Newcastle University
School of Chemical Engineering &Advanced Materials

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pig MONTHLY

process intensification group | www.pig.ncl.ac.uk | www.pinetwork.org

## Introduction

Welcome to Issue #3 of the process intensification group newsletter. In this issue, research activity for February and March 2017 is covered. There has been numerous conferences and visits since the last newsletter, and the first research spotlight for the group is presented here. In this inaugural article, Orlando Lopes do Nascimento explains his research involving micro circulating fluidised beds (μCFBs). In addition, PIG news and upcoming events are mentioned.

## Thailand Visit (Newton Fund)

The PIG was involved in a Newton Fund project running from April 2016 to March 2017. The project was titled: "Highly Energy and Cost Effective Biodiesel Production from Vegetable Source in Thailand". The role of the PIG was knowledge transfer of oscillatory baffled reactor (OBR) technology and biodiesel synthesis. Specifically, Newcastle University investigated the use of waste cooking oil as a source of triglyceride for the production of biodiesel in the presence of both free fatty acids and water, and consulted on the design and operation of a pilot-scale (25 mm diameter) OBR. In March, Prof Adam Harvey, Dr Anh Phan and Dr Valentine Eze travelled to Thailand (Chanthaburi Province) to visit the project partner, Thammasat University. During the visit, a demonstration of the pilot scale OBR was made at Pasak Chonlasit. Here, waste cooking oil from the village was transformed into the value added product, biodiesel. In addition, Prof Harvey and Dr Phan presented talks at the project's closing seminar on 8th March:

- Process Intensification at Newcastle University | Prof Harvey
- Intensified biofuel production | Dr Phan

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Prof Harvey, Dr Phan and students demonstrating the pilot OBR for biodiesel synthesis

# Thailand Visit: Extra Photos


Pilot scale OBR


Biodiesel synthesis from waste cooking oil (WCO)


Dr Valentine Eze (2nd from left), Prof Adam Harvey (centre) and Dr Anh Phan (2nd from right) at the closing seminar

## *Upcoming Conferences*

- **International Symposium on Green Chemistry, *ISGC*** (16-19 May 2017, La Rochelle, France). Early-Bird Registration Deadline: 15th April
- **5th International Conference on Green Chemistry and Technology** (24-26 July 2017, Rome, Italy). Early Bird Registration Deadline: 28th April
- **16th International Conference on Sustainable Energy Technologies** (17-20 July 2017, Bologna, Italy). Early Bird Registration Deadline: 9th June
- ***WCCE10+ECCE11+ECAB4+IPIC*** (1-5 Oct 2017, Barcelona, Spain). Early-Bird Registration Deadline: 30th June

- **2017 *AIChE* Annual Meeting** (Oct 29-Nov 3 2017, Minneapolis, US). Abstract Submission Deadline: 17th April
- **UK Fluids Conference** (6-8 Sep 2017, Leeds University, UK). Abstract Submission Deadline: 24th April
- **Global Biotechnology Congress** (10-13 July 2017, Boston, US). Abstract Submission Deadline: 10th June
- **15th UK Heat Transfer Conference** (4-5 Sep 2017, Brunel University, London). Extended Abstract Submission Deadline (2 Pages): 16 June

- **25th International Symposium on Chemical Reaction Engineering, ISCRE25** (20-23 May 2018, Florence, Italy). Abstract Submission Deadline: October 2017


A PI team attended the International Bioenergy Conference 2017 on 22-23 March in Manchester Central. The conference was organised by the SUPERGEN Bioenergy Hub funded by EPSRC and focused on bringing together the academic, industrial and policy communities working on sustainable bioenergy development. A wide range of topics were discussed: aviation biofuels, biomass resources, bioproducts and biorefineries, catalysis, combustion, development aspects, emissions, environment and ecosystems, gasification, green house gases, modelling, novel technologies, policy, pyrolysis, socio-economics and whole-systems.

The PI group was represented by Prof Adam Harvey, Dr Jon Lee, Dr Fernando Abegão, Dr Kui Zhang, Salihu Musa, Davit Okot and Akeem Babatunde. The PIG gave two talks in the Novel approaches session and displayed a poster.

**Fernando Jose Russo Abegao**

- Process Intensification of Biodiesel Production from Microalgae | Talk

**Kui Zhang**

- Treatment of Gasifier Effluents with Non-Thermal Plasmas for Tar Removal | Talk

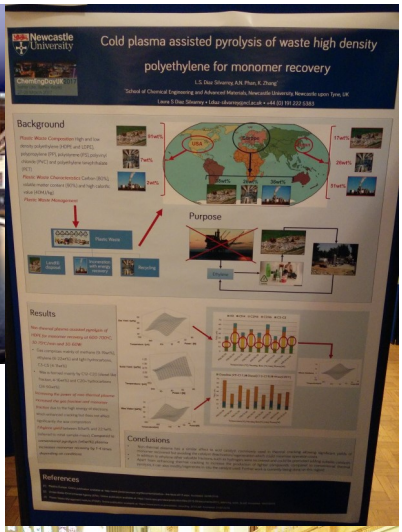
**David Okot**

- Briquetting of waste biomass for pyrolysis | Poster

17 AIChE
Spring Meeting, San Antonio, TX

Prof Adam Harvey recently presented a talk at the AiChE Spring Meeting in San Antonio (Texas) on 29th March. The title of the talk was “An Overview of Process Intensification Research at Newcastle University”. During the meeting, the AIChE officially launched the new $140m “RAPID” Institute (“Rapid Advancement in Process Intensification Deployment”). More information is available at: https://www.aiche.org/rapid. The purpose of the institute is to:

- Create a dynamic network of partners who collectively build a sustainable ecosystem
- Develop and broadly commercialize new modular chemical process intensification technologies
- Deliver dramatic reductions in energy, greenhouse gas, capital and operating cost
- Make US manufacturing and the workforce more competitive

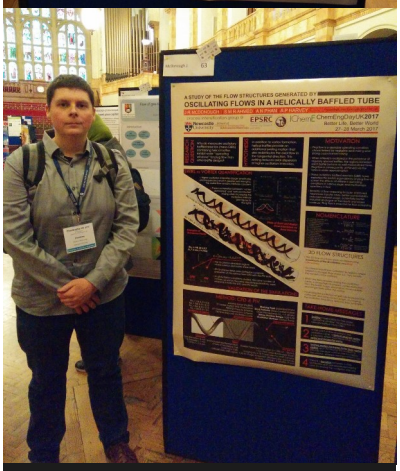

Laura Diaz Silvarrey, Jonathan McDonough and Dr Anh Phan attended ChemEngDayUK hosted at the University of Birmingham on 27-28 March. The conference had six main research themes: (1) Product Engineering, (2) Energy Generation, Storage and Utilisation, (3) Chemical Engineering Fundamentals, (4) Chemical Engineering at Interface, (5) Catalysis and Sustainable Green Chemistry, and (6) Biological Engineering. There were 2 plenary lectures, 6 keynote lectures, 12 research talks, 60 research highlight talks and over 170 poster presentations. Laura and Jonathan presented the following research at the conference.

**Laura Diaz Silvarrey**

- Non-Thermal Plasma Assisted Pyrolysis of Waste High Density Polyethylene for Monomer Recovery | Poster

**Jonathan McDonough**

- A Study of the Flow Structures Generated by Oscillating Flows in a Helically Baffled Tube | Poster and 3-Minute Research Highlight Talk
- Applications of 3D Printed Fluidic Oscillators to Process Intensification | Poster




**ChemEngDayUK 2017 Photos**

heat transfer society

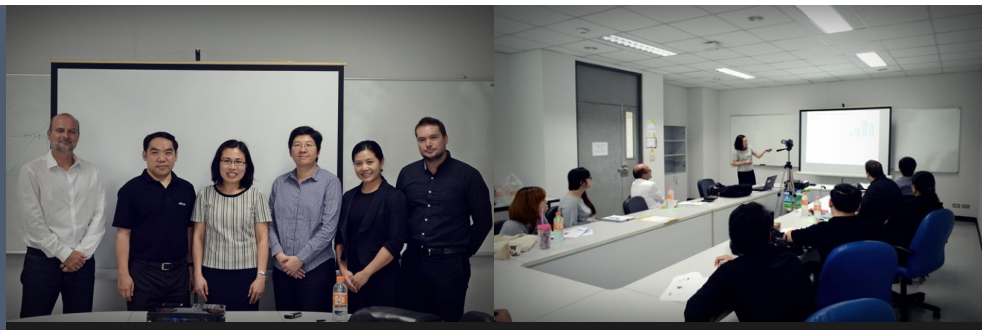
The 53rd Heat Transfer Society (*hts*) annual dinner was held in London on Friday 31st March. Prof David Reay, Dr Richard Law and Dr Ahmad Mustaffar were in attendance from the PIG. The *hts* was founded in 1964, and aims to promote all aspects of heat transfer and associated equipment via meetings/forums to discuss subjects of common interest. During the dinner, Stuart Cameron MBE FREng was installed as the 2017 *hts* President.

## Upcoming PIG Seminars

- Fri 7th April, 12:00-13:00. Dr Greg Mutch: Carbon capture and storage: Investigating surface chemistry by in-situ vibrational spectroscopy
- Fri 21st April, 12:00-13:00 Safaa Ahmed
- Fri 28th April, 12:00-13:00 Phuet Prasertcharoensuk
- Fri 5th May, 12:00-13:00 Luma Al-Saadi
- Fri 12th May, 12:00-13:00 David Okot
- Fri 19th May, 12:00-13:00 Abbas Umar

## Other Information

- Full contact details and research profiles for the PI group members can be found at the website: www.pig.ncl.ac.uk
- For enquires about collaborations or PhD study, see the website: www.pig.ncl.ac.uk
- If anyone would like to contribute any articles, or if anyone has any ideas regarding the newsletter please contact Jonathan McDonough: jonathan.mcdonough@ncl.ac.uk



Dr Anh Phan presenting at the Joint Graduate School of Energy and Environment

# Invited Talk

- Whilst visiting Thailand for the Newton Fund project, Dr Anh Phan was invited to speak at the Joint Graduate School of Energy and Environment (see pictures above)

# PIG News

- The PIG would like to welcome Warm In-Na, who started work in the group on 9th January 2017. Warm In-Na's PhD research is focused on carbon capture and conversion using solar-powered biocomposite foams. Her supervisors are Dr Jon Lee and Dr Gary Caldwell.

# PIG Seminars

- Mohamad Gunam Resul. *Intensification of Terpenes Epoxidation*. 24th Mar
- Dr Valentine Eze. *Biodiesel from Waste Cooking Oil*. 17th Mar
- Sahr Sana. *Solvent-antisolvent precipitation of starch nanoparticles in a spinning disc reactor*. 10th Mar
- Akeem Babatunde. *Reactive Coupling of Rapeseed for Production of Biodiesel and Polyglycerol*. 3rd Mar
- Laura Diaz Silvarrey. *Conventional, catalytic and non-thermal assisted pyrolysis of waste high density polyethylene (HDPE)*. 24th Feb
- Jonathan Harris. *Plasma Initiated Upgrading: Investigating non-thermal plasma assisted upgrading of bio-oil model compounds*. 17th Feb
- Jonathan McDonough. *Characterisation of fluidic oscillators and their applications in process intensification*. 10th Feb
- Dr Richard Law. *Heat Transfer in OBRs and Potential Heat Exchanger Applications*. 3rd Feb

# PIN & HEXAG Annual Meetings

- The Heat EXchanger Action Group (HEXAG) meeting will be held in CEAM on Tuesday 20 June 2017
- The Process Intensification Network (PIN) meeting will be held in CEAM on the following day, Wednesday 21 June 2017
- Offers of talks (short 'impromptu's' or longer presentations) are welcome. Please contact either David Reay (HEXAG) or Adam Harvey (PIN)


# Micro-Circulating Fluidized Beds (μ-CFBs)

*Orlando Lopes do Nascimento, Prof David Reay and Dr Vladimir Zivkovic*

Microfluidics is the science and technology of processing small volumes of fluids in channels having dimensions of the order of tens to hundreds of microns. This fascinating technology offers many applications including medical diagnostics, power generation, materials synthesis, chemical and biochemical research. Advantages of microfluidics include reduced reagent usage, low energy consumption, short analysis times, improved safety, and less pollution [1]. However, transport processes in microfluidic systems are dominated by molecular diffusion that comes with the inevitable laminar flows found in micron-sized conduits. Fluidized beds have long been used at the macro-scale to enhance mixing and, thereby, heat and mass transport. Recent experimental work has demonstrated that liquid-solid micro-fluidized beds are feasible (figure 1), offering the potential to overcome diffusion-limited fluid mixing, heat and mass transport, and provide higher sensitivity and multi-modal detection in the diagnostic context by virtue of the large surface area per unit volume that comes from use of microparticles.

The long term goal of this research is to produce an effective microscale device for high-throughput reaction screening and for high heat flux cooling applications

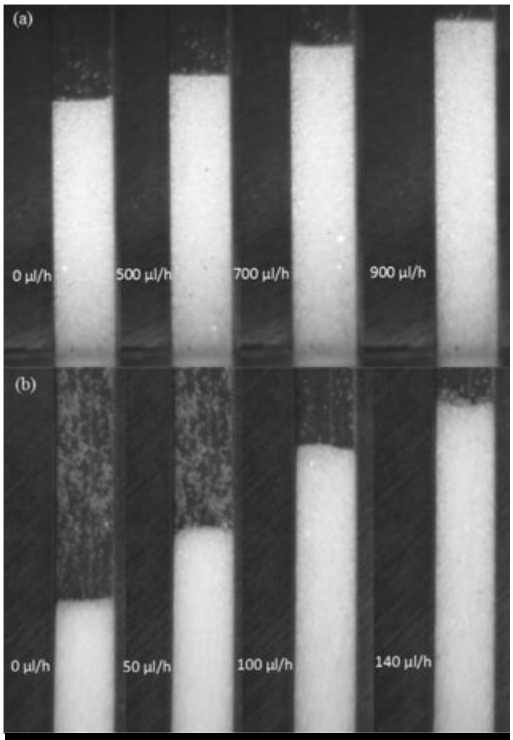



**Figure 1. Fluidization of (a) 115 μm and (b) 26.5 μm glass particles in water in a 1 mm square channel [2]**

Solid-liquid circulating fluidised beds (CFB) possess many qualities which makes them useful for industrial operations where particle-liquid contact is vital. They produce low back mixing, excellent solid-liquid contact (high slip velocities), improved heat transfer performance (uniform temperature), good reaction control and allow continuous regeneration of catalysts or biosolids. In spite of their numerous applications, such as wastewater treatment, biochemical, hydrometallurgy, mineral processing, reactions, bio-reactions, crystallizations and heat exchange, circulating fluidised beds have not yet been applied in the micro technology context.

Therefore, the long term goal of this research in the PIG is to design and study the hydrodynamics of a solid-liquid micro-circulating fluidised bed (μ-CFB) for possible application as novel micro (bio)-reactors, diagnostics, high-throughput kinetics screening, high-heat flux cooling and others. In order to successfully design a solid-liquid micro circulating fluidised bed system to operate at low Reynolds numbers, it is essential to understand their hydrodynamics such as the influence of surface forces, wall effects, and solid flux. This is because these determine the mixing and heat/mass transfer performance, which influence the choice of control strategy.

The initial research was performed in a μ-CFB constructed by micro-machining channels of 1 $mm^2$ cross section in Perspex as shown in figure 2a. Additive manufacturing (3D Printing) is also being used for fabrication of these μ-CFBs. This allows us to rapidly create micro-channels of any shape whilst providing high resolution of 50 μm in the x, y and z directions. PMMA and soda lime glass micro-particles were used as the fluidised particles and tap water as the fluidising liquid. The digital particle image velocimetry (PIV) method was used as a novel measurement technique to measure the solid flux in the micro-CFB system as shown in figure 2b.

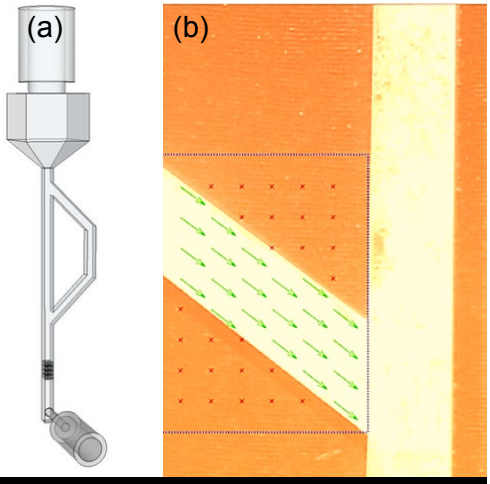



**Figure 2. (a) Schematic of a simple micro-circulating fluidized bed design, and (b) Velocity vector field obtained in PIVLab**

The results indicate that fluidisation in a solid-liquid μ-CFB can be categorised in to four operating regimes: fixed bed, conventional fluidisation, circulating fluidisation, and transport regime as shown in figure 3. Detailed study of fluidization in micro-fluidized bed reveals that the minimum fluidisation velocity is strongly influenced both by adhesion forces and wall effects. We discovered that the increase in the minimum fluidisation velocity is linearly proportional to the product of adhesion to drag force ratio and particle-to-bed diameter ratio. The transition velocity from conventional fluidization to circulating regime is strongly influenced by solid inventory, i.e. it decreases with solid inventory (1-9%) before levelling off at high enough solid inventory (10-25%). However, there was a weak increase in the normalised transition velocity, $U_{cr}/U_t$, with reference to the terminal velocity with increasing PMMA and glass particle diameters which may be due to an increase in the wall effect (higher particle to bed ratio). As in a macroscopic CFB, the solid flux in a micro-circulating fluidised bed increases with liquid velocity in two distinct zones, increasing sharply first then levelling off at higher inlet fluid velocities.

There are four operating regimes: (1) fixed bed behaviour, (2) conventional fluidization, (3) circulation fluidization and (4) transport.

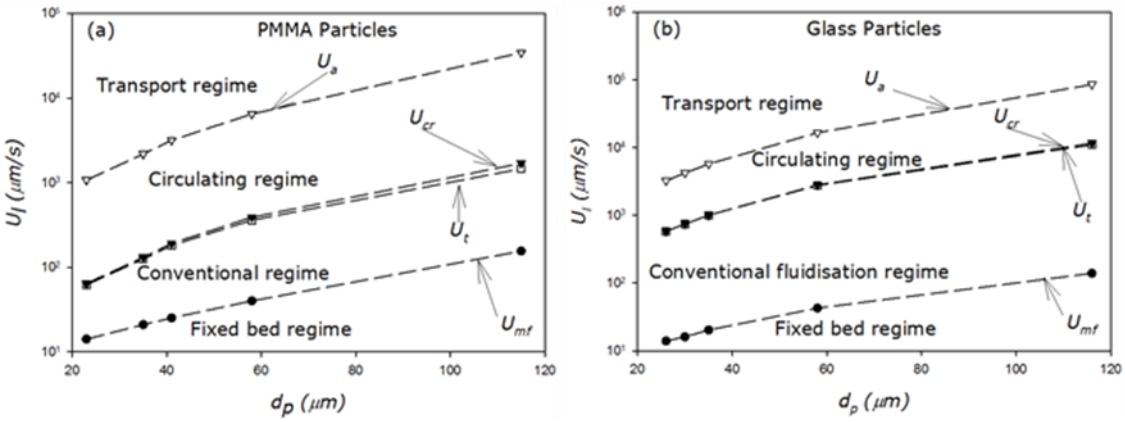



**Figure 3. Flow regime map for solid-liquid fluidization in a micro-circulating fluidized bed | (a) PMMA particles and (b) glass particles**

These results were published by Powder Technology [2] and presented at the Fluidization XV conference, UK Particle Technology Forum, and will be presented at the forthcoming 12th International Conference of Fluidized Bed Technology (May) and 10th WCCE (October).


[1] Zivkovic, V. and M.J. Biggs, *On importance of surface forces in a microfluidic fluidized bed.* Chemical Engineering Science, 2015. 126 :(0)p. 143-149.

[2] do Nascimento, O.L., D.A. Reay, and V. Zivkovic, *Influence of surface forces and wall effects on the minimum fluidization velocity of liquid-solid micro-fluidized beds.* Powder Technology.