Supersaturation Control during Fractional Crystallization

Daniel Griffin
dgriffin36@gatech.edu
Prof. Martha A. Grover, Prof. Yoshi Kawajiri, Prof. Ronald W. Rousseau

School of Chemical and Biomolecular Engineering
Georgia Institute of Technology, Atlanta, GA

The Department of Energy is faced with extracting, vitrifying, and encasing the hazardous constituents contained in 56 million gallons of nuclear waste currently stored at the Hanford site in the state of Washington. Separating non-radioactive components from the waste can reduce costs and expedite cleanup efforts. In particular, sodium salts—which are non-radioactive and innocuous by themselves—make up a significant portion of the unprocessed waste and can potentially be removed with a crystallization-separation operation. However, as nuclear waste solutions contain many solutes that can crystallize, methods for reliably monitoring and controlling multicomponent crystallizations are needed. In this research we explore model-free, closed-loop supersaturation control over fractional crystallization. This type of control applies in situ monitoring and basic feedback control techniques to keep operation in the so-called metastable zone. While successfully applied to a number of single-solute crystallizations, this is the first time supersaturation control has been extended to fractional crystallization.
Zeolitic Imidazolate Frameworks, a sub-class of Metal Organic Frameworks, are being widely studied by chemical engineers due to their potential application in separation processes. A recent development in this field came in the form of hybrid ZIFs wherein different ligands are incorporated into the same framework. This enables the selective tuning of their transport properties and engineer them to perform specific separation reactions with maximum effectiveness. In this study, ZIF 8-90 system is being investigated as a potential material for the separation of water and small alcohols from a biorefinery feedstock. PFG NMR technique is used to analyze the diffusion behavior and gravimetric methods are utilized to study adsorption behavior. 2D NMR experiments and computational modeling are being considered to get more insight into the structural complexity of the hybrid ZIFs. Hybrid ZIFs could become vital in the sequential separation of platform chemicals in a sustainable biorefinery plant design.
Nodular-Skinned Hollow Fiber Membranes for Carbon Dioxide Capture via Sub-Ambient Temperature Operation

Lu Liu
liu66@gatech.edu
Prof. William J. Koros

School of Chemical and Biomolecular Engineering
Georgia Institute of Technology, Atlanta, GA

Increasing atmospheric CO$_2$ concentration has been suggested as a factor causing climate change. A large percentage of CO$_2$ emission is attributed to pulverized coal (PC) power plants. Post-combustion flue gas CO$_2$ capture is a challenging application, but it has the greatest near-term potential for implementation. Our work considers the capture of CO$_2$ at sub-ambient temperatures using Matrimid® asymmetric hollow fiber membranes. Membranes with special nodular skin morphology have been successfully formed in this work. Compared to integrally defect free membranes, the nodular-skinned membranes display higher productivity and higher separation efficiency at sub-ambient temperatures, as well as good mechanical strength and tolerance for trace amount of water.
Influence of Pyrolysis Conditions on Gasification of Biomass Chars Formed in an Entrained-Flow Reactor

Gautami Newalkar
gnewalkar3@gatech.edu
Prof. Pradeep Agrawal, Prof. Carsten Sievers

School of Chemical & Biomolecular Engineering
Georgia Institute of Technology, Atlanta, GA

Any lignocellulosic biomass can be converted to syngas by gasification. Conversion of syngas to fuels/chemicals requires high pressures. High-pressure gasification prevents the need for the costly compression step for subsequent fuel/chemical synthesis applications of syngas. Flash pyrolysis (heating rate 103-104 K/s) of pine was performed in a pressurized entrained flow reactor (PEFR) at 873-1273 K and 5-20 bar. Slow pyrolysis (~10-50 K/s) of pine was performed in a PTGA at 800 °C between 5-30 bar.

Pyrolysis conditions have a drastic impact on the release of major gases (CO, CO2, H2, CH4), C2-C4 hydrocarbons, light oxygenates and tars. Gas phase free radical repolymerization reactions are considered as a plausible route for tar formation. The gasification activity of chars, using CO2 and H2O as gasifying agents, is found to be dependent on micropore surface area, nature of carbon (amorphous vs. graphitic), ash content, ash composition and distribution within the char matrix.
This work will describe the design of enzymatic reactive crystallization operations. Two different cases will be presented to demonstrate the concept. First, a reactive crystallization towards the manufacture of enantiomerically pure compounds will be presented. Using an enzymatic catalyst and a chemical reducing agent, racemic mixtures of DL-methionine and DL-phenylalanine were resolved into their enantiomerically pure forms. The resulted crystals had a chemical and enantiomeric purity over 99%. The second case presents the reactive crystallization of semi-synthetic β-lactam antibiotics by pen G acylase. The industrial application of this catalyst has been limited by the fact that the enzyme catalyzes the synthesis of ampicillin, but it also catalyzes its hydrolysis which reduces the yield of the reaction. Thus, in order to reduce ampicillin hydrolysis a crystallization scheme has been developed. Experimental data along process modelling and optimization will be discussed to evaluate the performance of these operations.
Architectural and Mechanical Cues Direct Mesenchymal Stem Cell Function on Cross-Linked Gelatin Scaffolds

Kathleen M. McAndrews
kmcandrews3@gatech.edu
Prof. Michelle R. Dawson

School of Chemical and Biomolecular Engineering
Georgia Institute of Technology, Atlanta, GA

Naturally-derived biomaterials have emerged as modulators of cell function and tissue substitutes. Here, we developed cross-linked gelatin scaffolds for the expansion and osteogenic differentiation of mesenchymal stem cells (MSCs). The mechanical and architectural properties of the scaffolds were altered by varying the concentration of gelatin and glutaraldehyde, which ultimately determined the differentiation potential of MSCs cultured on the scaffold. ALP activity (osteogenic marker) of differentiated MSCs on higher gelatin concentration scaffolds was dependent on traditional effectors, including matrix elasticity and cell spread area. In contrast, the differentiation capacity of cells cultured on lower gelatin concentration scaffolds did not correlate with these factors, instead were dependent on the hydrated pore structure. These results suggest scaffold composition can determine what factors direct differentiation and may have critical implications for biomaterial design.
Microneedle (MN) “patches” are designed to deliver vaccines in the skin, where they elicit a similar or improved immune response when compared to intramuscular injection. Dissolving polymer MN are projections measuring hundreds of microns in length, which are composed of water-soluble polymer with vaccine payload embedded along with formulation excipients. This research is to find a suitable method of producing MN patches and to elucidate trends in vaccine activity loss to allow for mechanistic interpretation and rational design of formulations.

Formulations have been systematically tested for stabilizing effects during microneedle manufacturing and storage. Ammonium acetate was chosen as a suitable buffer for drying vaccine formulations, and many compounds, mostly carbohydrates, were found to stabilize vaccine up to one week at elevated temperatures. For storage up to one month at 40°C, a novel combination of stabilizers was needed to maintain vaccine activity. Microneedle patches will be stored for at least 1 year to measure stability.
Development of a High-throughput Intracellular Delivery System Using Nanoneedles

Seonhee Park
spark360@gatech.edu
Prof. Mark Prausnitz
School of Chemical and Biomolecular Engineering
Georgia Institute of Technology, Atlanta, GA

Efficient delivery of genetic materials into cells is of widespread interest. Especially for gene therapy using stem cells, it is crucial to deliver proteins and DNA into cells efficiently without causing cell death. A number of biological, chemical, and physical methods have been developed and used for intracellular delivery.

To address limitations of previously developed methods, such as low throughput and toxicity, we are developing a new method of intracellular delivery using nanoneedles. The nanoneedle array is fabricated from silicon to contain approximately 250,000 needles, with tip diameters of approximately 25 nm, in a 5 mm x 5 mm array. Our study showed that nanoneedles puncture holes in cell membranes to increase intracellular uptake of fluorescent molecules. The magnitude of puncture was adjusted by various experimental parameters. This method demonstrated successful delivery of fluorescent molecules of sizes up to 500 kDa in adherent cells.
Ovarian Cancer Metabolomic Profiles Differ in Ovarian Cancer Initiating Cells

Kathleen Vermeersch
kvermeersch@gatech.edu
Prof. Mark Styczynski

School of Chemical and Biomolecular Engineering
Georgia Institute of Technology, Atlanta, GA

A key emerging area in cancer research is the study of stem-like “cancer initiating cells” (CICs) in tumor populations. CICs are a major concern for effective cancer treatment, as they can self-renew, differentiate into cancer cells, and exhibit chemoresistance; they are thus suspected as a primary cause of cancer recurrence. Metabolism is widely known to be dysfunctional in cancer, most famously via the Warburg effect, but there is limited knowledge about CIC metabolism. Here we present the results of an in vitro experiment to model baseline metabolic differences between ovarian cancer cells (OCCs) and ovarian CICs (OCICs). Extracellular and intracellular metabolite samples were taken over a period of two days and were analyzed using two dimensional gas chromatography – mass spectrometry. To our knowledge, this is the first metabolic profiling of OCIC metabolism. Distinct metabolic profiles were found for the two cell types, suggesting system-wide metabolic alteration of OCICs from OCCs.
An empirical FBRM model for monitoring crystal size distribution and crystallization kinetic study in batch cooling crystallization

Huayu Li
huayu.li@chbe.gatech.edu
Prof. Ronald Rousseau, Prof. Martha Grover, Prof. Yoshiaki Kawajiri

School of Chemical and Biomolecular Engineering
Georgia Institute of Technology, Atlanta, GA

The crystal size distribution (CSD) is a critical property, which determines the quality of products and efficiency of downstream processing. One technique to monitor CSDs is the focused-beam reflectance measurement (FBRM), which employs laser beam in situ so that the crystals are measured intact and in real-time. However, it is usually troublesome to infer the CSD based on the chord length distribution (CLD).

In this study, we establish a linear mapping between CSDs and CLDs empirically. Crystals of paracetamol were sieved into different fractions, and the characteristic CLD of each size fraction was calibrated in saturated ethanolic solution to obtain the linear empirical model. The empirical model was used to interpret the CLD data to CSDs. In batch cooling crystallization of paracetamol-ethanol, primary nucleation, secondary nucleation, and growth were successfully observed. Eight parameters for the kinetics were estimated and excellent consistency was achieved between experimental and simulation results.