriano Zaffora, Post-doctoral researcher

FAO - New Arrivals: Remember the CEB Pub Nights every second Friday of the Month!

**Dear Dr Sarah,**
What can be done to improve the standard of Part 1 Lab Reports? Anon.

*Dr Sarah says...*
*One has to sympathise with young students nowadays – many of them are unable to write decent technical English, which is no surprise considering the amount of colloquialisms and 'text speak' that have insidiously crept into our lives, and in some cases the Oxford English Dictionary. I can imagine receiving a lab report that says "And I got some sick results, yeah, and plotted them, like, on a proper nice graph, and got a totally straight line. Gr8 !"*

*The only way to improve one's technical English is, I'm afraid, to read lots of technical English. And some students just haven't got the time and/or inclination to read lengthy papers any more. They are used to searching for 0.36 seconds and clicking on an immediate answer. And who can blame them? Sounds like an efficient way to go about getting a degree, even if it is at the expense of comprehension. We are all subject to an increasingly 'instant' and 'packaged' lifestyle. Why post a letter, when you can email? Why spend an hour preparing a tasty, healthy meal when you can just wait for the 'ping' of the microwave; and while you're waiting you can wash up the dinner plate from last night. Now that's what I call multi-tasking !*

*People want results and they want them NOW ! Take for example this disgusting sample of instant*

*Dr Rough in action*

*coffee that I've just been given in the street, which has coffee, sugar and milk powder in it, as well as a list of other ingredients as long as my supervision timetable. Add hot water for an instant drink, yes. Resembles coffee, no. What type of lazy, tastebud-dead imbecile would buy such a product? It's the same with lab reports – anyone can report data in an instant. It's the interpretation and discussion of the data that needs thought and thus takes time. Yes, TIME.*

*Don't get me wrong, I'm not knocking technological advances. The interweb is a fantastic resource, but one has to bear in mind that anyone can put any old hogwash on it, eg how to grow your own bonsai kitten. Which is cruel and unusual, by the way. Some people say that information equals power. Pah ! This equation is dimensionally inconsistent and is thus clearly incorrect.*

*Anyway, I digress. In answer to your question, get the students to download the latest WangDoozle© app onto their iBlueberries, which will write the lab report for them. Or perhaps the report markers could improve the constructive feedback given to the students.*

*P.S. I've got some money-off vouchers for instant coffee if anyone is interested.*

## George Orwell was a Chemical Engineer

*Alastair Clarke*
*PhD Student*

I received a *Tea-time teaser* from a reader called JHC who wanted to know how the temperature of tea varies whilst it is being drunk. Together we develop a model which shows that the rate at which tea is drunk and the shape of the cup are important factors which determine how the temperature evolves.

Consider a cylindrical cup containing hot tea. Typically tea is drunk in sips and gulps, but for simplicity we will assume that the tea is drunk at a constant rate:

$$dV/dt = -Q$$

where $V$ is the scaled volume of tea, $t$ is scaled time and $Q\ (= qt_s / V_0)$ is a dimensionless measure of the drinking rate. We define $q$ to be the dimensional drinking rate, $V_0$ as the initial volume of tea and $t_s$ as a time-scale. We set $Q = 1$, so that time is measured relative to the drinking rate.

We assume the cup is insulating, so that heat can only leave the tea through its contact with air. To find how the temperature varies with time, we solve the equation:

$$d(VT)/dt = -Or\,T$$

where $T$ is the scaled temperature of the tea and $Or\ (= hA / \rho C_p q)$ is a measure of the heat transfer rate compared to the drinking rate which we call the Orwell number after the writer and tea-enthusiast, George Orwell. We define $h$ to be the heat transfer coefficient between tea and air, $A$ the contact area, $\rho$ the density of the tea and $C_p$ the heat capacity of the tea. We solve the two equations subject to the initial conditions, $T = 1$ and $V = 1$ when $t = 0$, and find:

$$T = (1 - t)^{Or - 1}$$

Figure 1 shows how the temperature evolves for three different values of *Or*, each one representing a different drinking scenario. For example, '*Or* is 1.5' could represent a scenario where one drinks quickly from a tall, narrow cup, whilst '*Or* is 3' could represent one drinking slowly from a short, wide cup. Initially, the temperature of the tea in the tall cup decreases slowly compared to that in the short cup. The tall cup loses less heat than the short cup because of its smaller exposed area. However the cups have similar volumes of tea in the early stages so the short cup experiences a larger temperature change. Later on, the temperature of the tea in the tall cup decreases more quickly than that in the short cup. The tall cup is drunk from at a faster rate than the short cup and a point is reached when the volume of tea in the tall cup becomes so low that even a small amount of heat loss will have a large effect on the tea's temperature.

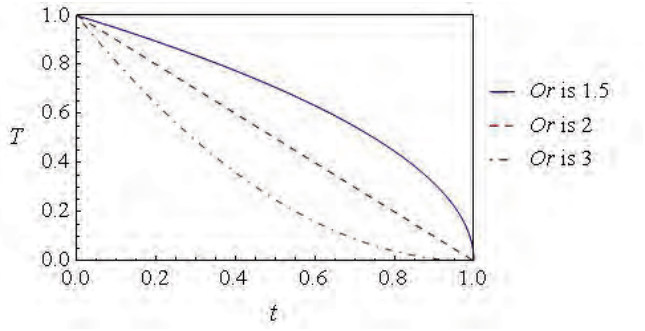



*Figure 1: How the scaled tea temperature (T) varies with scaled time (t) for three different Orwell numbers: Or = 1.5 (blue, solid line), 2 (red, dashed) and 3 (brown, dot-dashed)*

In 1946, George Orwell wrote an essay that contains eleven rules for making a *'nice'* cup of tea. Orwell revealed his inner chemical engineer on the eighth rule, which states, *'One should drink out of a good breakfast cup - that is, the cylindrical type of cup, not the flat, shallow type. The breakfast cup holds more, and with the other kind one's tea is always half cold - before one has well started on it.'* (Orwell, G., Evening Standard, 12th Jan., 1946).

Our simple model helps to explain Orwell's observations.

## Letters to the editor

We welcome comments from our readership. Please email us your views and suggestions for future articles on ceb-focus@ceb.cam.ac.uk

UNIVERSITY OF CAMBRIDGE

## Department of Chemical Engineering and Biotechnology


**New Museums Site**
Pembroke Street
Cambridge CB2 3RA

Tel: +44 (0)1223 334777
Fax: +44 (0)1223 334796

**Institute of Biotechnology**
Tennis Court Road
Cambridge CB2 1QT

Tel: +44 (0)1223 334160
Fax: +44 (0)1223 334162

**Magnetic Resonance Research Centre**
J J Thomson Avenue
Cambridge CB3 0HE

Tel: +44 (0)1223 334777
Fax: +44 (0)1223 334796

For further information please visit www.ceb.cam.ac.uk or contact us at emailus@ceb.cam.ac.uk



Design/production: www.cambridgedesigners.co.uk