Process Intensification Network

13TH PIN Meeting, The Beehive, University of Newcastle upon Tyne,

16 November 2006.

MEETING MINUTES

The 13th meeting of PIN was hosted by the Process Intensification Group at Newcastle University, which is headed by Jon Lee. Thirty-three members attended, including a number of post-graduates from Newcastle and Heriot-Watt Universities.

Colin Ramshaw, Chairman for the morning session, introduced Adam Harvey of the Newcastle Process Intensification Group, (http://pig.ncl.ac.uk) who welcomed us to the University. David Reay updated us on the PIN activities and mentioned that PI was likely to be included in the 7th EC Framework programme, due for kick-off around 22 December 2006. David's overheads are on the PIN web site.

Technical Presentations

(Note that most of the overheads from talks are available in pdf format on the PIN web site – www.pinetwork.org)

Jon Lee of Newcastle University (j.g.m.lee@newcastle.ac.uk) described features of the hydrodynamics of rotating packed beds, in particular looking at hold-up. He first looked at the methods for predicting drop size distribution in non-rotating packed columns and the estimation of hold-up in them. In a rotating packed bed (RPB) all factors change as a function of radius. A method for examining behaviour in the RPB was the matched refractive index (MRI) technique which presented different colours to show the hold-up in liquid-liquid systems.

The dispersed phase in one set of experiments was dodecane and the continuous phase a water/sugar solution – this gave a high density difference. Replacing dodecane with butanol gave a high difference in surface tension between the dispersed and continuous phase.

The test facility used a 0.18 m diameter rotor made of black PVC foam with a 95% void. A special lighting system was employed so that the behaviour of the fluids could be examined with cameras. Data revealed that the experimental error was very low at 5% maximum. Hold-up decreases as rotational speed increases and with increasing radius.

Jon described the model that had been developed, but to date it was found that at some very low flow rates the predictions were not fully satisfactory, possibly due to maldistribution of flow in the RPB. In the future Jon will be looking at different packing types, including ceramic units and perforated plates.

Richard Poynton of Profit & Planet (trp@pandp.datanet.co.uk) then presented us with some challenges with respect to the application of PI in the food industry. He started by comparing the positions of the chemical and food sectors. In the latter one needed to be very flexible,

give products of consistent quality and at low cost. Richard listed what one must accommodate and what one must deliver in the industry (see PIN web site). The PI opportunities were based largely upon the massive use of resources by the sector. Food takes 14% of the total UK energy use, 10% of the water and produces 10% of the waste. 10% of the sector is, stated Richard, at risk from climate change. If PI can contribute to minimising energy and water use and waste production, it could be of major importance. Richard suggested that some demonstration projects should be carried out, involving, for example, mixing + heating/reaction + cooling. He cited the continuous oscillatory baffle reactor as an example of equipment appropriate to the sector.

The main barrier to PI within the sector was that the food industry was innovative in products, but not innovative in processes!

Richard's 'solutions to savour' included the following areas:

- Cleaning – he suggested that a lab on a chip' device could be used to monitor cleaning in equipment.
- Process control – in continuous processes more sophisticated control is needed.

In discussion, Colin Ramshaw mentioned the demonstration at an earlier PIN meeting at Protensive of the production of custard on a spinning disc reactor. Richard said that the change from pasteurised milk to UHT treatment was a big step that was now accepted by the sector.

Adam Harvey of Newcastle University (a.p.harvey@newcastle.ac.uk) outlined the activities of his group (PIG) and went on to describe his research on biodiesel production intensification. He is using rapeseed oil as the feedstock, the attraction being generally that it is a renewable energy source, it reduces CO_2 emissions and pollution, and attracts tax relief in the UK at present. The range of PI projects in this area include a portable plant, solid catalysts (which allow a reduced number of process steps compared to liquid catalysts), the development of a reactive extraction process direct from the oilseeds, examination of cold flow properties and the production of biodiesel from algae.

The oscillatory baffle reactor/oscillatory flow reactor (OBR/OFR) types are seen as for niche applications, where one wants to convert a long residence time batch process to a continuous one. In the case of biodiesel, Adam said that a conversion could be carried out in 10 minutes, compared to 1-6 hours in continuous industrial processes.

The aim is to make the plant portable so that it will fit into a standard shipping container. The unit could be sold world-wide to farmers, for example, to produce their own fuel locally.

Alan Swanborough of Thermo Fisher Scientific (alan.swanborough@thermo.com) then described the twin-screw process used for melting and mixing polymer, but also applied in the food and paint, amongst other, sectors. The twin-screw unit exhibited a feederate characteristic that was independent of screw speed. Alan described the scaling up from, for example, flows of 5 kg/h to 150 kg/h. He explained that area varies as the square and volume as the cube of the characteristic equipment or reactor dimension, thus the area for heat transfer reduces per kg as one goes up in screw diameter. Alan also described ways in which one approaches the monitoring and control of the system in order to keep control of the temperature etc.

We returned to the research at Newcastle University with a talk by **Kamelia Boodhoo** (k.v.k.boodhoo@newcastle.ac.uk) on the topic of bioprocess intensification, in particular using porous mesh impellers to enhance mass transfer, specifically in oxygen flow. This is directed at overcoming the limitations of stirred tank units, particularly when handling high viscosity broths. Bubble column reactors would be used for shear-sensitive systems such as plant or mammal cells, and air-lift reactors would be an alternative if higher mass transfer is required. Both give low transfer rates compared to agitated systems, however.

Kamelia went on to describe the process of transferring the oxygen to the cells. She explained the effects of the boundary layers on the oxygen and the liquid film, and stated that the mass transfer (gas-liquid) across the liquid film boundary layer is a limiting factor. In order to address this problem Kamelia looked at a number of porous materials such as Declon, a compact fibre mesh and a woven stainless steel mesh. The first two, being polymer, could not be sterilised at high temperature, so the woven wire was selected.

The mesh was packed onto the shaft, replacing the conventional impellers (see presentation for photos). The porous mesh impellers were found to be better than the Rushton turbine type. Kamelia also pointed out that for PI one also needed to look at power use, in terms of W/m^3. The unit was best when one obtained a high $K_L.a$ with a low power input.

Kamelia then went on to describe the examination of the bubble size distribution for four systems. Most porous mesh impellers were found to give smaller bubbles. The knitted wire mesh allows more cells (e.g. E.coli) to be grown in a given time compared to the Rushton turbine. In the future, the research will examine the effect of mechanical shear on cells, and will encompass development of a centrifugal field bioreactor leading to integrated reaction and separation.

In the afternoon Technical Session **Alexis Bazzanella of DECHEMA e.V**. in Germany (bazzanella@dechema.de) described the EC-funded IMPULSE Integrated Project. Alexis described the pressures on the process industries (pharmaceuticals, speciality chemicals and consumer products), such as demands for agility of manufacturing, and the shortcomings, such as lack of ideal performance. He stressed the fact that the uptake of PI had been slow, and said that innovation will only take hold if business drivers are being met. He said that the vision was to take multi-scale processing to precision processing. Companies involved in IMPULSE include GSK, Degussa, P&G, Siemens (out of 20 partners in 8 EU countries) with a 17 MEuro over 4 years.

The principle of the activity is the construction of large-scale systems with small-scale inner structuring locally where needed. Project goals are design methods and tools covering decision-making criteria.

Alexis described specific application areas and opportunities. These generally revealed many advantages, but he stressed that care needed to be taken in showing where structuring can make sense. In the project the first target group is equipment manufacturers.

Beyond IMPULSE, Alexis said that aims were (i) overcoming barriers, (ii) breaking the economics of scale and (iii) the intensification of product engineering. Further data can be found on the project web site – www.impulse-project.org

John Whittle (john.whittle@ciktn.co.uk) described the activities of the UK Chemistry Innovation Knowledge Transfer Network. This arose out of the bringing together of three Faraday partnerships, (Crystal, IMPACT and Insight) and includes strategic partners such as CPI, (Teesside), EPSRC, Britest and Scottish Enterprise. John outlined the three categories of membership and their benefits/commitments. The mission of Chemistry Innovation is mainly to support product and process innovation in chemistry-using industries. There is a largely industrial innovation strategy board and an academic stakeholder forum, each numbering 20-30 people.

John said that as well as networking, the group aimed to influence policy and facilitate collaborative projects. The group also has links with the DTI and its Foresight and other activities. 'Technology platforms' of interest include green product technologies and high throughput technologies. PI could fall within the area of green products and there are currently 25 projects worth £9 million active in this category.

Impromptu Presentations

Mingzhi Zheng of Cambridge University (mz232@cam.ac.uk) described a scaled-down oscillatory baffle reactor – a meso-reactor. He showed CFD simulations of the flow within the unit, together with a video that effectively demonstrated the mixing achieved. Mingzhi then briefly presented three case studies, starting with a homogenous liquid phase reaction, followed by a liquid-liquid mixing reaction (equivalent to a biodiesel production process) and finally a precipitation reaction.

Jeremy Double of Britest (Jeremy.double@britest.co.uk) then reported on the outcome of a survey of the characteristics of industrial processes among Britest members, in the context of identifying suitable reactions for PI. In general they were low tonnage processes, and nearly all were batch. Greater than 60% involved solid feed, therefore for PI one needs a low rate of solid feed, grams to kg/h. Two thirds of the processes involve two or more phases during the reaction, and over 40% of these had solids present in the reaction. With regard to the outputs, 50% were liquid or a solution, 33% solids and the rest a paste or slurry. The reaction times varied from seconds to three days.

Jeremy said that rate limiting was, in 50% of the cases, due to chemical kinetics, 30% were mass transfer limited while the rest were heat transfer limited or limited due to unknown factors. 50% of processes had five or more work-up steps, suggesting areas to go for are in separation rather than reactions.

Jeremy made the following conclusions:

- The diversity of processes was large and several reactor types are needed
- There is a need for continuous reactions of 1-120 minutes residence times
- There is a need for small-scale continuous equipment for feeding, recovering solids, etc.
- There are opportunities in work-up.

There are supplementary data on the survey in the presentation – see the PIN web site.

Bart Hallmark of Cambridge University (bh206@cam.ac.uk) introduced us to microcapillary films (MCFs) which could be used for PI. They are also described on

http://www.microcapillaryfilms.org.uk/ and photos of the units are available in Mark's talk on the PIN web site. The polymer film 'ribbon' contains holes in the form of longitudinal capillaries of down to 7 microns in diameter.

Mark described two case studies (other applications are on his overheads), these being a chemical microreactor and a micro-heat exchanger. The heat exchanger could be used, for example, for cooling the Central Processor (CPU) on computers using water. Heat transfer densities of 14-15 MW/m^3K on one side of the unit. As a micro-pump, the unit could deliver multiple fluids with one pump head.

The meeting was then formally closed with thanks to our hosts and speakers, before we toured the research laboratories of the Process Intensification Group at Newcastle University.

PIN News

Please send articles for the next issue of PIN News to David Reay at DAReay@aol.com as soon as possible.

The Next PIN Meeting

The next PIN meeting will be held at the invitation of Ineos Ltd. at their Grangemouth, Scotland facilities. This will be on Thursday 26th April 2007. On the evening of 25th April a seminar on PI, at the invitation of the Scottish branch of the IChemE, will be given at Grangemouth by Prof. Colin Ramshaw and Dr. Adam Harvey.

Offers of talks by PIN members are welcome – please contact David Reay.

Further data on both events will be circulated in March.

Minutes prepared by David Reay, 2 January 2007.