Chapter Three: Structured Matter

The Development of Unique Cyclic Polymers

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Keywords: cyclic polymers; nanostructures; advanced materials

This project will provide the synthetic methods and knowledge required to advance cyclic polymers to the next level at which commercial materials can be envisioned. Two of the most promising techniques for the preparation of technologically important cyclic polymers, namely ring-opening metathesis (ROMP) and group transfer polymerisation (GTP), have been significantly under utilised and as a result, this project aims to elaborate and build upon these techniques to produce next-generation functionalised and multi-component cyclic polymer architectures. The versatility of these polymerisation methods will enable the rapid production of a range of unique cyclic polymer derivatives (Fig. 1), such as cyclic block polymers (comprised of different types of monomers), bicyclic block polymers (consisting of rings joined together and comprised of different types of monomers), cyclic-ladder and cyclic-graft or "sun-shaped" polymers (consisting of a central ring from which linear polymer chains radiate). Cyclic block polymers (polystyrene-b-polyisoprene, polystyrene-b-polybutylene and poly(ethylene oxide)-b-poly(propylene oxide) and the ordered structures that they form have been the subject of several investigations, although the variety of the monomeric building blocks from which they are comprised has been limited as a result of the synthetic methods used for their preparation. As a result, this project aims to broaden the selection of cyclic block polymers that are available for study and introduce new amphiphilic (polymer comprised of segments with opposite properties) cyclic block polymers that, to date, it has not been possible to synthesise.

Whereas linear block polymers in solution form spherical structures (micelles) comprised of many polymer chains, the cyclic block polymers that have been studied form giant "worm-like" tubes (precursors to organic nano-tubes) or vesicles, which are not obtainable using linear polymers. Thus, it is clear that cyclic block polymers possess extremely interesting and distinctive properties. Similarly, the few experimental studies that have been conducted on surfaces reveal that cyclic block polymers form organised nano-structures with remarkable morphologies that are significantly different to their linear polymer analogues and provide new and exciting opportunities for advanced materials and nano-lithography techniques. Thus, the unique cyclic polymers prepared in this proposal will also lead to new and useful ordered structures in solution and on surfaces.

The project will yield cyclic polymers with a large range of commercial and industrial applications (e.g. drug delivery, contamination clean-up, nano-wires, sensors) that will result in positive economic and social benefits for Australia. The research will underpin and extend Australia's leading position in the development of innovative polymeric and advanced materials.

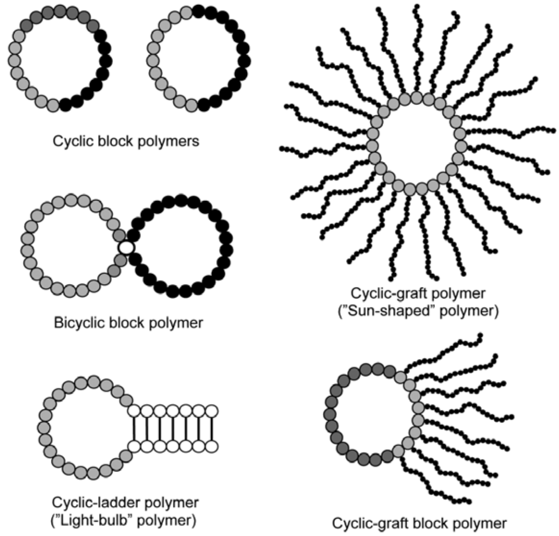

Fig. 1: Examples of advanced cyclic polymers.

Nanoengineered Particles for Cardiovascular and Alzheimer's Disease Diagnosis

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Sponsors: Australian Research Council, NanoVic

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Keywords: nanoengineered particles; MRI contrast agents; cardiovascular disease; Alzheimer's disease

Magnetic resonance imaging (MRI) is a powerful non-invasive imaging technique currently used to detect abnormalities in living tissues. The ability to distinguish diseased cells at early stages of a disease is vital because early diagnosis is often crucial in developing effective treatments. The main limitation of commercially available contrast agents for MRI is that they are not targeted to specific cells and they do not localise at a specific area for any length of time. Targeted delivery of contrast agents represents an excellent way to assess the progress of a disease and the efficacy of treatments because MRI does not use harmful radiation.

An emerging technique to control the structure of particles on the nanoscale is the layer-by-layer assembly process [1]. In this process, layers of interacting polymers are deposited into the pores of mesoporous silica templates, which act like a sponge to soak up the polymer. This technique allows for fine control over the properties of the particles by altering the number of layers deposited, the material deposited at each layer, and also by controlling the assembly conditions. A porous polymer particle is subsequently formed by dissolving the sacrificial silica template. We have functionalised these porous particles with MRI contrast agents and are currently functionalising the capsules with antibodies [2, 3] which will target the particles to amyloid fibrils, which are linked to the onset of Alzheimer's Disease, and to the plaque build-up in cardiovascular tissue to help with the diagnosis of heart disease.

[1] J.F. Quinn, A.P.R. Johnston, G.K. Such, A.N. Zelikin and F. Caruso, "Next generation sequentially assembled ultrathin films: beyond electrostatics", *Chemical Society Reviews*, **36**(5), pp. 707-718, 2007.

[2] C. Cortez, E. Tomaskovic-Crook, A.P.R. Johnston, B. Radt, S.H. Cody, A.M. Scott, E.C. Nice, J.K. Heath and F. Caruso, "Targeting and Uptake of Multilayered Particles to Colorectal Cancer Cells", *Advanced Materials*, **18**(15), pp. 1998-2003, 2006.

[3] C. Cortez, E. Tomaskovic-Crook, A.P.R. Johnston, A.M. Scott, E.C. Nice, J.K. Heath and F. Caruso, "A General Approach for DNA Encapsulation in Degradable Polymer Microcapsules", *ACS Nano*, **1**(1), pp. 63-69, 2007.

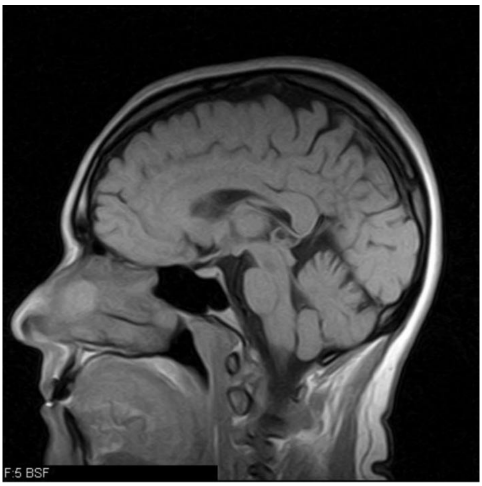

Fig. 1: Targeted delivery of nanoengineered capsules assembled using the Layer-by-Layer technique (www.umshp.org/rs/images/mri_brain.jpg).

Targeted Delivery of Therapeutics Using Nanoengineered Materials

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Keywords: targeted drug delivery; nanoengineered materials; cancer treatment

In chemotherapy, cytotoxic drugs are distributed evenly throughout the body with detrimental effects on healthy cells, causing side-effects including hair loss and digestive problems. The ability to specifically target the drugs to cancer cells has the potential to greatly decrease the side-effects by delivering high doses of the therapeutic agents only to specific sites where they are required. Targeted delivery therefore has the potential to revolutionise current methods of cytotoxic drug administration to improve the clinical outcomes for cancer patients. This project exploits the coupling of two innovative approaches to cancer treatment: immunotherapy and nanotechnology.

An emerging technique to deliver drugs is by immobilising the drug inside a nanocapsule [1]. The capsules are prepared by the layer-by-layer deposition of interacting polymers onto a sacrificial template particle. This technique allows for fine control over the properties of the capsule by altering the number of layers deposited, the material deposited at each layer, and also by controlling the assembly conditions. The surface of the capsules can be functionalised with signalling molecules, such as antibodies, peptides and other small molecules. We have demonstrated that antibody functionalised, nanoengineered capsules specifically bind to cancer cells and are internalised into the cancer cells [2, 3].

We are currently investigating the loading of these capsules with chemotherapy drugs, peptides and nucleic acids [4] and evaluating the release of these theraputics *in vitro* and *in vivo*. We are also currently investigating the biodistribution of these capsules in animal models.

[1] A.P.R. Johnston, C. Cortez, A.S. Angelatos and F. Caruso, "Layer-by-Layer Engineered Capsules and their Applications", *Current Opinion in Colloid & Interface Science*, **11**(4), pp. 203-209, 2006.

[2] C. Cortez, E. Tomaskovic-Crook, A.P.R. Johnston, B. Radt, S.H. Cody, A.M. Scott, E.C. Nice, J.K. Heath and F. Caruso, "Targeting and Uptake of Multilayered Particles to Colorectal Cancer Cells", *Advanced Materials*, **18**(15), pp. 1998-2003, 2006.

[3] C. Cortez, E. Tomaskovic-Crook, A.P.R. Johnston, A.M. Scott, E.C. Nice, J.K. Heath and F. Caruso, "A General Approach for DNA Encapsulation in Degradable Polymer Microcapsules", *ACS Nano*, **1**(1), pp. 63-69, 2007.

[4] A.N. Zelikin, Q. Li and F. Caruso, "Degradable Polyelectrolyte Capsules Filled with Oligonucleotide Sequences", *Angewandte Chemie International Edition*, **45**(46), pp. 7743-7745, 2006.

[5] A.N. Zelikin, A.L. Becker, A.P.R. Johnston, K.L. Wark, F. Turatti and F. Caruso, "Influence of Size, Surface, Cell Line and Kinetic Properties on the Specific Binding of A33 Antigen-Targeted Multilayered Particles to Colorectal Cancer Cells", *ACS Nano*, **1**(2), 93-102, 2007.

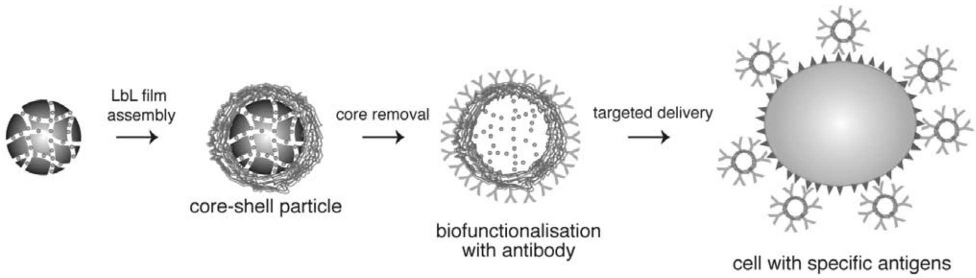

Fig. 1: Targeted delivery of nanoengineered capsules assembled using the Layer-by-Layer technique.

Advanced Nanoparticle Stabilisation and Functionalisation: Small Particles with Huge Potential

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Keywords: nanotechnology; diagnostic particles; targeted drug delivery; cancer

Australia is strongly investing in nanotechnology through the government's priority goals 'Frontier Technologies for Building and Transforming Australian Industries'. This research will help develop an internationally recognised nano-industry. It is envisaged that the particles made during this work will create a new class of medical diagnostic particles with better resolution and specificity. These particles have the potential to diagnose patients more precisely and at an earlier stage than is currently available. Additionally, these particles could be designed to load drugs and hence could be used to treat diseases such as cancer.

Characterisation of Adhesives of Marine Biofouling Organisms Using Atomic Force Microscopy

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Keywords: biofouling organisms; atomic force microscopy; bioadhesives; antifouling coatings

Bio-fouling is a phenomenon affecting all surfaces in the marine environment. Fouling affects all surfaces, whether they are stationary objects such as oil rigs or pipelines, or sea-going vessels. The problems range from increased weight and drag in shipping, to increased need for cleaning and increased susceptibility to corrosion. Atomic Force Microscopy (AFM) has proven useful in the study of the adhesion of marine organisms, specifically probing the adhesive mucilage pads secreted by diatoms in this work. By studying the single molecule extensions of biomolecules in these pads using AFM we are able to quantify the structures of the proteins in these pads that act as bioadhesives. This has been accomplished previously with materials such as muscle proteins or spider silk, but this work was the first to achieve this on a living biological organism. Understanding the molecular structure of these proteins and bioadhesives will help in the design of antifouling coatings for marine vessels.

Dynamic Interactions in Soft Matter Systems

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Keywords: soft matter materials; foams and emulsions; atomic force microscopy

In many established Australian industry sectors, such as pharmaceutical formulations, dairy products and food processing, as well as in the growing high-value sectors of biotechnology and nanotechnology, a key step is the processing and control of soft matter materials like emulsions and foams. Emulsions include everyday items such as salad dressing, milk and shampoo, as well as industrial processes such as solvent extraction used for pharmaceutical purification. Equally, foams or mixtures of bubbles in liquids form the core of everyday products, such as ice cream, as well as being used in minerals processing.

In both foams and emulsions, droplets and bubbles are dynamic in nature as they move through the suspending liquid and collide with each other. During collisions, the droplets or bubbles may bounce off each other so the emulsion or foam remains stable and retains its desired properties. Alternatively, the droplets and bubbles may collide and coalesce, resulting in an unstable emulsion. In everyday products, stability is important, however in many industrial processing situations, a stable emulsion or foam may be required during one stage of a process but may subsequently need to be destabilised in a controlled manner, at another. In addition, the outcome of these collisions is related to the types of molecules present at the interface between the two liquids in the case of the bubble-liquid interface or foam. While adjusting the molecules present at these interfaces offers a means of controlling stability in processing conditions, the precise correlation between the nature of the molecules and the effect on the droplet or bubble interaction, is not particularly well understood and can be complicated to measure because the relevant dimensions are on the nano-scale of nanometer (nm) – a millionth of a millimeter. The objective of this research is to develop nano-scale experiments and theories to measure and predict the interactions between droplets and bubbles that underpin the innovative applications of foams and emulsions.

This project measures these interactions directly using a novel method employing atomic force microscopy to gain new insights into the interactions in these systems. This approach is coupled with complementary indirect methods to discern correlations between types of molecular structures and the inter-droplet interaction forces in systems with clear industrial relevance.

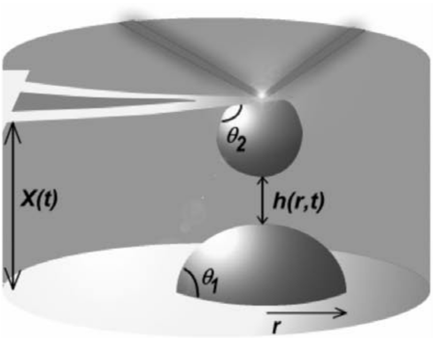

Fig. 1: A schematic of an AFM fluid cell with two oil droplets in water. The oil droplets are immobilised on the surface and the cantilever of the AFM. The radii of the droplets are typically 30 to 50 microns.

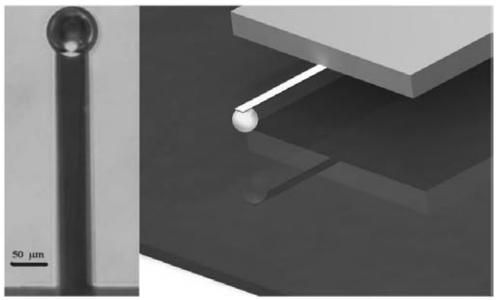

Fig. 2: A video microscopy image of a bubble immobilised on a custom built AFM cantilever. A schematic of an AFM experiment of a bubble interacting with a flat mica plate.

Visualising the Water Uptake and Growth of Aerosol Particles on Multiple Length Scales

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Keywords: aerosol particles; climate change; environmental scanning electron microscopy; atomic force microscopy

Greenhouses gases are commonly perceived as the main cause of global climate change, yet aerosol particles are just as important. These tiny particles, which come from both natural and anthropogenic processes, range from a few nanometers to microns in size and are always present in our atmosphere. Aerosols play a large role in the climate by adsorbing or reflecting solar radiation or by taking on water to form clouds, fogs, hazes or smog. The water uptake and growth of aerosol particles is still poorly understood in cloud formation and remains the largest uncertainty in global climate models. This study focuses on visualising this process on multiple length scales using two different techniques. A novel approach employing environmental scanning electron microscopy (ESEM) to directly observe the condensation of water droplets on micron size aerosol particles is employed at Bucknell University led by Professor Timothy Raymond. Atomic Force Microscopy (AFM) is employed to image aerosol particles on the nanometer scale as a function of relative humidity at the University of Melbourne. The combination of these two techniques (ESEM and AFM) as well as the ability to measure physical properties using the AFM will provide new information on aerosols across a large size range.

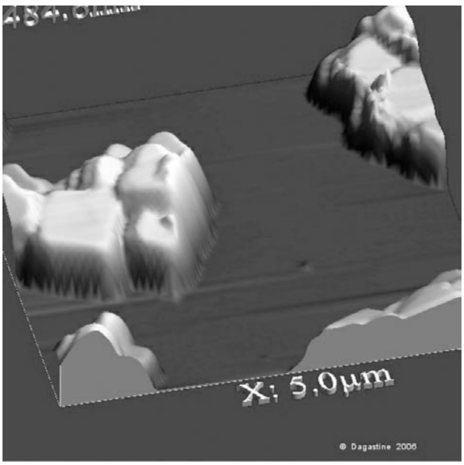

Fig. 1: An AFM image of sodium chloride nanocrystals generated by drying an aerosol of liquid droplets.

Forces in High Salt Concentrations: from Mineral Processing to Proteins

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Keywords: high-salt concentrations; silica shells; total internal reflection microscopy; optical tweezers

Proteins crystallise, drops coalesce and mineral particles flocculate in high salt concentrations. These are all examples of how the forces between particles and droplets play an important role in the Australian food, pharmaceutical and mining industries. The physical origins behind these forces are crucial to control particle and droplet stability. Yet, an understanding of these forces in concentrated salt solutions is still an uncharted area, despite the prevalence of these systems. Through a novel development of a highly sensitive experimental technique, total internal reflection microscopy, this study will identify the physical origins of these forces. This fundamental study will help connect colloid science to high salt conditions relevant to both industry and biology.

This project will contribute to the fundamental understanding of colloidal science; the study of particle suspensions. It will help answer longstanding questions in the food, pharmaceutical and mining industries, two of which are primary industries for Australia. In these industries, innovative solutions can substantially improve productivity, increasing export potential and reducing environmental impact.

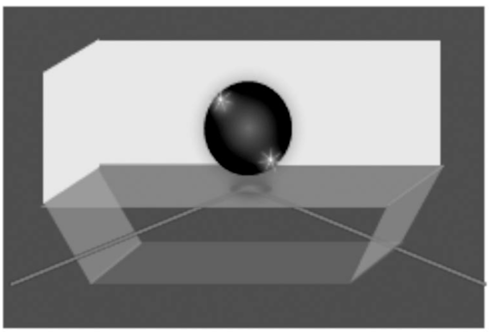

Fig. 1: A TIRM uses a levitated colloidal particle (radius ~ 2-3 microns), free to move under Brownian motion, to gauge the interaction with a stationary surface. Evanescent light scattering is used to measure the separation distance.

The Effect of a Silica Nanoparticle Super Hydrophobic Surface on Hydrodynamic Drainage Forces

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Keywords: hydrodynamic drainage; hydrophobic surfaces; nanoparticles, atomic force microscopy

The dynamic forces between a large silica sphere and a silica nanoparticle super hydrophobic surface (SNP-SHS) were studied in the presence and absence of surfactant by atomic force microscopy. The surface roughness and the presence of trapped air pockets on the SNP-SHS in liquid, significantly mediated the hydrodynamic drainage forces in the system. The addition of surfactant adsorbed at the trapped air/water interface on the SNP-SHS increased the observed drainage forces by modifying either the morphology or the hydrodynamic boundary condition of the trapped air pockets. The surface roughness and the lateral heterogeneity of SNP-SHS made it complicated to analyse the results by Reynolds lubrication theory. These results put a ceiling on the applications of ideas gained about hydrodynamic drainage models developed for smooth surfaces to practical situations where surface roughness and lateral heterogeneity are concerned.

Fig. 1: Two views of the same glass plate where the slightly opaque half has been made into a silica nanoparticle super hydrophobic surface. The clear half is uncoated glass. The drops of water, tinted in red, have a high contact angle on the super hydrophobic side but spreads on the uncoated side.

Controlling Clay Behaviour in Suspension: Developing a New Paradigm for the Minerals Industry

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Student: Josephine Lim

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Sponsors: Australian Mineral Science Research Institute, Australian Research Council, AMIRA International BHP/Billiton, Rio Tinto, Anglo Platinum, Phelps Dodge Mining, Xstrata Copper, Orica Australia

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Keywords: clay behaviour; mineral processing; minerals industry

The Australian Mineral Science Research Institute (AMSRI) was formed in 2006 to conduct research into fundamental phenomena that have an influence on mineral processing. The Institute is composed of researchers from the University of Melbourne, the University of South Australia, the University of Newcastle and the University of Queensland. The Institute is jointly sponsored by the government (Australian Research Council) and a consortium of industry partners. The aim is to investigate research areas where quantum leap changes in mineral processing can be realised and to develop technologies to enable the new ideas to be taken up by industry.

The behaviour of clays in suspension can have a controlling effect on the efficiency of mineral processing operations. Whether throughout ore beneficiation or tailings dewatering and disposal, the high surface area, plate-like, readily dispersible nature of clays can result in problems which have significant economic and environmental ramifications, such as excess suspension viscosity, reduced mineral recovery and poor tailings dewaterability. In spite of this impact, the mineral industry's understanding of the origins and solutions of clay-related processing issues remains poor and in many cases issues associated with clays are simply avoided altogether by deeming clay-tainted ore bodies 'unviable'.

The classical way to tackle behavioural problems in clay suspensions is to attempt post-dispersion remediation, usually only at the point of tailings dewatering and disposal. However in view of current indications that up-front control of initial clay dispersion during wetting is significantly more effective at improving clay behaviour than any post-dispersion treatment, implementation of a holistic approach to dealing with clay issues makes more sense. To this end, any new approach requires not just a chemical and engineering solution but a systems overview of the problem, where the nature and cost of problematic clay behaviour across all aspects of a minerals processing operation are considered.

This project will investigate the concept that a combined chemical, engineering and systems approach to the issue of clays in mining is necessary to make a paradigm shift in the way that the minerals industry currently deals with clays, namely as an end-of-pipe issue. The project will develop integrated chemical and engineering strategies for controlling the dispersion and rheology of both swelling and non-swelling clays. This will require both modelling of the dewatering operations as well as consideration of the effect of shear and operational parameters on the solutions developed. The result will be a novel and operationally achievable approach to dealing with clay-related processing issues, tackling new and existing clay-rich ore bodies and improving performance of operations which may not even perceive they have clay-related performance limitations.

Macromolecular Self-Assembly of Amyloid Fibrils

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Keywords: protein misfolding; protein assembly

The misfolding of proteins is a key issue in public health. Common diseases, such as Alzheimer's disease, type II diabetes and heart disease are associated with protein misfolding, and have a major impact on society. The use of proteins as therapeutic drugs is now common (e.g. as vaccines, for immune disorders) but they can be rendered ineffective or harmful by protein misfolding. Through this project, we will enhance the fundamental understanding of the processes of protein assembly in solution, at solid surfaces, and under shear.

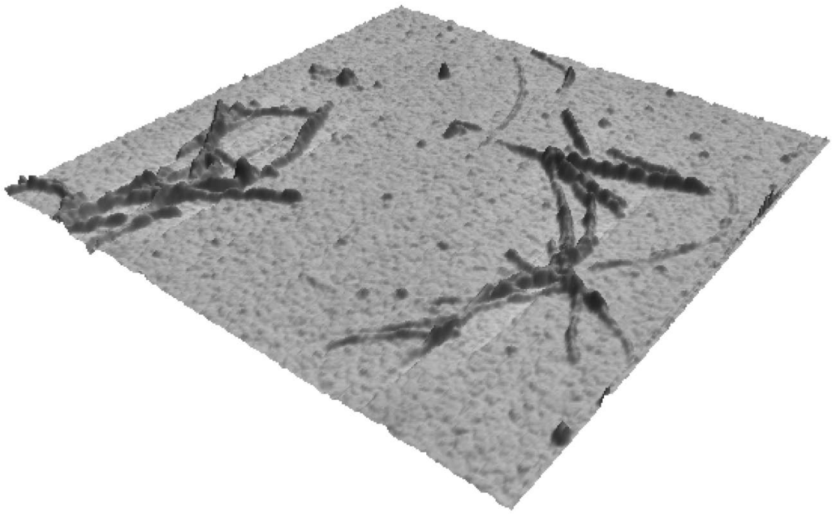

Fig. 1: Atomic force Microscope Image of Amyloid Fibrils formed from Beta lactoglobulin.

Nano-assembly of Light Emitting Polymer Films

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Keywords: light emitting polymer film; advanced materials; nano-assembly

Since the invention of luminescent polymers, considerable effort has been made to produce viable flexible displays using the polymers in thin films. The luminescent properties of these films depend on the processing conditions of the polymers, and it has been established that the conformation of the luminescent polymer is directly related to its light emitting properties. This project studies the properties of MEH-PPV, a common luminescent polymer, by molecule orientation and single molecule spectroscopy, in order to gain a better understanding of how an ideal light emitting film can be produced.

This research will assist Australian industries to further advance these processes and devices leading to better quality, cheaper and more efficient products. The Australian community will benefit through economic and technological advances. These advanced materials will promote health and environmental wellbeing.

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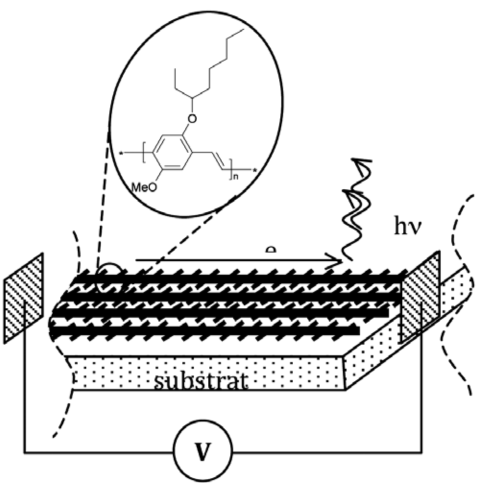

Fig. 1: Device for the conversion of light into electrical energy or visa versa. The insert shows the chemical structure of the light emitting polymers used.

Alternative Fuel from Algal Fermentation

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Keywords: carbon free fuel efficient systems; hydrogen production; bioprocess engineering

Recent developments in bioprocess engineering have great potential in numerous applications such as hydrogen production, carbon capture and sequestration, production of bioplastics, and production of biofuels including biodiesel. This research project involves the use of mini reactors to produce small-scale reactors with a focus on Hydrogen production. The technical and commercial implementation of these technologies for carbon-free, fuel-efficient systems will be developed. An overview of the process and key biochemical pathways which could be improved will be elucidated. Further to this a number of key engineering aspects will be researched in order to improve the commercial viability of these systems.

A New Paradigm in Near-Net-Shape Advanced Ceramic Component Processing

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Sponsor: Australian Research Council

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Keywords: ceramic processing; suspension rheology; green strength

The raw materials for high performance ceramics (such as alumina and zirconia) are readily available and produced in Australia. Nearly all of these raw materials are exported. The development of processing to make high value-added ceramic components from these raw materials will result in greater profit and more jobs for Australians. The proposed research is to develop a novel innovative process to drive a value-adding ceramic processing industry in Australia. Factors to be studied include the rheology of suspensions and influence of binders on green strength and the flow of fluids through the porous powder compact during removal of the fluid from the compact, and how this influences cracking.

Compressibility and Permeability of Stimuli Responsive Suspensions: Application to Modelling Mineral Dewatering Processes

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Research Centre: Australian Mineral Science Research Institute (AMSRI)

Sponsors: Australian Mineral Science Research Institute, Australian Research Council, AMIRA International, BHP/Billiton, Rio Tinto, Anglo Platinum, Phelps Dodge Mining, Xstrata Copper, Orica Australia

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Keywords: mineral processing; stimulant responsive polymers; flocculation; flotation

The importance of efficient separation of water from solid particles in mineral processing, is gaining emphasis with increasing environmental regulation and economic rationalisation. High molecular weight polymers, called flocculants, are commonly used to induce aggregation and settling of slurry particles. This project investigates the development and use of flocculants that respond to stimuli such as changes in temperature or acidity, to manipulate particle-particle interactions. The approach provides a strategy for improving dewatering efficiency by producing both fast sedimentation of fine particles (by aggregation) and dense (low moisture) sediment beds. A stimulus is used to change the force between particles first to attractive. The particles then aggregate, rapidly settle and can be removed with a thickener. Then, by changing the inter-particle force back to repulsive, the particles in the sediment will undergo further consolidation resulting in additional expression of water from the solids suspension.

The primary parameters which influence the performance of dewatering operations such as thickening are the suspension compressibility and permeability. The techniques to measure these properties and the models used to predict performance of dewatering operations in industry have been developed over the past few years. The aim of the project is to measure these properties of suspensions when the stimuli responsive flocculants we have developed are used. The results of the measurements will be used to determine the optimum time to "switch" the stimulus in order to recover the most water in the least time.

[1] G.V. Franks, C.V. Sepulveda and G.J. Jameson, "pH-sensitive flocculation: Settling rates and sediment densities", *AIChE Journal*, American Institute of Chemical Engineers, **52**(8), pp. 2774-2782, 2006.

[2] G.V. Franks, "Improved Solid/Liquid Separation using Stimulant Sensitive Flocculation and Consolidation", *Journal of Colloid and Interface Science*, Elsevier, **292**, pp. 598-603, 2005.

[3] G.V. Franks, Y. Yan, S. Biggs and G.J. Jameson, "Stimulant Sensitive Flocculation and Consolidation", Patent Cooperation Treaty number WO2005021129, 10 March 2005.

Smart Polymer Development and Application as Stimulant Responsive Flocculants

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Student: John-Paul O'Shea

Research Centre: Australian Mineral Science Research Institute (AMSRI)

Collaborators: Jonas Addai-Mensah (University of South Australia), Allan Hatton (Massachusetts Institute of Technology, USA)

Sponsors: Australian Mineral Science Research Institute, Australian Research Council, AMIRA International, BHP/Billiton, Rio Tinto, Anglo Platinum, Phelps Dodge Mining, Xstrata Copper, Orica Australia

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Keywords: smart polymers; stimulant responsive flocculants

The importance of efficient separation of water from solid particles in slurries produced from mining or paper milling processes, is gaining emphasis with increasing environmental regulation and economic rationalisation. High molecular weight polymers, called flocculants, are commonly used to induce aggregation and settling of slurry particles. This project investigates the development and use of flocculants that respond to stimuli such as changes in temperature or acidity, to manipulate particle-particle interactions. The approach provides a strategy for improving dewatering efficiency by producing both fast sedimentation of fine particles (by aggregation) and dense (low moisture) sediment beds. A stimulus is used to change the force between particles first to attractive. The particles then aggregate, rapidly settle and can be removed with a thickener. Then, by changing the inter-particle force back to repulsive, the particles in the sediment will undergo further consolidation resulting in additional expression of water from the solids suspension.

There are several methods of controlling the inter-particle forces to be either attractive or repulsive. The use of pH, temperature or light sensitive "smart" polymers appears to have the potential for significant reduction in mineral tailings volume and enhanced water recovery. Preliminary results with model colloids indicate that for the pH controlled system up to 40% reduction in sediment volume is possible within three hours, and for the temperature sensitive system up to 13% reduction in sediment volume is possible in less that one day.

The aim of the project is to synthesise novel homo- and co-polymers which respond to stimuli such as temperature and or light. The influence of polymer properties such as molecular weight, fraction of charged monomers and responsive unit chemistry on the polymer solution properties, polymer adsorption and suspension behaviour will be investigated.

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Advanced Ceramic Powder Processing

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Keywords: ceramic powder processing; ceramic component shape forming; thin film production; advanced materials

Materials scientists can produce ceramic materials in the lab in small quantity with any imaginable property. These ceramics will enable emerging technologies such as advanced heat engines and electronics. The obstacle to their widespread use is the lack of low cost, reliable processes for complex shaping. Our group develops innovative processes for producing high-strength complex shaped advanced ceramic components. Current research focuses on development of new and improved gelcasting binders for thick section complex shaped component production and aqueous tape casting for thin film production. Other projects include production of ceramic foams and understanding cracking in drying ceramic bodies.

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[3] S.B. Johnson, D.E. Dunstan and G.V. Franks, "Rheology of Crosslinked Chitosan / Alumina Suspensions Used for a New GelCasting Process", *Journal of the American Ceramic Society*, Wiley-Blackwell, **85**, pp. 1699-1705, 2002.

Oxide Surfaces

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Research Centre: Particulate Fluids Processing Centre

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Sponsor: Australian Research Council

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Keywords: oxide surfaces; crystal growth morphology; zinc oxide

The surface charging properties of colloidal metal oxide particles in aqueous suspension controls the inter-particle forces between those particles. The inter-particle forces influence behaviour of suspensions of particles such as stability against sedimentation, rheology (flow) and particle packing. These suspension behaviours are important in applications such as ceramic powder processing and solid-liquid separation in mineral processing. Oxide surfaces such as alumina, titania and zinc oxide have important applications in the production of aluminium, solar cells, photocatalysis, orthopaedic implants and blue light emitting diodes.

Our research focuses on the reactivity of these surfaces in environments where water is prevalent (such as aqueous solutions or humid air). Our approach combines experimental techniques such as zeta potential measurements, Atomic Force Microscopy, spectroscopy and Diffuse Functional Theory modelling. Understanding the relationship between surface structure and surface reactivity (such as surface charging behaviour) is a goal of the research. We hope to gain a fundamental knowledge of the factors that control crystal growth morphology and rates.

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Deformation and Flow of Networked Suspensions

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Keywords: networked suspensions; particulate materials

The deformation and flow of attractive particle networks is important in a wide variety of fields including nanotechnology, minerals and ceramic powder processing. Our research is aimed at improving understanding of how factors such as particle size, shape, volume fraction, and surface interactions influence the shear and compressive flow behaviour of particulate suspensions. Rheological properties such as yield stress, viscosity, elasticity and compressibility as well as permeability are typically studied for a range of particulate materials.

Aggregate-Sediment Bed Property Relationships

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Keywords: solid-liquid separation; aggregate properties; particle networks; flow and consolidation

The relationship between aggregate properties and flow and consolidation behaviour of sediment beds is not clearly understood. This relationship is important in developing solid-liquid separation processes that result in both rapid settling aggregates and sediment beds that dewater well. The aim of the research is to determine the relative importance of aggregate properties (such as size and structure) and inter-particle bond force in determining the attractive particle network structure, flow and consolidation behaviour.

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Functional Foods and Advanced Dairy Technology

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Sponsors: Department of Innovation, Industry, Science and Research (DIISR), Business Victoria

Collaborators: Andrew Barber (South Australian Research and Development Institute), Chiranjib Bhattacharjee (Department of Chemical Engineering, The University of Javapur), P.K. Bhattacharya (Department of Chemical Engineering, Indian Institute of Technology Kanpur, India)

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Keywords: functional foods; dairy industry; prebiotics; oligosaccharides

Research in this area is focused on the development of functional foods and the understanding of how process parameters influence the microstructure of cheese and other dairy products. Functional foods (also known as neutraceutical products) are foods which deliver medicinal benefits in addition to their nutritional benefits. Functional foods are a burgeoning global industry and Australia has a vibrant dairy industry which is well poised to capture a significant portion of this market, through the development of specialised dairy ingredients for domestic and export use.

The specific focus of our functional foods research is to investigate the enzymatic production of galacto-oligosaccharides from a number of processed milk streams using industrially relevant conditions. Work is also being conducted to develop galacto-oligosaccharide enriched dairy ingredients by purification and concentration of the products of the enzymatic reaction. The project is an exciting example of the translation of fundamental research findings to an industrial setting and the development of novel dairy products.

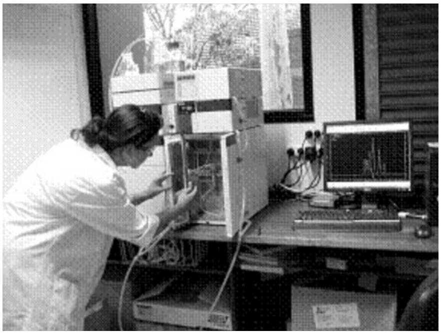

Fig. 1: A research student analyses functional food products by chromatography.

Metabolic Engineering, Fermentation Processes, and Biomolecule Production

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Sponsor: Rowden White Fund, University of Melbourne, Collaborative Research Grant

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Keywords: metabolic engineering; fermentation processes; biomolecule production

Metabolic Engineering is concerned with the metabolism of cells. It aims to improve cellular properties or increase the production of cellular products by making directed changes to cell metabolism, either at a DNA, RNA, or protein level. Research in this area typically begins with systems approaches that model the large networks involved in cell metabolism and assess potential targets for directed changes. Improvements can then be introduced by recombinant DNA techniques. This is a truly multidisciplinary area which involves chemical engineering, mathematics, biochemistry and molecular biology. It is also linked to recent breakthroughs in Metabolomics.

We have developed a new fermentation laboratory in the Department of Chemical and Biomolecular Engineering for the study of Metabolic Engineering, fermentation processes and biomolecule production. This laboratory contains four medium scale (5 L capacity) fermenters that can be used for the growth of bacterial, fungal or mammalian cells and the production of natural or recombinant biomolecules. Products include protein drugs, intracellular metabolites and other biomolecules that are useful for research or industrial processes. The medium scale capacity of these fermenters will allow us to study the scale up and optimisation of a wide range of fermentation processes.

Fig. 1: A Biostat Aplus fermenter system (http://www.sartorius.com/biostat_aplus/). (Photo courtesy of Sartorius Stedim Biotech GmbH.).

Protein Misfolding and the Self-Assembly of Non-Native Protein Nanostructures

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Sponsors: The University of Melbourne Early Career Researcher Scheme, Australian Academy of Science, Selby Scientific Foundation

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Keywords: protein misfolding; nanobiomaterials; peptide synthesis; amyloid fibrils

We are currently developing novel nanobiomaterials. Our research spans several disciplines ranging from peptide synthesis and microscopy, to spectroscopy and protein structural studies. Our studies are centred around a theme of protein or peptide self-assembly and the formation of non-native protein structures, such as amyloid fibrils. These fibrils are found in a number of diseases (e.g. Alzhiemer's and Type-II diabetes) but are also associated with positive functions, can be made from generic proteins and have outstanding properties including strength and stability in a wide range of environmental conditions. We examine how amyloid fibril-like structures made from synthetic precursors can be used to make new materials. We also seek to determine their structure and to extend their properties for biotechnology and nanotechnology applications.

A second goal is to understand how cells interact with their immediate environment, including nanomaterials, both outside and inside the body. We are currently developing nano-structured surfaces which can be used to examine and exploit cell behaviour.

We use peptide synthesis (microwave assisted and manual) to make the starting materials for building fibrils and other protein-based materials. We monitor protein aggregation and self-assembly (light scattering, dye binding), and characterise the properties (Fourier transform infrared spectroscopy, circular dichroism), structure (fibre X-ray diffraction using Wide and Small X-ray sources such as the synchrotron) and appearance of samples (microscopies including Transmission Electron Microscopy, Scanning Electron Microscopy and Atomic Force Microscopy). Cell lines are also cultured and used to study cell adhesion, cell migration and cell behaviour (confocal microscopy) in response to new nanostructured surfaces or nanofibers and to examine the potential toxicity of these novel materials.

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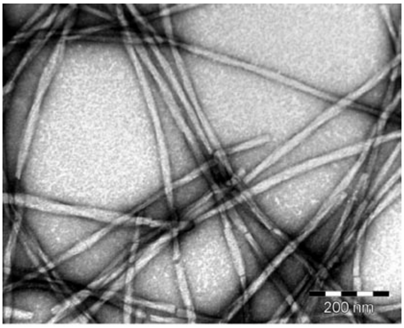

Fig. 1: A transmission electron micrograph image of a protein nanofibre. The scale bar is 200 nm in length.

Control of Surface Forces Using Synthetic Peptides

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Keywords: synthetic peptides; surface forces; surface functionalisation

Polymers have been widely used as a means of controlling the properties of a surface. We are investigating how peptides, which are effectively advanced polymers, can be used to modify surfaces and offer better control of surface properties. Peptides can display a wide range of physicochemical properties resulting from the sequence of natural and non-natural amino acid monomers. Many peptide sequences are also known to display biological activity when attached to a surface. We are developing chemical techniques to assemble peptides onto different materials. Once this technology has been established, it will be straightforward to make surfaces that display different peptides and interact in different ways with their surrounding environment.

Surfactant Effects in Sonoprocessing

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Keywords: surfactant effects; sonoprocessing; ultrasonic applications

This project provides the fundamental science required to further develop a range of ultrasonic applications for use within the Australian food industry, the wastewater treatment industry and in medical science. In particular, it will assist applied research currently sponsored by both the Victorian Government's Science Technology and Innovation (STI) initiative and the Commonwealth Scientific and Industrial Research Organisation (CSIRO) Food Futures Flagship, which considers the use of ultrasound to assist in bioactives separation, food emulsification and membrane operations. The development of ultrasound contrast agents (surfactant coated microbubbles) also has the potential to increase both the length and quality of life for many Australians. The work addresses both National Research priorities and the CSIRO Food Futures Flagship goals.

Ultrasonics as a New Platform Technology in Dairy Processing

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Sponsors: Australian Research Council, Dairy Innovation Australia

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Keywords: dairy processing; ultrasonics; energy efficiency

The financial viability of the Australian dairy industry relies heavily on the manufacture and export of milk powders and dairy protein concentrates. In an earlier ARC Linkage Project, we achieved a significant breakthrough in the manufacture of whey protein concentrates by using ultrasound to lower the viscosity and improve the heat stability of these systems. In this project, we will further develop a fundamental understanding of why these changes occur. We will also extend our research to incorporate casein-based systems and to consider the impact of ultrasound on dairy membrane processing. Results will be used to increase the energy efficiency of Australian dairy manufacturing plants and to develop novel heat stable dairy ingredients.

CSIRO Water for a Healthy Country Flagship: Advanced Membrane Design Cluster

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Keywords: fouling mechanisms; novel membrane materials; desalination

A major component of the energy demand associated with desalination arises from the fouling of membrane surfaces, which reduces the flow of water achievable. In this project, we characterise fouling mechanisms and desalination performance of both existing and novel membrane materials using bench scale experimentation. This work falls within the CSIRO Water for a Healthy Country, Advanced Membrane Design Cluster.

CSIRO Food Futures Flagship: Bioactives Separation Cluster

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Keywords: bioactive ingredients; foam stability; ultrasonics

The aim of this project is to investigate the use of foam fractionation to isolate high value bioactive ingredients. Once a viable approach is developed, we will determine the operating conditions under which ultrasonics provide both maximum and minimum foam stability. We also aim to investigate at a preliminary level the viability of ultrasonic atomisation.

Curd and Dairy Microstructure and Texture Quality Control Tools

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Research Centre: Particulate Fluids Processing Centre

Collaborators: Murray Goulburn Cooperative Co. Ltd., National Foods, Warrnambool Cheese and Butter Factory Company Holdings Limited, Burra Foods Australia, Mark Auty Moorepark Food Research Centre, Teagasc Moorepark

Sponsors: Australian Research Council, Dairy Innovation Australia Ltd., Business Victoria

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Keywords: curd and dairy microstructure; advanced dairy products; quality control

The microstructure of cheese is one of the major controlling factors that determine cheese texture and functional properties. Changes in the process conditions or the choice of ingredients can alter the microstructure of the curd and cheese considerably and thus the functional properties. Our research focuses on the use of advanced microscopy such as Confocal Laser Scanning Microscopy and the Cryo Scanning Electron Microscopy to study the microstructure of curd and cheese. Our research also looks at the influence of varying the process and ingredient parameters on the development of the viscoelastic and textural properties of the milk gel using rheological methods and textural analysis.

To date, we have developed methods to characterise cheese and curd microstructure under conditions relevant to manufacture by our industry partners. Further progress will help Australian manufacturers to produce advanced dairy products with enhanced product consistency. This project also has the potential to provide an important tool for the quality control of dairy products.

The Removal of Mercury from Solution by Polymer Inclusion Membrane Extraction

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Student: Patrick Mornane

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Keywords: polymer inclusion membranes; metal ion extraction

Solvent extraction is used extensively in the hydrometallurgical industry as a means of separating metals from their pregnant liquors and also refining them by selective removal of impurities. Generally large quantities of flammable and toxic solvents and extractants are required making this process environmentally unfriendly and potentially unsafe. An alternative to solvent extraction is polymer inclusion membrane extraction. In this case polymeric membranes (see Fig. 1) have extractants (or carriers) incorporated into them, which facilitate the transport of metals though them. In this configuration the free carrier is continuously regenerated allowing for the reagents to be used more efficiently [1].

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Fig. 1: Polymer inclusion membrane.

Geopolymers for Nuclear Applications

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Sponsor: Australian Research Council

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Keywords: nuclear waste storage; geopolymers

With the pressing need for the reduction of Greenhouse gas emissions from electricity generation in Australia, one option that must be seriously considered is nuclear energy. However, the issue of nuclear waste storage must be addressed. Geopolymeric cements are expected to perform much better than traditional Portland cements in nuclear applications, both for solidification of radioactive wastes and also for the construction of underground waste storage bunkers. This project will use Australia’s strong existing knowledge in geopolymers research, and apply it to the development of materials to fill the need for environmentally secure waste storage solutions.

Polymer Additives for Improving Nickel Extraction Processes

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Collaborators: Geoff Senior (BHP-B), Chris du Plessis (BHP-B)
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Keywords: mining industry; nickel extraction; polymer additives

The importance of the mining industry for the extraction of mineral and metals to Australia's economy has received much publicity in recent years. Nickel is one of the most significant of these metals in terms of its contribution to export. However, the process of extracting nickel from its natural ores can be complicated by the presence of unwanted gangue minerals.

The extraction process can be aided by the addition of natural polymers such as guar gum to modify the surface properties of the minerals. However, the improvements shown by this process have proven to be somewhat unpredictable and are not well understood. Therefore, a detailed explanation of the roles of the biopolymers in this process would significantly improve its efficiency. The potential rewards to the Australian economy from improvements in nickel extraction efficiency are extensive.

The research towards this has focused on two distinct areas: (i) a detailed chemical and physical characterisation of guar, and (ii) an investigation of how these factors influence the efficiency of guar in the nickel extraction process. In addition to improving the performance of guar itself, one of the aims of this project is to synthesize a synthetic analogue of guar. The approach employed involves the development of a deep understanding of the mechanism of the guar-talc interaction so that it may be mimicked through the application of synthetic analogues. Synthetic polymers have the potential to be cheaper, more efficient and, most importantly, more consistent than their natural equivalents. So far the research conducted has shown much promise and has led to the filing of two provisional patent applications for synthetic aids to the flotation process (Fig. 1).

Fig. 1: Flotation cells used at Mt Keith (Western Australia) for nickel production. (Reproduced with permission of BHP-Billiton.)

Novel Nanoparticles for Advanced Automotive and Industrial Coatings

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Sponsor: Australian Research Council

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Keywords: novel nanoparticles; automotive and industrial polymer coatings

In conjunction with our industrial partner (DuPont), this project aims to develop the next generation of automotive and industrial polymer coatings that can be integrated into existing production systems. The new coatings will be environmentally friendly and will make a significant contribution towards solving the emission issue of volatile organic compound (VOC) faced by the industry. The novel nanoparticles developed in this project will possess unique rheological and film forming properties, whilst maintaining a commercially competitive price. The technologies developed in this project represent the cutting edge of macromolecular science.

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Core-Crosslinked Star (CCS) Polymer and their Clusters: The Next Generation in Polymeric Particles

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Sponsor: Australian Research Council

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Keywords: CCS polymers; polymeric materials; unique macromolecules

This project involves the development of a relatively new type of macromolecular architecture, termed core-crosslinked (CCS) star polymers and their clusters. As part of a research strategy to develop novel CCS polymers and their applications, the Polymer Science Group has prepared a large variety of polymeric materials based on CCS polymers.

Recent developments include the production of CCS clusters, fullerene functionalised CCS, fluorescent CCS, Dendron-CCS, CCS dumbbells and CCS-quarto polymers. In addition, the group has conducted a variety of fundamental studies to determine the properties of these unique macromolecules, which is helping to establish their potential applications. These new macromolecules will not only advance polymer science into a new era, but will provide a basis for the development of technologically superior materials for coatings, drug delivery systems, organic photovoltaics, rheology modifiers and biomolecular separations.

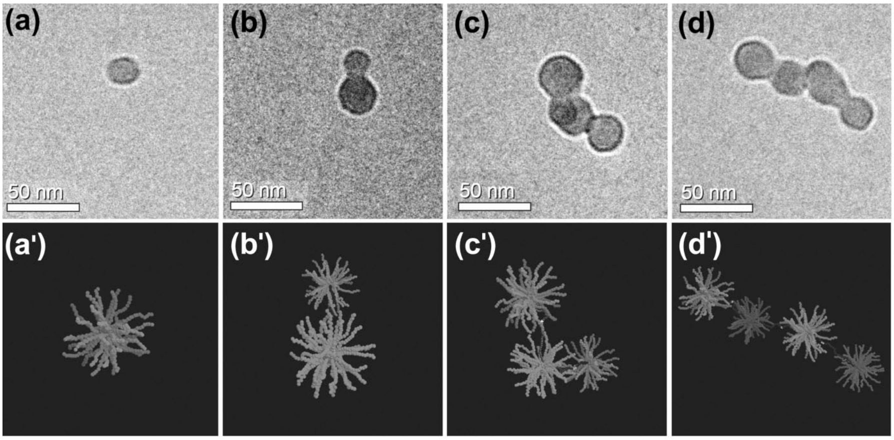

Fig. 1: Cryo-TEM images of poly(methacrylic acid)-based (a) core cross-linked star polymer, (b) dumbbell polymer, (c) tri-star assembly and (d) quad-star assembly. Computer simulated perspective models (a'-d') represent the orientation of the macromolecules towards the cryo-TEM camera.

[1] L.A. Connal, R. Vestberg, C.J. Hawker, G.G. Qiao, "Synthesis of Dendron Functionalized Core Cross-linked Star Polymers", *Macromolecules*, ACS Publications, **40**(22), pp. 7855-7863, 2007.

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Design and Synthesis of Super-Macromolecular Architectures with Selectively Degradable Functionality

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Students: Nashrul Fazli Mohd Nasir, Jing Min Ren

Sponsor: Australian Research Council

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Keywords: drug delivery; CCS polymers; cancer treatment

In the past decade considerable attention has been focused on the merging fields of polymer chemistry and the biological sciences. One particular area which has attracted a great deal of interest concerns the use of polymers as potential drug delivery vehicles. Properties such as the capacity to solubilise hydrophobic drugs, target specific physiological sites such as cancerous cells, and have control over the rate of drug release have proven quite attractive for many potential applications. The use of such macromolecules can also lead to reduced dosage requirements and consequently minimise any potentially undesirable side effects associated with the drug.

This project involves the development of selectively degradable CCS polymers. The ability to control the rate at which encapsulated molecules can be released is an important factor in the design of efficient drug delivery devices. In this regard, several different techniques for incorporating degradable functionality into CCS polymers have been examined as a potential means of controlling release kinetics.

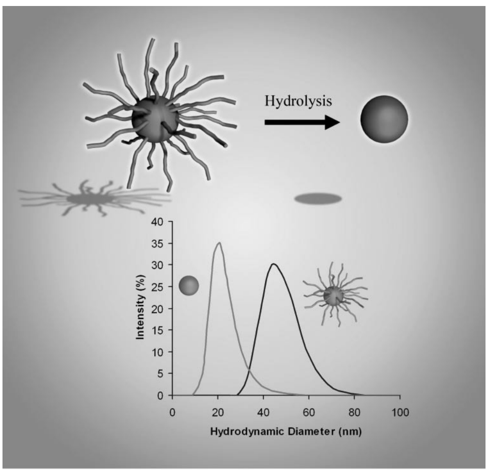

Fig. 1: Arm degradable CCS polymer was hydrolyzed to produce the core. DLS experiments indicate the size change of these nanoparticles before and after degradation.

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Flexible Honeycomb Films

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Keywords: honeycomb films; biotechnology industry; biosensor systems

Micro-porous polymer films with self-assembled honeycomb morphology produced by the 'breath figure' technique have distinct advantages over other lithographic techniques; there is no need for expensive equipment, it is a simple and cheap process that can control pore sizes through varying casting conditions. These ordered porous films have potential applications particularly in biotechnology industries. Similar films have been made from a variety of polymers, for example, star polymers and CCS polymers.

In this project we have developed a technology to coat honeycomb films on non-flat surfaces. For example, an ordered honeycomb film has recently been coated onto the surface of non-flat TEM grids by using CCS polymers with low glass transition temperatures (T_g). The advantage of these low T_g systems is that the resulting honeycomb films have better elastic properties, which therefore leads to more robust and uniform films that are resistant to fracture. A similar system has also been developed to coat particulate surfaces, including glass microbeads, kaolin particles, salt and sugar crystals. The process is very robust and the project is now applying this technology to developed biosensor systems.

Fig. 1: Regular porous honeycomb films were produced on the surface of TEM grid (left) and particle surface (right). (Magazine covers reproduced with permission of Wiley-VCH Verlag GmbH & Co KGaA and the Royal Society of Chemistry.)

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Investigating the Structure-Property Relationships in Micro/Nano-Reinforced Thermoset Polymer Systems

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Keywords: micro/nano-reinforced thermosetting systems; polymer nanocomposites

Thermosetting polymers offer advantages such as light weight, high strength and excellent mechanical properties. Polymer nanocomposites are a relatively new class of polymers that exhibit markedly superior physical and chemical properties, with low filler concentrations. In collaboration with CSIRO, this project is investigating the structure-property relationships in micro/nano-reinforced thermosetting systems, more specifically, how changes in molecular architecture surrounding the fillers impact on the overall performance of the material. New nanocomposite material are currently being synthesised, modelled and their curing kinetics evaluated. The systems will be analysed by a range of analytical and physical performance techniques, including x-ray diffraction, transmission electron spectroscopy, nuclear magnetic resonance, infrared spectroscopy, thermal and thero-mechanical techniques, to assess the structure-property relationships.

Polymer Characterisation Facility (PCF)

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Keywords: advanced materials science; macromolecular science; nanotechnology; biotechnology

Future development of macromolecular and biotechnologies have the potential to revolutionise everyday life. Current applications include plastics for engineering, diagnostic devices for biochemical analysis, polymer therapeutics for drug delivery and prosthesis with specific functions.

The PCF provides the analytical tools required for the execution of cutting-edge research by internationally renowned researchers at the University of Melbourne, to probe and develop advanced materials with application in medicine, agriculture, composites, cosmetics, communications and electronics. The facility will enable researchers at Melbourne and their partner organisations to maintain their position at the forefront of advancing macromolecular, nano- and bio-technology and advanced material sciences. The multi-user facility will provide inter-disciplinary collaboration with researchers in academia and industry, and will be vital in training the next generation of Australian scientists. The PCF comprises of state-of-the-art instruments for the characterisation of synthetic and biological macromolecules, nano and micro-particles, surfaces and biomaterials.

Fig. 1: The suite of instruments that make-up the PCF.

Building Advanced Polymeric Nanotubes for Targeted Drug Delivery

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Keywords: drug delivery; advanced polymeric nanotubes; cancer treatment

Advanced drug delivery devices have major commercial applications in fighting diseases like cancer and infectious viruses. The success of this project will provide fundamental knowledge for the design of new drug delivery devices based on polymeric nanotubes. The project will also further advance Australia's nano- and bio-technological research and industries. This project will also provide additional benefit for developing controlled release systems in drug delivery and artificial vessels, and improve sensitivity in molecular sensors. The pioneering work proposed will ensure that Australia remains at the forefront of innovative scientific research within the rapidly advancing disciplines of nanotechnology and novel macromolecular design.

Solid-Liquid Separation: Characterisation, Modelling and Application

Staff: Peter Scales, Shane Usher, Adam Kilcullen, David Dixon, Ross de Kretser, Anthony Stickland

Students: Rudi Spehar, Anat Kiviti-Manor, Ben van Deventer, Ashish Kumar

Collaborators: Murray Rudman, Darrin Stephens, Phil Fawell (CSIRO), Professor Lee White (University of South Australia), Professor Richard Buscall (MSACT Consulting, UK)

Sponsors: RioTinto, Australian Mineral Industries Research Association (AMIRA), Australian Research Council

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Keywords: solid-liquid separations; fluid dynamics; suspension mechanics

The industrial utilisation of many fundamental approaches to process modelling of solid-liquid separations is low and the gulf between academia and operations is indeed wide. A comprehensive description of suspension compressional dewatering was first published in 1987 and this theoretical description has now been complemented with the development and validation of rigorous laboratory and field characterisation methods for the extraction of material property parameters for input to process modelling. To achieve this task, test rigs and software tools for dewatering parameter estimation have been developed and licensed. Simple steady state and one dimensional phenomenological mathematical models of sedimentation, thickening, plate and frame filtration, gravity belt filtration, and batch and continuous centrifugation have also been developed. These models have proven to be successful in describing the basics of many process operations in the minerals industry and for non-biological particulate suspensions (sludges). Despite the successes, the models have been inadequate in many instances. It is often not clear if this is as a result of model or parameter estimation difficulties. To this end, the aim of this work is to extend the models to two and three dimensional descriptions and to include transient rather than steady state behaviour. The modelling is based on analytical, numerical and computational fluid dynamics approaches. Application of the modelling has been to processes in the minerals, dairy, water and waste water industries and this will remain the focus of the work.

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Stabilisers for Nanoparticles and their Use in Nanoparticle Synthesis

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Keywords: nanoparticle synthesis; stabilisers

Particles with diameters in the nanometre range are of interest for a wide variety of industrial applications, but preventing such fine particles from growing or aggregating remains a challenge. The project is exploring ways of growing, measuring and improving the stability of inorganic nanoparticles dispersed in fluids of industrial interest. Of particular interest, is the growth and stabilisation of nanoparticles in an aqueous environment at high solids. This has required the development of novel surfactant and polymer moieties and controlled shear manufacture technologies. The particle targets of the work are metals and metal oxides that show either conducting, semi-conductor and resistive properties as potential for use in inks and as fillers.

Suspension Rheology

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Sponsors: Australian Research Council, Australian Mineral Industries Research Association (AMIRA)

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Keywords: suspension rheology; colloidal networks; particulates

The flow properties of concentrated suspensions of colloidal particles is of interest to a wide range of industries. The aim of our work is to provide a fundamental understanding of the failure of attractive colloidal networks and to establish new methodologies for the measurement of particulate suspension rheology across a wide range of solids concentrations and shear rates. To this end, new applications of techniques are being developed to understand the behaviour of colloidal networks in small and large amplitude oscillatory shear. The expected outcome is a more quantitative methodology for the interpretation of flow property data for particulate suspensions. In addition, the use of methodologies that are less likely to exhibit slip such as the vane in 'infinite' media measurement technique and small angle oscillatory method using a vane are being explored as an alternative to cup and bob and other techniques for the measurement of industrial particulate suspensions. These measurements are being coupled with capillary rheometry to provide a broad shear rate range for suspension characterisation. In addition, the failure of flocculated suspensions in compression remains a challenge for which a range of new experimental options are being developed.

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Development of In Ground and On Site Technologies for Low Cost Metal Remediation of Remote Contaminated Sites

Staff: Geoffrey Stevens

Collaborators: Damian Gore (Macquarie University), Ian Snape (Australian Antarctic Division, Hobart), PANalytical Spectris Australia Pty Ltd, Veolia Environmental Services Pty Ltd (formerly Collex Pty Ltd)

Sponsor: Australian Research Council

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Keywords: metal remediation; remote contaminated sites; environmental protection; Antarctic

Internationally, Australia has taken a leading role in promoting environmental awareness and is committed to both tackling existing pollution and mitigating future hazards. The clean-up of contaminated Australian, Antarctic and sub-Antarctic sites is seen as a national priority and research into in-situ technologies is central to meeting established remediation goals. Successful development of a low-cost in-ground remediation scheme will provide vital protection for remote Australian, Antarctic and sub-Antarctic areas. It will also do much to cement Australia as a global leader in environmental protection, offering as it does a generic remote regions metal contamination remediation solution.

Development of Low Cost In Situ Techniques for Petroleum Remediation in Cold Regions

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Keywords: hydrocarbon remediation; cold regions; environmental protection; Antarctic

The clean-up of abandoned Antarctic sites is a priority, and research into low-impact technology is central to meeting established remediation goals. Successful development of a low-cost in-situ remediation scheme will not only serve to protect vulnerable Antarctic habitats in Australian stewardship, but will do much to cement Australia as a global leader in environmental protection offering as it does, a generic cold region hydrocarbon remediation solution.

Influence of Impurities in Commercial Solvent Extraction Processes

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Keywords: solvent extraction; remediation of waste water; metal recovery

This project directly supports the solvent extraction industry in Australia. This industry is responsible for generating in excess of $600M annually of export earnings for Australia. This type of technology can be applied in the recovery of base metals such as coper, nickel, cobalt, etc. and in the environmental area for the clean up of heavy metals from waste water. Solvent extraction has the advantage of high selectivity that enables metals to be recovered and recycled, thus reducing the wastage of these metals in, for example, the chromium plating process.

Next Generation of Separation Equipment for Natural Product Extraction

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Keywords: natural product extraction; membrane contactors; fouling control; solvent extraction

This research will assist GlaxoSmithKline to upgrade to a more efficient plant, which is important for maintaining their competitive position in the global economy. The benefit to other Australian processing industries will be an improved understanding of the performance of membrane contactors when used for natural product separation and more specifically, a reliable method for controlling fouling in this type of equipment, which is a currently a significant industry problem.

Development of Biocompatible, Biodegradable Composite Scaffolds for Adipose Tissue Engineering

Staff: Geoffrey Stevens, Andrea O'Connor

Collaborator: Bernard O'Brien Institute of Microsurgery

Sponsors: Australian Research Council, National Health and Medical Research Council (NHMRC)

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Keywords: tissue engineering; advanced materials; scaffolds

The aim of the research is to develop biocompatible, biodegradable composite materials (collagen/mesoporous silica) for adipose tissue engineering applications. These materials would constitute the 'constructs' onto which new vascularised adipose tissues may regenerate and repair tissue defects due to trauma (e.g. deep burns), tumour defects (e.g. breast cancer) or disease (e.g. Poland Syndrome). When realised, these scaffolds will constitute a significant advancement particularly in the field of plastic reconstructive surgery from which new clinical therapies could originate to enhance the lives of many patients afflicted by the aforementioned pathologies.

Investigation of the Coupling of Bio-active Groups to Biodegradable Polymers

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Keywords: biodegradable polymers; coupling techniques; bioactive molecules; tissue engineering

The synthesis of biodegradable polymers containing functional groups which can be utilised for further coupling reactions with bio-active molecules have uses in many different applications including tissue engineering, drug delivery and biosensors. These functional groups are incorporated into the polymer backbone through the synthesis of a functional monomer and subsequent co-polymerisation with a standard monomer. This project investigates the efficiency of several different coupling techniques in attaching various bio-active molecules before looking at different properties that can be attained and some applications.

Bioactive Tissue Engineering Scaffolds

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Keywords: tissue engineering; bioactive scaffolds; 3D biodegradable polymers

Three dimensional (3D) biodegradable polymeric scaffolds play an important role in the development of tissue engineering. They must provide both an optimal physical and chemical template for cell attachment, migration, proliferation and tissue generation. In this project, 3D scaffolds with large and highly interconnected pores (> 300 μm) are fabricated from poly(lactic-co-glycolic acid) (PLGA) using thermally induced phase separation (TIPS). Scaffolds are tested for mechanical strength and in vitro cell attachment and proliferation. The scaffolds will be modified by incorporating basic fibroblast growth factor (bFGF) for enhanced bioactive properties. The approach involves using a layer-by-layer (LbL) technique which allows the build up of multilayer films via the alternate deposition of polycations and polyanions onto charged surfaces. The bFGF release kinetics will be determined by immunoassays. The modified scaffolds will be tested in vitro for cell attachment and proliferation. Finally, the promising scaffolds will be used for in vivo animal tests towards a potential new human applicable biomaterial scaffold.

Cell Migration Models

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Keywords: T cell development; cell migration models

Throughout life, T cell development occurs in the thymus. The seeding of the thymus by multipotent stem cells from the bone marrow is periodic (approximately every 3 weeks), however it is well known the output rate of cells from the thymus is constant. Imaging data of the thymus show immature T cells are highly motile and are actively interacting with antigent presenting stromal elements. Immature thymocytes out-number the stromal cells 200 to 1, and this raises the possibility of competition between cells for survival and maturation signals. The maturation of cells also depends on spatial signals in the thymus. A combination of systems of ordinary and partial differential equations are used to model T cell development.

Microemulsion Templated Mesoporous Silica for Affinity Separations

Staff: Geoffrey Stevens, Andrea O'Connor

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Keywords: advanced materials; microemulsion templated mesoporous silica foams; bio-affinity separation

In areas such as the production of protein-based pharmaceutics, the selective adsorption of biological macromolecules is an important step to achieving the required purities. Recently developed microemulsion templated mesoporous silica foams which consist of highly porous 3-dimensional networks, offer the potential to be adsorbents with both high selectivity and high capacity. The study has focused on the development of these materials for protein-A IgG bio-affinity separations and has involved both materials science aspects of synthesising, functionalising and characterising these materials, as well as the application side in demonstrating their use in the protein-A IgG bio-affinity separation. Significantly the work has shown that these materials have over twice the adsorption capacity of commercially available media, highlighting their potential in this area.

Development of Mesoporous Bioaffinity Adsorbents for Biological Applications

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Keywords: mesocellular foam; industrial bio-separations; mesoporous bioaffinity adsorbents

This study investigates potential application of mesocellular foam (MCF) for industrial bio-separations application. Several techniques are being explored such as a templating method, in-situ particle enlargement, as well as post synthesis enlargement. In the templating approach, a porous template of polyacrylamide was selected for the composite MCF adsorbent to form and retain its structure. Sedimentation polymerisation of polyacrylamide coupled with optimisation of calcination temperature were directed towards controlling the enlarged particles' stability, for bio-separation application. Upon MCF particles size enlargement, reusability and adsorption kinetics of enlarged adsorbent will be studied as well as regeneration methods required to prolong the adsorbent lifetime in their application.

Use of Zeolites as Controlled Release Fertilisation Systems for Petroleum Hydrocarbon Remediation at Low Temperatures

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Keywords: petroleum hydrocarbon remediation; zeolites; Antarctic

During the 2005/06 Casey Station Antarctic season a permeable reactive barrier was built and installed at the end of a hydrocarbon plume. The barrier contained a range of materials (zeolites, nutrient amended zeolite, granulated activated carbon, maxbac and sand), to capture hydrocarbons and degrade them via microbial stimulation. The barrier was heavily sensored with twenty six temperature sensors, ten oxygen sensors and forty multiport strings. In addition, the barrier contained oxygen distributors and heat tracing. During the season the performance of the barrier was continually monitored and work is still continuing.

Characterisation of Glassy Polyimide Gas Separation Membranes at Elevated Temperature

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Sponsor: CRC for Greenhouse Gas Technologies (CO2CRC)

Collaborator: Colin Scholes (CO2CRC)

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Keywords: global warming; polymeric membranes; carbon dioxide capture

In response to growing concern over increases in globally averaged surface temperatures and associated global warming phenomena, there has recently been added interest in geosequestration of carbon dioxide as a possible short/medium term solution. This project investigates the use of polymeric membranes as a possible CO_2 capture technology for geoseqestration. Specifically, this project considers polyimide membranes for the separation of carbon dioxide from the flue gases of coal-fired power stations, as well as from natural gas. Several facets of glassy polyimide membranes have been investigated, including the relationship between temperature and the CO_2-induced plasticisation tendencies of such membranes. Enhancement of polyimide membrane performance with increasing temperature due to charge transfer complex formation has also been investigated. Recently completed work included examination of improved membrane stability through grafting of epoxy material into the membrane's polymeric structure. This project is a collaborative effort between the Particulate Fluids Processing Centre (PFPC) and the CRC for Greenhouse Gas Technologies.

CO_2 Recovery Using a Modified Polypropylene Gas Absorption Membrane

Staff: Geoffrey Stevens, Jilska Perera, Sandra Kentish

Student: Michael Simioni

Collaborators: Particulate Fluids Processing Centre (PFPC) and the CRC for Greenhouse Gas Technologies (CO2CRC)

Sponsor: CRC for Greenhouse Gas Technologies (CO2CRC)

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Keywords: carbon dioxide separation; membrane contactors

Membrane contactors have significant advantages over packed columns for CO_2 separation from other gases using chemical absorption. The membrane offers a larger interfacial area between phases but must be compatible with the solvent. The extreme hydrophobicity of polytetrafluoroethylene makes this an ideal membrane material but it is expensive. While untreated polypropylene is insufficiently hydrophobic for use with low surface tension amine based solvents, polypropylene membranes that are treated may provide a cheaper alternative. Different membranes are being developed and tested using both hollow fibre and flat sheet membrane configurations.

Impact of Impurities on Polyimide Membrane Performance

Staff: Geoffrey Stevens, Sandra Kentish

Student: Colin Scholes

Collaborators: Particulate Fluids Processing Centre (PFPC) and the CRC for Greenhouse Gas Technologies (CO2CRC)

Sponsor: CRC for Greenhouse Gas Technologies (CO2CRC)

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Keywords: polyimide membrane performance; impurities; carbon dioxide separation

Previous studies have shown that polyimide membranes exhibit high permeabilities and permselectivities for the removal of CO_2 from both natural gas and flue gas streams. However, most of these studies have been conducted with pure gases in the absence of any contaminants. Contaminants such as hydrocarbons, water and sulphur compounds may restrict the performance of a membrane and result in premature membrane failures in the field. This research is aimed at understanding the impact of these contaminants on 6FDA-Durene and Matrimid 5218 membrane performance. Results will allow for the improved design of pre-treatment systems to remove these contaminants prior to the membrane system. The possibility of regeneration of the membrane to restore the original performance after it is exposed to contaminants will also be studied.

Capture of Carbon Dioxide from Flue Gas Using Potassium Carbonate

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Sponsor: CRC for Greenhouse Gas Technologies (CO2CRC)

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Keywords: carbon dioxide capture; potassium carbonate solvents; flue gas

The absorption of carbon dioxide in chemical solvents has been extensively utilised for the capture of CO_2. However, the capture of CO_2 from coal-fired power plant flue gas streams presents new challenges to current absorption technologies. These are due mainly to the nature of these emissions, being extremely large volumetric flows with low total and CO_2 partial pressures. This project has been investigating various process flowsheet options and equipment designs to optimise the energy requirements of a process utilising a potassium carbonate solvent. To date, detailed process simulations, experimental verification of simulations utilising a lab scale rig and preliminary design studies have been performed.

Emulsion Stability in the Pharmaceutical Industry

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Sponsor: Australian Research Council

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Keywords: emulsion stability; droplet coalescence; pharmaceutical industry

Emulsion stability and coalescence rates of liquid-liquid systems are an important consideration in numerous large-scale processes including solvent extraction. This project examines the mechanisms that dominate in film drainage, a process that controls droplet coalescence and emulsion stability. A novel method employing imaging ellipsometry is used to study the thin film drainage between a silica surface and oil droplet in an aqueous phase. The effects of interfacial tension and mass transfer across the liquid-liquid interface have been the focus of recent studies. This project is also aimed at developing current experimental methods to study thin films between silica and a 'free' oil droplet in a continuous phase approaching the silica surface with known velocity.

Hydrodynamic Interactions between a Silica Particle and a Deformable Oil Droplet – Effect of Particle/Droplet Size Ratio

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Keywords: hydrodynamic interactions; silica particle/oil droplet size ratio

In many industrial applications such as froth flotation, foams and emulsions, the interactions between solid and deformable interfaces, or two deformable interfaces, is of critical importance. Understanding these micro-scale interactions is vital for the prediction and control of the macro-scale behaviour. This project specifically aims to investigate the existence, or otherwise, of a slip boundary between the two interacting surfaces. Experimental data will be collected using the atomic force microscope, and modelled using a mathematical model developed within the PFPC. This data will then be compared to the theoretical interactions, in which different slip lengths can be incorporated. The major challenge with this project is using the optimum parameter space, where the strength of the hydrodynamic interaction, and the theoretical effect of slip, are maximised. To this end, interaction profiles between large silica particles (>50μm diameter) and oil droplets of similar size or smaller have been measured, and will be compared to interaction profiles predicted by the mathematical model.

Influence of Fine Particles on Collection Efficiency in Flotation

Staff: Geoffrey Stevens, Raymond Dagastine

Sponsors: Australian Mineral Science Research Institute, Australian Research Council, AMIRA International, BHP/Billiton, Rio Tinto, Anglo Platinum, Phelps Dodge Mining, Xstrata Copper, Orica Australia

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Keywords: mineral processing; fine particles; flotation; sustainability

Flotation is a major process used to separate valuable minerals from clays, silica and other non valuable materials in many mineral processing operations. The process involves the use of surfactants to attach the valuable materials to the air – water interface. This project aims to measure the colloidal and interfacial forces at the gas liquid interface using the atomic force microscope. Comparing the forces for the bare air – water interface with interfaces covered with fine dispersions of clay, for example, will help to understand the role of these fine particles in the flotation process. This information is vital to the minerals industry in controlling its water usage and long term sustainability.

Synthesis and Functionalisation of Advanced Polymer Films and Particles

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Sponsor: Australian Research Council

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Keywords: smart polymers; biomedical applications; drug delivery; nanostructures

Scientific and technological advances at the frontiers of nano and biotechnology are poised to revolutionise the scope of treatment and healthcare options. This project will involve the synthesis of engineered polymer building blocks with the capability for multifunctional and intelligent response. These smart polymers will then be assembled into responsive nanostructured materials for investigation in biomedical applications. Layer-by-Layer (LbL) assembly is one method that will be investigated for designing such materials, as it offers a simple and versatile technique for synthesising thin films of diverse composition. The work will focus on utilising a novel approach to LbL assembly, developed by the Caruso group, which allows a range of low-fouling, multifunctional components to be readily incorporated into the system. It is hoped this project will facilitate the development of new nanostructured materials for eventual application in drug and gene delivery.

Sustainable Technologies for Construction and Minerals Processing

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Students: Ailar Hajimohammadi, Claire White, Nee San Yap, Chu Zheng Yong, Syet Li Yong

Research Centres: Particulate Fluids Processing Centre, CO2CRC

Sponsors: Australian Research Council, Geopolymer Alliance, US Air Force Asian Office of Aerospace Research and Development, Zeobond Pty Ltd

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Keywords: mineral processing; geopolymers; sustainable technologies

The research of the Geopolymer and Minerals Processing Group (GMPG) has two primary foci: geopolymer materials as a sustainable alternative to Portland cement concretes; and improving the efficiency of minerals extraction processes. In the minerals field, research efforts are focused on developing a better understanding of the separation-in-froth flotation technique, as well as the use of environmentally friendly alternatives to cyanide in gold extraction.

Research into geopolymers is aimed at the use of these materials as an alternative to Portland cements, due mainly to the very high CO_2 emissions (around 5% of global emissions) associated with cement production. GMPG members are currently working on projects ranging from the nanoscale (molecular structure of the geopolymer binder phase) to the macroscale (full-scale fire testing of geopolymer concrete panels). The reaction mechanisms involved in the synthesis and ageing of geopolymers is an area of particular interest (Fig. 1). Advanced characterisation techniques, in particular solid state NMR, in situ infrared spectroscopy and synchrotron beamline methods, have provided key information regarding the roles played by many of the components of the complex geopolymerisation system. Mathematical modelling and surface interactions are also areas of interest and key importance in the study of geopolymers.

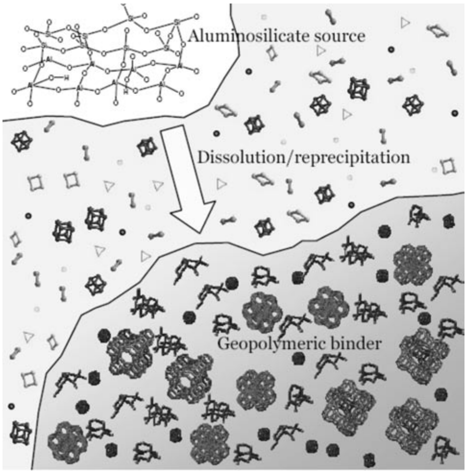

Fig. 1: Schematic diagram of the reaction processes involved in geopolymerisation.

Engineering Properties of Inorganic Polymer Concrete

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Keywords: inorganic polymer concrete; sustainable technologies; geopolymers

Inorganic polymer concretes (IPCs) can be made predominantly from industrial waste materials, such as fly ash (a coal combustion by-product), granulated blast furnace slag (GBFS), mine tailings and contaminated soil. They are aluminosilicate polymers synthesised by reacting aluminium and silicon containing materials with an alkaline silicate solution. The resultant mixture is then cured at ambient temperature and pressure to form a hardened ‘concrete like’ material in appearance. IPCs can exhibit superior chemical and mechanical properties to ordinary Portland based cement concrete (OPC).The recent increased pressure on industry by governments world-wide to identify new sustainable technologies that offer reductions in CO_2 emissions, energy consumption as well as being able to add value to the existing industrial by-products, may facilitate the wider uptake of the technology in the near future.

The objective of the project in hand is to investigate the engineering properties of the IPCs. In order to use IPCs in structural engineering applications, a precise evaluation of these properties is essential. The properties that are being investigated for a variety of IPC formulations include compressive strength, splitting tensile strength and flexural strength, static chord modulus of elasticity, Poisson's ratio and bond strength. This work will therefore serve as a basis for the future development and understanding of the structural engineering properties of IPCs. Figure 1 depicts the normalised bond strength of IPCs with the reinforcement obtained by two types of tests carried out (direct and beam-end specimen). The results of the recent tests indicate that Australian, USA and European design guidelines and recommendations developed for ordinary concrete are applicable for IPC. For instance, Fig. 2 indicates the tensile strength of six IPC mixes compared to standard recommendations. Tensile strength is an important property when considering the reinforcing-concrete interactions. The ongoing research is considering the applications of the IPCs as reinforced structural elements. A typical application of the IPCs where it can benefit the speedy construction process due to its early gains in strength (when compared to OPC) is the anchorage zones of post-tensioned slabs.

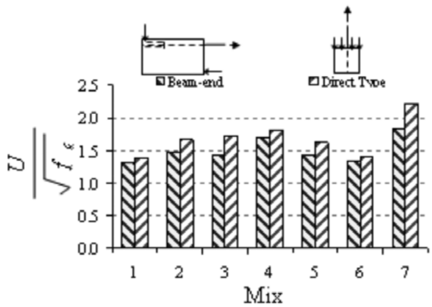

Fig. 1: Normalised bond strength of concrete.

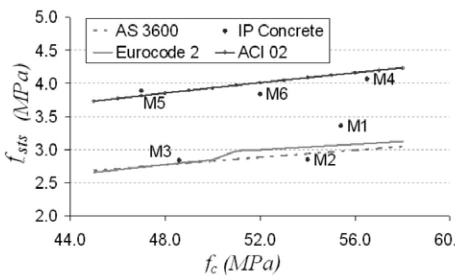

Fig. 2: Tensile and compressive properties of IPCs.

Design and Synthesis of Complex Nanostructured Materials for Enhanced Performance

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Keywords: nanostructured materials; mechanical properties; microstructure design

This project aims to significantly enhance mechanical properties of existing light alloys, including room temperature, strength and ductility, and high temperature creep resistance, and to achieve a good combination of these properties. In particular, the microstructure will be designed using a selection of metallic, intermetallic, ceramic, amorphous and other structures. The designed microstructure will be synthesised from particles, in particular nano-sized and nano-structured particles, using the newly developed back-pressure equal channel angular consolidation process, which achieves instantaneous bonding and full density at much lower temperatures than those used in conventional sintering. This approach enables more flexible design of composition and microstructure and production of a large volume of high integrity materials for reliable characterisation and study of mechanical behaviour. The project will integrate design of microstructure, realisation of the designed microstructure through novel processing, characterisation of microstructure and mechanical behaviour, and modelling of the correlation between microstructure and mechanical behaviour.

Ultra high-strength Al and Ti based materials have been produced. More sophisticated alloys are being designed and processed. These new materials will offer significantly enhanced properties. More importantly, the approach will usher in the era of materials by design.

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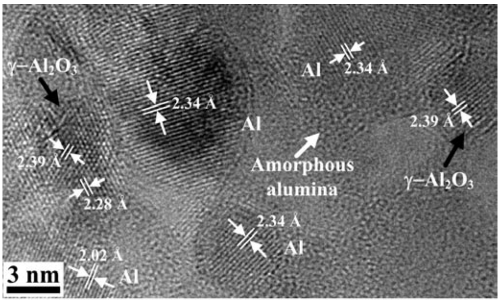

Fig. 1: Nanocrystalline Al and Al_2O_3 composite structure obtained by consolidation and severe plastic deformation of ultrafine Al particles.

Recycling of Metallic Machining Chips

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Keywords: metallic machining chips; nanostructured materials; recycling; sustainability

Machining of metals and alloys into final shapes is required in many applications, especially in aerospace and electronics manufacturing. The proportion of machining chips can amount to 40% or higher, which is usually treated as scrap, making machining one of the most wasteful of operations. It is highly desirable that the machining chips, especially from such expensive metals as titanium and nickel, be recycled to reduce costs and make machining operation more environmentally friendly.

In this project, severe plastic deformation is used to consolidate metallic machining chips in their solid state. The severe plastic deformation would not only bond the chips together, but also refine them into ultrafine and nanostructured bulk materials with unique mechanical properties. It adds value to the recycled materials, and has great potential for commercial applications.

Interfacial Nanofluids

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Keywords: interfacial nanofluids; nanobubbles

This project will study the formation and properties of interfacial nanofluids including gas nanobubbles[1], gas nanolayers[2], and oil nanodroplets[3]. This project will also investigate the influence of nanofluids on lubrication and surface interaction. The research findings will have an impact on water treatment, minerals processing, the food industry, pumping of fuel and water, and the development of miniature devices, such as, lab-on-a-chip and microfludics or nanofluidics systems.

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[3] X.H. Zhang, W.A. Ducker, "Formation of Interfacial Nanodroplets Through Changes in Solvent Quality", *Langmuir,* ACS Publications, **23**(25), pp. 12478-12480, 2007.

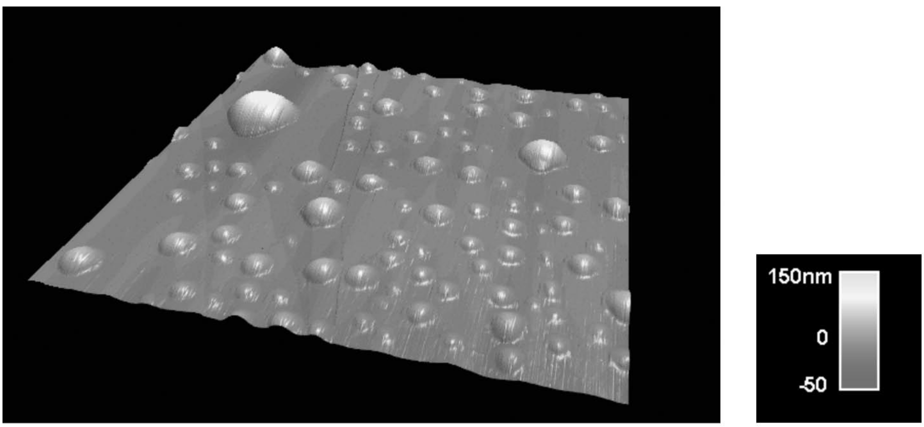

Fig. 1: Atomic force microscopy image of nanobubbles. The scan size is 12um×12um. The bubbles are very flat, typically only about 20 nm thick and several microns across.
