Institution: WestCHEM
Unit of Assessment: Sub-panel 8 – Chemistry
Title of case study: Multi-million pound sales and efficiency gains through formulation development and process optimisation

1. Summary of the impact

Significant economic impact was achieved as a result of research into polymer nanocomposites and their formation, conducted at WestCHEM from 2000 to 2010. Collaboration over the six-year period 2004-2010 with Carron Phoenix Ltd, the world's largest manufacturer of composite 'granite' kitchen sinks, led to nanocomposite technology being incorporated into over one million sinks, generating income for the company in excess of £50M from 2007 to the present day. Considerable production efficiency gains saved in excess of £1M annually through the reduction in manufacturing time, the reduction of raw materials wastage, and the reduction in landfill costs (and commensurate environmental benefit) for failed and out-of-spec products. In addition, a £4M capital investment by the company at the Falkirk plant was secured, enabling the company to sustain its leading position in the designer kitchen sink market. With the site consequently designated as the parent company's competency centre for composite sink technology, employment for 170 workers was secured.

2. Underpinning research

Context

Carron Phoenix Ltd, based in Falkirk and part of the Swiss Franke PL Colour Group, is the world's largest manufacturer of composite kitchen sinks. Prior to our engagement with the company, their manufacturing (moulding) process was energy- and labour-intensive with variable product quality, and represented a significant cost to the company in terms of down-time, remedial work, wastage and disposal costs. There were also significant licensing costs. With major financial concerns, the company sought expertise to increase efficiency and reduce wastage costs together with the development of new products for the market.

Key Researchers

Since about 2000, the research groups of Richard Pethrick (appointed 1969, promoted to Professor in Physical Chemistry in 1984, retired in 2008 but maintains research interests as non-salaried research professor) and John Liggat (appointed 1994, promoted to Senior Lecturer in 2003 and to Reader in Physical Chemistry in 2009), developed expertise on the preparation and evaluation of polymer nanocomposites, particularly by dispersion of functionalised nanoclays, that underpins the success of this project. This knowledge and understanding, together with the complementary expertise of chemical engineer, Carl Schaschke (appointed 1990, promoted to Senior Lecturer in 2001, to Reader in 2006 and to Professor in Chemical & Process Engineering in 2010), were crucial in transforming the technology at Carron Phoenix, resulting in the impacts described here.

Key Research Findings

The most significant findings from this extensive research base in terms of this impact case study include:

(i) Detailed understanding of how to control and utilise the rheological changes that occur in monomer systems when generating nanocomposites through *in situ* polymerisation [1, 6];

(ii) Understanding of what process factors, such as mixing regimes and additives, optimise the nanocomposite dispersion in the first instance [1, 4];

(iii) Identification of the chemical and physical property benefits, such as reduced cure time, increased glass transition temperature and accelerated crystallisation, that can result from effective nanocomposite formulation [2–6];

(iv) Knowledge of how different modifiers and the extent of surface treatment for the montmorillonite and sepiolite range of organically modified clays affected the morphology of the dispersion in polymerisable solvents and how this subsequently affected rheology, cure chemistry, and post-cure properties [1,6];

(v) Identification of effective mixing regimes and the use of coupling agents to control the dispersions [1].

The initial interaction (2002) with Carron Phoenix was through an EPSRC CASE studentship beginning our formal partnership and identifying the value of nanoclay dispersions to the company and some of the specific outputs from this research with are included in [6]. Together, these research outputs were crucial in allowing Carron Phoenix in conjunction with their WestCHEM partners to develop, implement, and fully optimise a new faster production process. Initially, the implementation of more rapid heating rates (an imperative for increased efficiency) led to an unwanted greater sedimentation of the fillers resulting in product defects. Detailed and extensive chemical and processing studies, informed by the earlier research base, were required in terms of formulation, cure characteristics, rheological, and thermal properties of the nanoclay materials. From these studies an innovative nanocomposite rheology modifier was developed, based on the earlier research-led formulations, which provided the required anti-sedimentation controls without adversely affecting the material flow behaviour or cure chemistry. Without this additive, the new cost effective process technology could not have been implemented. The additive was also incorporated into the standard process leading to much reduced rework and wastage.

3. References to the research

References 1, 2, and 4 best exemplify the quality of the body of research. Reference 6 is included in REF2.

[1] Study of the factors influencing the exfoliation of an organically modified montmorillonite in methyl methacrylate/poly(methyl methacrylate) mixtures. M. McAlpine, N. E. Hudson, J. J. Liggat. R.A. Pethrick, D. Pugh, and I. Rhoney, *Journal of Applied Polymer Science*, 2006, 99, 2614-2626. DOI: 10.1002/app.22582

[2] Influence of the epoxy structure on the physical properties of epoxy resin nanocomposites, S. McIntyre, I. Kaltzakorta, J.J. Liggat, R.A Pethrick, and I. Rhoney, *Industrial and Engineering Chemistry Research*, 2005, 44, 8573-8579. DOI: 10.1021/ie048835w

[3] Properties of epoxy nanoclay system based on diaminodiphenyl sulfone and diglycidyl ether of bisphenol F: influence of post cure and structure of amine and epoxy. S.E. Ingram, J.J. Liggat and R.A. Pethrick, *Polymer International* 2007, 56, 1029-1034. DOI: 10.1002/pi.2237

[4] Some factors influencing exfoliation and physical property enhancement in nanoclay epoxy resins based on diglycidyl ether of bisphenol A and F; S. Ingram, I. Rhoney, J.J. Liggat, N.E. Hudson and R.A. Pethrick, *Journal of Applied Polymer Science*, 2007, 106, 5-19. DOI: 10.1002/app.25474

[5] Effects of organically modified clay loading on rate and extent of cure in an epoxy nanocomposite system, S.E. Ingram, R.A. Pethrick, and J.J. Liggat, *Polymer International*, 2008, 57, 1206 – 1214. DOI: 10.1002/pi.2452

[6] Influence of clay type on the enhancement in physical properties of *in situ* polymerised poly(methyl methacrylate) nanocomposites, S. Ingram, H. Dennis, I. Hunter, J.J. Liggat, C. McAdam, R.A. Pethrick, C. Schaschke, and D. Thomson, *Polymer International*, 2008, 57, 1118-1127. DOI: 10.1002/pi.2453

4. Details of the impact

From research to impact

EPSRC and industrially funded research at WestCHEM, including an EPSRC CASE studentship (2002-2005) with Carron Phoenix Ltd, resulted in the development of novel polymer nanocomposite formulations with mechanical, thermal, and barrier properties superior to the base polymers. Of particular relevance to the company, acrylic formulations with enhanced rheological control had been developed that offered the potential of significant benefits to Carron Phoenix Ltd in terms of process flexibility, enhanced product performance, and reduced wastage. This led to the creation of one major Knowledge Transfer Partnership (KTP) collaboration and a follow-on Short KTP (sKTP) collaboration between the company and the University, over the period 2004 to 2010, established with the aim of introducing this nanocomposite technology to the company's product and processes (£268k funding in total). This allowed the company to sustain its position in the designer kitchen market worldwide.

The KTP associates were embedded in the company to undertake the process and product development work, supported by the WestCHEM academic partners. The associates also made frequent use of specialised WestCHEM facilities. The programme began with a full evaluation of the chemical processing practices, as well as material and energy audits. The detailed understanding of the mixing, reaction characterisation, heat and flow properties was also completed. This led to a radically new approach being devised for all aspects of the process operation, including the reallocation of labour, reduced process times, increased mould tool usage and major capital investment in automation.

In view of the highly competitive and financially lucrative market for high-end kitchen products and the propensity to replicate the product by other manufacturers, Carron Phoenix and WestCHEM took the mutual decision not to protect IP through patenting, instead choosing to retain key knowledge in-house but publicising the relevant technological development by way of a conference presentation and refereed journal publication [6] to prevent other manufacturers patenting the process.

Nature of the Impact

Improved manufacturing process

The KTP projects consolidated the findings of the preliminary research by providing a full evaluation of the chemical processing practices as well as material and energy audits. From a detailed understanding of the mixing, reaction characterisation, heat and flow properties, a radically new approach was devised for all aspects of the process operation, including the reallocation of labour, reduced process times, increased mould tool usage, and major capital investment in automation (Source 1).

Process acceleration and automation created new challenges in terms of control of the flow behaviour of the composite sink formulation during the final curing step. In particular, more rapid heating rates led to greater sedimentation of the fillers resulting in product defects. Detailed and extensive chemical and processing studies were required in terms of formulation, cure characteristics, flow and thermal properties of the nanoclay materials. This provided the necessary platform for the development of a completely new process with the successful commercial production of high-end designer synthetic kitchen sinks sold worldwide. The research enabled the team to identify a suitable type and concentration of nanoclay filler and rheology modifier to allow control of (a) the mixing and distribution of materials, (b) the effective transfer of the mix, and (c) heating and curing rate, to produce synthetic sinks free from warpage and surface blemishes and thus reduce wastage from spoiled products. Prior to this project, it had been necessary to re-work moulded kitchen sinks in such a way as to avoid warpage and product spoilage. The company is forthright in its acknowledgement of the criticality of the new formulation:

> "*The nanoclay influenced the processability significantly and enabled us to introduce the new process technology with its significant savings. No nanoclay - no new process at that time, it is as "simple" as that*" (Source 2, Head of R&D, Carron Phoenix Ltd)

Production efficiency and cost savings

The implementation of the changes to the process enabled by the new nanocomposite formulation resulted directly in considerable production efficiency gains through the reduction of raw materials wastage, the reduction in manufacturing time and the significant reduction of landfill costs of failed and out-of-spec products. These savings alone amounted to in excess of £1M annually, significantly in excess of the 25% target defined for the project. The Franke PL Colour's Sustainability Report 2011 notes that:

> "*Our production processes mainly use electricity and natural gas. We have experienced that the combination of process and technological improvements result in major energy savings […] In Falkirk, United Kingdom, the energy required for the moulding of granite composite could be reduced by 20 % per annum with an innovative process called "Rapid Energy Distribution*" (Source 3 p.19)

Competitive advantage to the company

By creating superior high-quality products and reducing production costs, the research outcomes from this project have enabled the company to maintain its international business and market share in the higher-end designer kitchen sinks. The company has been able to use these efficiency savings to sustain its drive to maintain the economic viability of the Falkirk site relative to other competitive options. In 2010, Franke PL Colour, the parent company, subsequently established Carron Phoenix in Falkirk as the Group Competence Centre for composite sink technology, due in part to the strong research and development brought about by the incorporation of nano-composite technology. This has secured both major employment for 170 workers in the composite sink division at the Falkirk site and retained the associated supply chain infrastructure supporting further employment locally and nationally (Source 4).

Investment

The successful research outcomes from this project were further supported by internal company investments securing significant investment in new automated production facilities with a capital investment of approximately £4M. These were installed in 2008 and 2009 to incorporate the new nanocomposite technology with the production and sale of over one million kitchen sinks by Carron Phoenix. This resulted in generating income in excess of £50M for the company as well as generating support for the associated supply chain involved and contributing to the UK economy generally.

On-going collaboration

The Carron Phoenix company remains in regular contact with researchers at WestCHEM using facilities such as the Advanced Materials Research Laboratory. Schaschke and Liggat provide training courses on polymer chemistry and process technology for company staff. Skilled researchers from WestCHEM have transferred to posts in the industry; a PhD graduate from the Liggat research group, and an MEng graduate Chemical & Process Engineering have been employed by Carron Phoenix since 2012.

5. Sources to corroborate the impact

[1] The KTP programme was assessed on a quarterly basis by and minutes of these meeting are held by the West of Scotland KTP Centre, 50 George Street, Glasgow G1 1QE 0141 548 2430. www.ktpws.org.uk

[2] Head of R&D, Carron Phoenix Ltd, has provided a statement, and can be contacted to confirm company perspective on the impact of the research, including quantitative estimates of the benefits.

[3] http://www.franke.com/content/dam/frankegroup/pdf/publications/Sustainability_Report_2011.pdf provides evidence of increased efficiency and cost savings at the Falkirk site

[4] Commercial & Product Support Manager, Carron Phoenix Ltd, can be contacted to confirm company perspective on the impact of the research, including quantitative estimates of the benefits.