Institution: University of Greenwich

Unit of Assessment: (UoA 15) - General Engineering

Title of case study: Avoiding and Resolving Problems with Handling of Powders and Other Particulate Materials in Industry: 'QPM' and related projects including 'Powder Flowability Tester'

1. Summary of the impact

Powder handling research at the Centre for Numerical Modelling and Process Analysis (CNMPA) enables industries to reduce the risk in new powder processes and to troubleshoot existing ones. The study focuses on two closely-related projects that have resulted in a series of instruments, analysis techniques, training and spin-out research that has found application in a large number of companies all over the world, in a wide range of industries. The case is typical of the influence that the CNMPA has had on industry awareness and practice in the UK and globally.

2. Underpinning research

From 1998 to 2002, the Wolfson Centre for Bulk Solids Handling Technology (a team within CNMPA) at the University of Greenwich was the lead member of three academic and six industry groups collaborating on a substantial project, **Quality in Particulate-based Manufacturing (QPM)** (EPSRC £913,838 / industry £1,100,000) [3a] to develop techniques to predict the level of 'quality loss' in handling of particulate materials through conveying, storage and logistics processes. The research was stimulated by the large financial losses from these causes experienced by many industries that involve powders, granules and grains as their feedstocks, intermediates and finished products. Investigators were Patel, Reed, Bradley, also Cross (Cross departed Greenwich 2006).

The output was a 'toolkit' of:

- Techniques [3.1-3.3] including three novel instruments to measure the propensity of particulate materials to suffer from the three main problems identified, namely particle breakage (degradation), caking (lump formation) and segregation (demixing);
- process models enabling the outputs of the instruments to be used in conjunction with known process conditions to predict the degree of the problem to be expected in a new process.

This enabled new manufacturing processes and products to be analysed prior to finalisation of their design or formulation, and existing ones to be improved through 'what if' studies, to eliminate problems. Detailed study of many plants processing solids led to a deep insight into the common problems, their causes, and the properties of the particulate materials that control this behaviour.

From 2004 to 2009 an instrument arising from QPM, the novel (manually operated) shear tester for measurement of powder strength, originally conceived to measure the strength of caked powders, was the basis of further research at the Wolfson Centre by one of the QPM investigators (Bradley, PI on the new project) and researchers (Berry). The DEFRA [3b] and international industry-funded project aimed to deliver a fully robotised, automated **instrument intended to widen the use of powder flow property measurement** throughout industry [3.4]. Poor or erratic powder flow causes great loss of productivity, so there was a clear need for an instrument that could be used by non-specialists to assess the handling problems inherent in any given powder, in order to:

- assist with formulation (engineering the powder to avoid the problem)
- design of the equipment around the powder to avoid or eliminate the difficulty
- quality control on powder products in production and purchasing.

The research outputs from these two projects underpinned a substantial number of related bulk solids research projects in Wolfson, involving Bradley, Berry, Deng or Farnish as PIs. Examples include EPSRC [3c, 3d], DEFRA [3e, 3f], Oil Industry Technology Fund [3g], British Coal Utilisation Research Association [3h, 3i, 3j], EU [3k] and many from industry. These have focused on diverse aspects of bulk solids processing including plant wear by bulk solids, powder formulation for favourable handling properties, optical sorting of particles, soil remediation, on-line measurement

of flow properties, handling of wet ores, coal handling, pneumatic conveying [3.5], fluidised powder transport, biomass handling, powder electrostatics [3.6], powder metallurgy and others.

3. References to the research (REF UoA15 submitted staff in bold, **UoA15 submitted outputs)

3.1 Chapelle, P., Christakis, N., Wang, J., Strusevich, N., Patel, M. K., Cross, M., Abou-Chakra, H., Baxter, J., & Tuzun, U. (2005). Application of simulation technologies in the analysis of granular material behaviour during transport and storage. *Proceedings of the Institution of Mechanical Engineers, Part E: Journal of Process Mechanical Engineering*, *219*(1), 43–52. http://dx.doi.org/10.1243/095440805X7044

3.2 Abou-Chakra, H., Tuzun, U., Bridle, I., Leaper, M., Bradley, M. S. A., & Reed, A. R. (2003). An investigation of particle degradation by impact within a centrifugal accelerator type degradation tester. *Proceedings of the Institution of Mechanical Engineers, Part E: Journal of Process Mechanical Engineering*, *217*(3), 257–266. http://dx.doi.org/10.1243/095440803322328908

3.3 Christakis, N., Chapelle, P., Strusevitch, N., Bridle, I., Baxter, J., Patel, M., Cross, M., Tüzün, U., Reed, A. R., Bradley, M. S. A. (2006). A hybrid numerical model for predicting segregation during core flow discharge. *Advanced Powder Technology*, *17*(6), 641-662. http://dx.doi.org/10.1163/156855206778917715

3.4 **Berry, R. J.,** & Bradley, M. S. A. (2007). Investigation of the effect of test procedure factors on the failure loci and derived failure functions obtained from annular shear cells. *Powder technology*, *174*(1-2), 60–63. http://dx.doi.org/10.1016/j.powtec.2006.10.023

3.5 ****Deng, T**., Farnish, R. J., & Bradley, M. (2008). Evaluation of particle degradation due to high-speed impacts in a pneumatic handling system. *Particulate Science and Technology, 26*(5), 438–450. http://dx.doi.org/10.1080/02726350802367522

3.6 Hussain, T., Kaialy, W., **Deng, T**., Bradley, M. S. A., Nokhodchib, A., Armour-Chélu, D. (2013). A novel sensing technique for measurement of magnitude and polarity of electrostatic charge distribution across individual particles, *Int. J. Pharmaceutics, 441(1-2)*, 781–789 http://dx.doi.org/10.1016/j.ijpharm.2012.10.002

The Brookfield Powder Flowability Tester: The product itself is described at: http://www.brookfieldengineering.com/products/pft/powder-flow-tester.asp

Accolades recognising the quality of the outputs and impact of the cited research:

- **QPM project:** IChemE Awards 2006 (Chemistry Innovation Award for Innovation in Applied Catalysis and Colloid Science): Highly Commended
- **Powder Flowability Tester (PFT):** R&D magazine top 100 Award Winners (USA) 2011 (http://www.rdmag.com/award-winners/2011/08/powder-flow-measurement-gets-twist)
- **PFT:** IMechE Bulk Materials Handling Award for Innovation 2012 (ref. IMechE secretariat T_Khatun@imeche.org, certificate available)
- **PFT:** Runner-up in IChemE Innovation Awards 2010 (certificate available)
- **PFT:** Shortlisted in Times Higher Education Awards 2010 (certificate available)

Grant references:

3a M. Cross. *Quality in Particulate Based Manufacturing*. EPSRC (Ref. GR/M15057/01). Nov 1998-Oct 2002. £913,839.

3b M Bradley. *Development of an Economic yet Useful Powder Flowability Measuring Device*. DEFRA (Ref. AFM 206). 2004-2008. £169,761.

3c MSA Bradley. *Development of a Model to Predict the Life of Pneumatic Conveyor Bends Subject to Erosive Wear*. EPSRC (Ref. GR/M05980/01). Oct 1998-Jan1999. £137,651.

3d MSA Bradley. *Engineering the Green State of Powder Products*. EPSRC (Ref. GR/S70937/01). Oct 2003-Jul 2007. £84.839.

3e M Bradley. *Handling of Food Leaves for Successful Optical Inspection.* DEFRA (Ref. AFM 167). 2001-2002. £50,000.

3f MSA Bradley. *Development of a toolkit for controlling flow properties of engineered food powders.* DEFRA (Ref. AFM 276). 2010-2013. £134,999.

3g MSA Bradley. *Microwave Pyrolysis for Treatment of Oil Contaminated Drill Cuttings.* DEFRA. 2004-2008. £300,000 (UoG component £55,000).

3h MSA Bradley. *Direct On-Line Measurement of Wall Friction of Coal as an Indicator of*

Handleability. BCURA (Ref. B66). 2002-2006. £60,000.

3i MSA Bradley. *Handling Characteristics of Biomass/Coal Mixes for Co-Firing: Measurement Techniques and Establishing Benchmarks*. BCURA (Ref. B69). Oct 2003-Jun 2007. £59,480

3j MSA Bradley. *Improving Performance of Discharge Equipment for Coals with Poor Handling Characteristics.* BCURA (Ref. B89). Oct 2007-Sep 2010. £67,785.

3k RJ Farnish. *Biopowders* (*Research training in powder technology for competitive manufacture of food, pharmaceutical, nutraceutical and biological powders).* EU FP6-MOBILITY (Ref. 512247). Nov 2004-Oct 2008. €2,493,880 (UoG component £38,652).

4. Details of the impact

Impact delivery mechanisms

The research outputs from the two specific projects have been developed into a number of "delivery vehicles" which have been adopted and embedded very widely by industry:

- In-depth insight into the key issues with powder quality and flow on a large number of industrial plants that have been studied (12 during the research and around 100 more since), which have been built in to the dissemination routes described below. These include such issues as where to look for causes of problems in a plant; how to obtain meaningful samples from the plant and characterise them in ways that synthesise the behaviour seen on-plant; how to redesign equipment to avoid problems; and how to use the techniques to ensure right-first-time designs.
- A series of innovative instruments and facilities used by industry (the Brookfield Powder Flowability Tester; QPM Segregation and Degradation Testers, and Caking Test Suite) for measuring behavioural properties of powders, specifically their flow properties and their tendencies to segregate, degrade and cake in handling, processing and storage.
- A series of techniques for using the results from the above-mentioned instruments – mainly analytical and numerical models – to predict the behaviour of the powders in industrial processes (eg storage, transport, feeding/dispensing, heating/cooling, conveying) for use in plant design, powder formulation and process trouble-shooting.
- A much augmented series of educational courses for engineers in industry, to allow them to use this knowledge practically in their companies. Example course titles include Powder Quality, Bulk Solids Handling, Biomass Handling, and Design of Hoppers (www.bulksolids.com).
- A service used extensively by industry (+50 projects PA) for plant design and troubleshooting, eg reducing or eliminating problems with caking, degradation or segregation and poor flow of particulates, also fugitive dust, poor product quality etc which are commonplace and very costly.

Realisation of impact

Realisation has been through several channels: since 2008, 16 companies around the globe (from SMEs to multinationals) have funded 23 substantial programmes of consultancy or applied research to embed the direct outputs from the initial QPM project. They are either embedding the instruments and techniques directly in their own material characterisation and product design roadmaps, or funding studies at the Wolfson Centre to research the behaviour and formulation of their own materials further using the QPM techniques, and using the outputs of these further projects in their plants. There have also been three KTP projects.

Example 1: converting Drax power station to biomass: the world's largest biomass power project, involving conversion of the 3960MW Drax (UK) coal fired power station to 50% biomass. Wolfson was engaged to deploy QPM techniques to inform and optimise the design of the new £210M fuel handling, storage and feeding facility, predicting and minimising the physical degradation of the wood pellet fuel in the handling process (dust and fines have a profound effect on safety, performance and efficiency of fuel delivery to the power station) and ensuring reliable flow. Similar studies were also made for Tilbury (becoming for two years the world's largest biomass power station) and Uskmouth power stations.

Example 2: the Brookfield 'Powder Flowability Tester' (PFT), arising from QPM via the following DEFRA AFM 206 research, is manufactured in the US by multinational Brookfield Viscometers and on sale globally. Around 200 machines (value ~£2M) have been sold in 24 countries in three years since launch in 2010. It has become the most widely-used shear tester world-wide for studying the behaviour of powders, in industries as diverse as food,

pharmaceuticals, energy, chemicals and any others that use powders. A further 42 companies have embedded through 61 funded projects of consultancy or applied research at Wolfson, based on use of the instrument and its underpinning research on powder flow, to research and improve their feedstocks, processes and products.

Wider impacts

The powders research that built on the QPM and DEFRA outputs have had deep impact in their fields (173 embedment projects funded by ***123 companies*** since 2008). Manufacturing sectors reached include pharma, food, minerals, powder metallurgy and chemicals overseas and in the UK, including many blue-chips eg ***GlaxoSmithKline*** (11 projects to embed the research in plant design or problem-solving, protecting ***multiple £Billions of production*** annually), ***Masterfoods*** (9), ***Norgine*** (7), ***Unilever*** (6), ***Portasilo*** (4) and many others. These impacts are significant improvements to the design of new or existing plants which process many millions of pounds of product annually, an enduring impact of on-going benefits to process efficiency and/or product quality in products ranging from cosmetics, drugs and snack foods to cement, automotive parts and power generation. Letters from these and other companies are provided by way of illustration.

The resulting heavily revised and augmented series of educational courses for engineers in industry (http://www2.gre.ac.uk/about/schools/engineering/wolfsoncentre/coupro/sc), has been attended by 677 paying delegates from over 250 companies since 2008, including delivery locally at 12 companies in the UK, EU and overseas including India and China; demand for places on these courses is accelerating. Many of these companies have gone on to use the techniques to improve their manufacturing systems or equipment designs (see SHAPA corroboration).

This research has set the Wolfson Centre and CNMPA up as the “go to” centre for expertise in powder and bulk solids handling in the UK and Europe, and one of the three leading groups globally. This ensures its ability to attract the top research challenges and collaborators within its field, and embed the outputs in not only the top “blue chip” manufacturing companies globally but also a large number of SMEs that together make up a substantial portion of the supply chain.

5. Sources to corroborate the impact

Letters provided:

1. Brookfield Engineering Laboratories (Chief Executive Officer) corroborates the key underpinning (DEFRA funded) research at Wolfson to delivery of the Powder Flowability Tester, and the reach and impact of the Powder Flowability Tester on global industry
2. Shepherd Construction (Drax Eco-Store Project Manager) confirms the example of use of the QPM-generated characterisation and design techniques to inform fundamental and detail design decisions on the world’s largest biomass power construction project.
3. GlaxoSmithKline (company Materials Science Lead) confirms the influence of the QPM, Powder Flowability Tester and related research including powder electrostatics, to their plant efficiency, reduction of losses and protection of quality and production efficiency for multiple £Billions of annual production.
4. Solids Handling and Processing Association (General Secretary) – the trade association for UK manufacturers of solids handling equipment - corroborates the embedment and impact of the QPM and DEFRA research and its spin-outs, on the £1Bn+ UK industry in this field
5. Electricite de France (Carbon reduction programme manager) confirming the embedment of QPM and related research outputs, and its resulting cost savings (£5M pa and rising) across their nuclear power stations.

Public domain references:

6. Report on award of IMechE Prize for Powder Flowability Tester:

   http://www.imeche.org/wolfson-centre-and-brookfield-awarded-imeche-materials-handling-award-for-innovation-2012

7. Brookfield Video describing application of Powder Flowability Tester:

   http://www.youtube.com/watch?v=RH4FsDgQc80