

## In This Issue

- PIG attendance at the 10<sup>th</sup> World Congress of Chemical Engineering in Barcelona
- HEXAG and PIN meeting dates
- Viva successes!
- PIG news
- PIG research activity
- Upcoming conferences and PIG seminars
- TRIZ workshop
- Research visitors from UNAM
- Research Spotlight: "Novel adsorbents applied to integrated energy-efficient industrial CO<sub>2</sub> capture"



The **10th World Congress of Chemical Engineering (WCCE10)** recently took place from 1st–5th October in Barcelona. Over 3,000 delegates from over 80 countries gathered to present research from a diverse range of topics, including: Knowledge, Education & Training; Unit Operations & Separation Processes; Chemical Reaction Engineering; Process Systems Engineering; Product Engineering & Advanced Materials; Applied Biotechnology; and Environmental & Sustainable Chemical Engineering. In addition, WCCE10 hosted many joint events, including ESCAPE27 (27th European Symposium on Computer-Aided Process Engineering) and IPIC1 (1st International Process Intensification Conference). The Process Intensification Group was well represented by 13 researchers at the congress, who combined, presented 1 keynote presentation, 5 full oral communications, 4 short oral communications and 7 posters (summarized on the next page). Additionally, Prof Adam Harvey also chaired a session on Hybrid and Multifunctional Processes, with presentations focused on biofuel production, and attended a meeting regarding the organization of the future European Process Intensification Conferences.

## Upcoming Conferences

- **2018 AIChE Spring Meeting** (22-26 April 2018, Orlando, Florida). Registration Deadline: 13 November 2017
- **25th International Symposium on Chemical Reaction Engineering, ISCRE25** (20-23 May 2018, Florence, Italy). Early Registration Deadline: End of March 2018
- **16th International Heat Transfer Conference** (10-15 August 2018, Beijing, China). Registration Deadline: 25th July 2018
- **Heat Powered Cycles Conference (HPC)** (16-19 September 2018, Bayreuth, Germany). Extended Abstract Submission Deadline: 15 December 2017
- **6th International Congress on Green Process Engineering (GPE)** (3-6 June 2018, Toulouse, France). Abstract Submission Deadline: 15 January 2018
- **ChemEngDayUK2018** (27-28 March 2018, Leeds, UK). Abstract Submission Deadline: End of January 2018
- **6th International Conference on Micro and Nano Flows, MNF2018** (9-12 Sep 2018, Atlanta, Georgia, US). Abstract Submission Deadline: 30 March 2018
- **2018 AIChE Annual Meeting** (28 Oct-2 Nov 2018, Pittsburgh, PA, US). Abstract Submission Opening: Mid-January 2018

## WCCE10 Presentations

- S Ahmed, A Phan, A Harvey | *A study of gas-liquid flow regimes and mass transfer enhancement in various designs of oscillatory baffled reactors* | OC-21891
- S Ahmed, A Phan, A Harvey | *Developing a scale-up correlation for oscillatory baffled reactors* | OC-21931
- M Al-Karawi, O Gordon, S Musa, G Caldwell, J Lee | *Drainage enhancement in the continuous foam flotation column used for algae biomass recovery* | OC-46701
- H Wang, A Phan, V Zivkovic, K Boodhoo | *Particle classification via Taylor-Couette flow: Experimental and Simulation Studies* | SOC-66376
- A Lopez Fernandez, M Gunam Resul, A Harvey | *Sustainable Epoxidation of Terpenes using Continuous Mesoscale Oscillatory Baffled Reactor under Microwave Irradiation* | SOC-47596
- J McDonough, R Law, A Harvey | *Intensification of Transport Phenomena using 3D Printed Fluidic Oscillators* | KN-61641
- J McDonough, S Ahmed, A Phan, A Harvey | *A study of the flow structures generated by oscillating flows in a helical baffled tube* | SOC-25471
- S Musa, M Al-Karawi, G Caldwell, J Lee | *Combined Harvesting and Oil Extraction of Microalgae for Biodiesel Production using a Foam Column* | OC-56661
- A Mustaffar, K Boodhoo, A Phan | *Heat Pipe Screw Dryer: a novel, energy-efficient drying technology* | SOC-26506
- A Rehman, A Lopez Fernandez, A Harvey | *Intensification of cyclic carbonate synthesis from epoxides and CO<sub>2</sub> using tube-in-tube gas/liquid microreactor* | OC-48541

## WCCE10 Posters

- K Boodhoo, M von Sosch, M Beard, E Richmond, M Flickinger | *Enhancement of CO<sub>2</sub> gas-liquid mass transfer in thin wavy film flow on a spinning disk* | JE-IPIC-011
- T Horie, N Numata, S Wang, A Harvey, N Ohmura | *Evaluation of Mixing Characteristics in a Micro Oscillatory Baffled Reactor* | JE-IPIC-054
- O do Nascimento, V Zivkovic, D Reay | *Effect of Circulating Fluidised Bed geometry on the hydrodynamics of liquid-solid flow micro channel* | JE-IPIC-026
- M Resul, A Rehman, A Lopez, A Harvey | *Intensification of terpenes epoxidation using continuous meso-scale Oscillatory Baffled Reactor* | JE-IPIC-005
- S Sana, V. Zivkovic, K Boodhoo | *Exploiting the spinning disc technology for solvent-antisolvent precipitation of starch nanoparticles* | JE-IPIC-007
- A Umar, P In-na, G Caldwell, J Lee | *Growth and Maintenance of Microalgae on a Filter Paper Strip and its Potential for Biological CO<sub>2</sub> Mitigation* | T6.6.261
- K Zhang, F Saleem, AP Harvey | *Intensification of Gasifier Effluent Treatment Using Non-Thermal Plasmas* | JE-IPIC-064



## PIN & HEXAG Meetings

The date for the next **Heat EXchanger Action Group (HEXAG)** meeting is Tuesday 15th May 2018. The **Process Intensification Network (PIN) meeting** will be on the following day, Wednesday 16th May 2018. Both meetings will be held in the Research Beehive in the Old Library Building at Newcastle University. Please contact David Reay (DAReay@aol.com or David.Reay@newcastle.ac.uk) if you would like to present a talk.

## PIG Viva Successes

Congratulations to the following students, who successfully defended their theses in November:

- **Victoria Outram** | 8<sup>th</sup> Nov | EngD | “*In Situ* Product Recovery of Butanol from the Acetone Butanol Ethanol Fermentation”
- **Akeem Babatunde** | 23<sup>rd</sup> Nov | PhD | “*In Situ* Transesterification of Rapeseed for Production of Biodiesel and Secondary Products”
- **Ruili Feng** | 24<sup>th</sup> Nov | PhD | “Synthesis and Evaluation of Pharmaceutical and Fine Chemicals Processes for Intensification and Sustainability Benefits”

## PIG News

- A recent paper related to the IbD project (review of process intensification applied to solids handling) was the most downloaded article in the last 90 days in Chemical Engineering and Processing (CEP:PI). A link to CEP:PI is included below:  
<https://www.journals.elsevier.com/chemical-engineering-and-processing-process-intensification>
- Adam and Kamelia recently gave presentations at AkzoNobel on 22<sup>nd</sup> Nov, the home of Dulux paint, to get them thinking about process intensification. It turns out that paint production, after 70 years in Slough, is in the process of moving to Ashington!
- The PIG would like to welcome the following new PhD students:
  - **Zakaria Adejoh**, who is working with Adam and Kui on particulate emissions from biomass boilers and their mitigation
  - **Long Duong**, who is working with Anh and Kui on upgrading bio-oil from pyrolysis of biomass
  - **Yi Zhang**, who is working with Vlad (co-supervised by Dr Yuen Ling Ng and Dr Kheng-Lim Goh at the Singapore campus) on CFD simulations of a miniaturized bioreactor
- The PIG would also like to welcome back **Thea Ekins-Coward**, who started a 3 month postdoc position with Adam on 27th November as part of the Sustainable Polymers project
- The PIG would finally like to officially welcome several new academic members of staff following the formation of the new School of Engineering:
  - **John Dalton**
  - **Dr Chris O'Malley**
  - **Dr Mark Willis**
  - **Dr Jie Zhang**

## Upcoming PIG Seminars

- Friday 8<sup>th</sup> Dec  
**Luma Al-Saadi**  
“A study of process conditions required for high conversion of high free fatty acid and water triglyceride feedstocks to biodiesel”
- Friday 15<sup>th</sup> Dec  
**James Hendry**  
“Pressure Drop and Flooding in a Rotating Packed Bed”
- Friday 12<sup>th</sup> Jan  
**Various**  
*New PhD Student Session*  
1. An opportunity for new students to introduce themselves and their projects
- Friday 19<sup>th</sup> Jan  
**Various**  
*New PhD Student Session*  
2. An opportunity for new students to introduce themselves and their projects
- Friday 26<sup>th</sup> Jan  
**Sahr Sana**  
TBD

## New Publications

- J.M. Gong, H. Yang, S.H. Lin, R. Li, **V. Zivkovic**. Spatial filtering velocimetry for surface velocity measurement of granular flow. Powder Technology 324 (2018) 76-84
- **V. Zivkovic**, N. Ridge, M.J. Biggs. Experimental study of efficient mixing in a micro-fluidized bed. Applied Thermal Engineering 127 (2017) 1642-1649

## Recent PIG Seminars

- **Abbas Umar** | 6<sup>th</sup> Oct  
“Adhesion screening protocol for the production of microalgae bio-composites for CO<sub>2</sub> mitigation”
- **Warm In-Na** | 20<sup>th</sup> Oct  
“Carbon capture and conversion using textile-based algae bio-composites”
- **Regina de Monserrat Gonzalez Balderas** | 27<sup>th</sup> Oct  
“DSC study on the thermal properties of microalgae biomass and proteins”
- **Dr Seham Moussa** | 27<sup>th</sup> Oct  
“Bio-electrogenic potential of microalgae in photo-biological fuel cell (PhFC) using waste water and CO<sub>2</sub>”
- **Oscar David Gonzalez Galvez** | 27<sup>th</sup> Oct  
“Production of bio-oils through the catalytic cracking of biomass obtained from a wastewater lake in Mexico”
- **Dr Ana Lopez** | 3<sup>rd</sup> Nov  
“When microwaves & ultrasound processing should and should not be used”
- **Laura Diaz-Silvarrey** | 10<sup>th</sup> Nov  
“Pyrolysis of plastic waste”
- **Ibrahim Mohammed** | 17<sup>th</sup> Nov  
“Combined Reactive Extraction and Reactive Coupling for Biodiesel and Polyglycerol Production”
- **Aumber Abbas** | 24<sup>th</sup> Nov  
“Investigating the Conversion of Biomass-Waste into Graphene Quantum Dots”
- **Ha Phan** | 1<sup>st</sup> Dec  
“Converting biomass waste into activated carbon materials”

# ***TRIZ Two-Day Problem-Solving Meeting***

## ***IbD Project, Leeds University***

The 10 million Euro EC-funded IbD project, in which Newcastle University Chemical Engineers play a major role, is directed at addressing the concerns of potential users of process intensification equipment in applications where solid particles are present, or likely to be formed in the process.

This is being done in part by constructing a 'Knowledge-Based Engineering' (KBE) database of appropriate technologies with data on their benefits, limitations and applications, supported by six Case Studies, where solids-handling PI equipment is being evaluated in pilot plants or at industrial sites. The host companies for these Case Studies range from a large ore mining company in Finland to pharmaceutical product manufacturers in Spain.

Each project, as part of the equipment selection and improvement process, undergoes a TRIZ analysis, that typically last two days. TRIZ is the Russian acronym for Teoriya Resheniya Izobretatelskikh Zadatch – which translates into the theory of inventive problem-solving. The process was invented in 1946 and a leading specialist in applying the methodology in Europe is Prof. Dr.-Ing. Pavel Livotov, <https://www.zoominfo.com/p/Pavel-Livotov/123369379> who is based at the Offenburg University of Applied Sciences in Southern Germany.

Prof. David Reay attended the two-day TRIZ meeting at Leeds University, hosted by Prof. Frans Muller and colleagues, with personnel from the reactor manufacturer, AM Technology – see [www.amtechuk.com](http://www.amtechuk.com). The Coflore Agitated Tube Reactor (ATR), an example of which is shown in the photo (next page), was the subject of the TRIZ analysis and features as Case Study 5 in the IbD project. Pavel, third from the left behind the hardware and next to Frans Muller, led the highly structured sessions.

Before the meeting, Pavel circulated responses to questions answered by AM Technology regarding the equipment, the main components and their function, how the system operates, and benefits, limitations etc. These were then briefly reviewed and the organisation of the TRIZ sessions explained. The first day involved an analysis of the initial problem situation and the generation of ideas. A critical session involved the 'systematic process of ideas generation', based upon the 40 TRIZ principles – one familiar to Newcastle PI researchers is 'Spheroidality and Rotation' which covers the following:

- a) Replace rectilinear parts or forms with curved, ball-shaped forms or structures.
- b) Use balls, rollers, spheres, domes or spirals. Apply cylindrical, conical or multiconical configurations.
- c) Provide rotary motion of parts, substances or force fields. Replace a linear motion of objects or substances with rotation.
- d) Use vortex flows and swirling motion for cyclonic separation, cooling or heating.
- e) Use centrifugal and Coriolis forces.

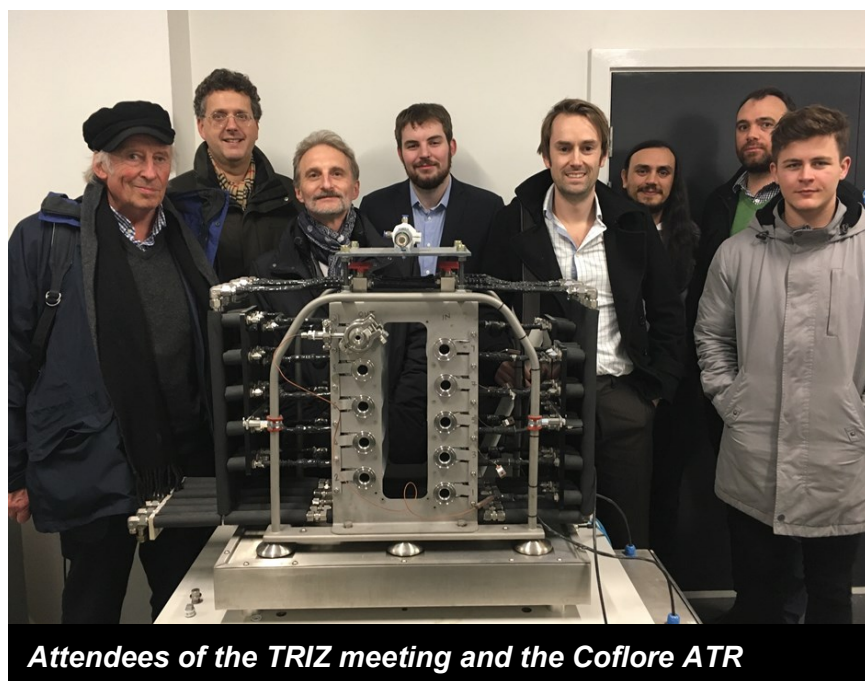
As the ATR involves components that rotate/shake, this principle was one of several that were selected for 'brainstorming sessions' in which those attending split into groups of two or three (there were up to 12 people at the meeting), after which each group presented their ideas for open discussion.

This approach carried on into the second day, and moved forward to the development of solution concepts based on the strongest ideas arising from the groups. Each group concentrated upon a component of the reactor, such as the agitator inside the tube, the tubes themselves, the bends connecting the tubes and the shaker table itself. Monitoring and control was also tackled. An interesting aspect considered by all groups was fouling, as the solids – in the case of the ATR these are catalyst particles – could lead to fouling and/or blockage.

At the end of the day, AM Technology left with a number of ideas for further improving the ATR, or developing new variants. Pavel stressed that TRIZ exercises often lead to patentable ideas/improvements, so intellectual property is a valuable by-product of TRIZ.

*Prof. Adam Harvey pointed out that Britest has a similar procedure and it may well be that the implementation of such an exercise will be proposed to PIG researchers!*

David Reay,  
15 November 2017



**Attendees of the TRIZ meeting and the Coflore ATR**

## Other Information

- Full contact details and research profiles for the PI group members can be found at the website: [www.pig.ncl.ac.uk](http://www.pig.ncl.ac.uk)
- For enquires about collaborations or PhD study, see the website: [www.pig.ncl.ac.uk](http://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](mailto:jonathan.mcdonough@ncl.ac.uk)

# **Research Visitors from UNAM\***

## ***Production of Biofuels and Biocompounds from Microalgae***

Dr Sharon Velasquez-Orta is currently hosting two research students from UNAM on a project involving microalgae. Microalgae are an attractive feedstock for the next generation of biofuels and biocompounds. In order to realise a profitable process, an integrated biorefinery approach is required. Microalgae can accumulate internal lipids, carbohydrates, and proteins. Proteins, as one of the major constituents of the algae biomass (up to 50% [w/w]), are expected to play an important role in the algae biorefinery. Due to their abundance and their amino acid profile, microalgae proteins have long been considered as an alternative protein source, generating interest to find feasible product extraction methods.

**Regina de Monserrat Gonzalez Balderas** is studying the changes in the protein extracted abundance and structure obtained through the pre-treatment of *Scenedesmus obliquus* and *Desmodesmus sp* biomass with either ultrasound or ozone. She is using techniques available at Newcastle University such as SDS-PAGE 2D, High Resolution Mass Spectrometry, Liquid Chromatography, Differential Scanning Calorimetry, Isothermal Scanning Calorimetry, and Capillary Rheometer.

**Oscar David Gonzalez** is analysing the behaviour of microalgal biomass under catalytic cracking conditions, for its application in bio-oil production. The bio-oils are condensed liquid mixtures of various compounds and functional groups, usually of dark colour and high viscosity. Bio-oils are commonly composed of linear and branched aliphatic compounds such as alkanes, alkenes, aromatic and phenolic compounds, alcohols, esters, organic acids, nitriles, sugars, furans and nitrogen heterocycles. These are being analysed using the Gas Chromatography and Mass Spectrometry libraries available in the main PIG lab. The main purpose this research is to understand the reactions that occur exclusively in the microalgal biomass during its transformation to bio-oils, with or without a catalyst.

\*UNAM stands for “Universidad Nacional Autonoma de Mexico” which is one of the largest universities in Latin America (~343,000 students).





## Novel Adsorbents Applied to Integrated Energy-Efficient Industrial CO<sub>2</sub> Capture

EPSRC (EP/N024540/1)

*Prof David Reay, Dr Vladimir Zivkovic, Dr Richard Law, Jonathan McDonough*

The UK Government has an ambitious target to reduce CO<sub>2</sub> emissions by 80% by 2050. Industrial processes account for 25% of total EU CO<sub>2</sub> emissions, and moreover, they are already operating at or close to the theoretical limits of efficiency. Therefore, CO<sub>2</sub> capture and storage (CCS) is the only technology that can deliver the required emission reductions. However, efficiency and capital cost penalties associated with CO<sub>2</sub> capture are hindering the deployment of CCS. There is an opportunity here for industrial CCS to operate at a wider range of temperatures and to integrate available thermal streams with heat required for on-site sorbent regeneration.



This multidisciplinary project unites engineers and scientists from the Universities of Heriot-Watt, Newcastle and Sheffield to realise the integration of novel hydrotalcite solid sorbents with advanced heat integration processes for industrial CO<sub>2</sub> capture. Hydrotalcite materials present a big potential for industrial CCS, as they show faster kinetics and better regenerability over other high temperature sorbents; however, their application in industrial capture processes remains largely unexplored. In this research project, novel methodologies to enhance and tailor performance of hydrotalcites for CO<sub>2</sub> capture over a wide range of conditions needed in industrial processes are being explored. The project will also address the challenge of designing a suitable process that combines the roles of heat management (heat recovery for desorption) and mass transfer (ad- and desorption) across a range of process conditions (temperature, pressure, humidity, gas constituents) with a degree of flexibility that is economically and technically viable. The project is split into four interconnected work packages:

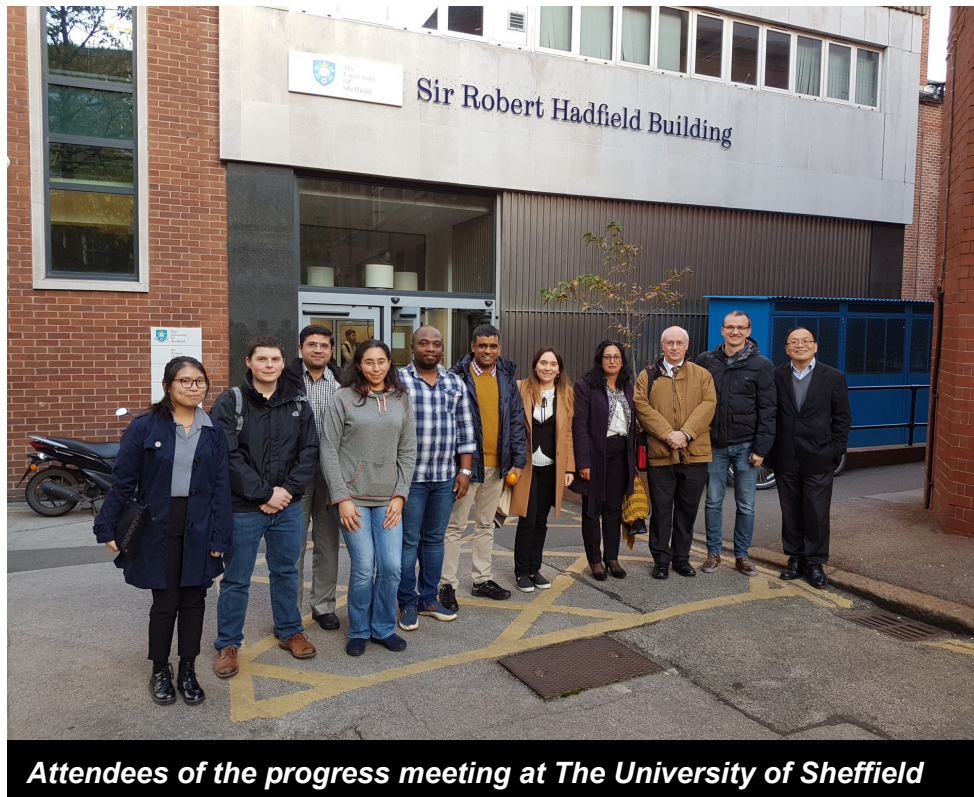
- **WP1.** Synthesis and screening of novel, tailored and low-cost hydrotalcites for industrial CCS processes (led by Heriot Watt)
- **WP2.** Process intensification of a combined energy-efficient unit for capture (led by Newcastle)
- **WP3.** Process modelling and simulation of the adsorber and the carbon capture process (led by Sheffield)
- **WP4.** Whole system integration, technical, economic and environmental assessment of the proposed technology

## Work Package 2 Tasks (led by Newcastle)

- **2.1. Scoping of heat sources and gas stream conditions for energy-efficient adsorption-desorption cycles.** Through a review of industrial and literature data, the aim is to identify CO<sub>2</sub> and waste heat source streams from cement, iron/steel and refining industries that can be targeted for the development of the carbon capture system (e.g. for tailoring hydrotalcite performance at industrial relevant conditions).
- **2.2. Performance testing under operating conditions using micro-scale standard bed designs.** Different hydrotalcite materials synthesised by Heriot Watt will be screened in different mini-fluidized bed designs and at different operating conditions to investigate adsorption and desorption behaviour.
- **2.3. Hydrodynamic investigations of micro-scale novel bed designs.** Small scale fluidized beds and miniaturised Torbed reactors are being manufactured via 3D printing and characterised through pressure drop measurements and high speed imaging to build a flow map of the various observed flow regimes. The aim is to identify a suitable fluidized bed configuration with a flow regime that minimises external mass transfer resistances.
- **2.4. Pilot-testing using a Torbed reactor.** The final stage of WP2 will involve performing experiments in a pilot scale Torbed reactor to investigate whether the small-scale CO<sub>2</sub> capture results can be replicated at up to 100 kg/hr throughputs.

## Progress

A meeting was recently held at the University of Sheffield on 30th October, where researchers from **Heriot Watt** (Mercedes Maroto-Valer, Susana Garcia, Graeme White, Amir Jahanbakhsh, Manohara Gudiyor, and Li Anna Cheah), **Newcastle** (David Reay, Vladimir Zivkovic, and Jonathan McDonough) and **Sheffield** (Meihong Wang, Mathew Aneke, and Phebe Bonilla Prado) provided progress updates on Work Packages 1 and 2.



*Attendees of the progress meeting at The University of Sheffield*

## UK Heat Transfer Conference 2017

David Reay and Jonathan McDonough recently co-presented a talk at the 15th UK Heat Transfer Conference (UKHTC) hosted by Brunel University from 4th—5th September. The title of the talk was “*Intensified Carbon Capture using Adsorption: Heat Transfer Challenges and Potential Solutions*”. The talk provided an overview of the proposal for using a Toroidal Fluidized Bed (Torbed) for capturing CO<sub>2</sub> from the cement and iron/steel industries using hydrotalcite sorbents. The project is aimed at capturing CO<sub>2</sub> from an industrial flue gas, then using a waste heat source to regenerate the particles via TSA. Challenges relating to this approach were discussed, including: justifying the use of waste heat for sorbent regeneration instead of direct power generation, practical considerations for efficiently transferring heat to the sorbent particles for regeneration, and avoiding capturing dilute CO<sub>2</sub> in a dual fluidized bed system. A short paper based on the talk is currently being assembled for the TSEP special issue on the UK Heat Transfer Conference.

