Institution: Lancaster University		
Unit of Assessment: 8 Chemistry		
Title of case study: Lancaster University research improves the monitoring, control and optimisation of paint wastewater processing at one of the UK's largest paint manufacturing companies		
Period when the underpinning research was undertaken: 2015 – 2019		
Details of staff conducting the underpinning research from the submitting unit:		
Name(s):	**Role(s) (e.g. job title):**	**Period(s) employed by submitting HEI:**
Peter Fielden Alastair Martin	Professor Professor	01/10/2012 – 30/09/2020 08/09/2014 – present
Period when the claimed impact occurred: April 2014 to present		
Is this case study continued from a case study submitted in 2014? N		

1. Summary of the impact

Fundamental research into the behaviour of particles suspended in liquids by Lancaster University (LU) researchers has resulted in a number of applications in an industrial context with wide ranging impacts. These include impacts through two companies and related Knowledge Transfer Partnerships (KTPs):

Process Instruments (PI): A new sensor for monitoring suspended solids in wastewater was developed as part of a KTP and applied research by LU researchers, leading to two new products (SoliSense® and TurbSense®) manufactured by a specialist manufacturing company, called PI. These sensors have the highest specification in terms of range and linearity of any similar commercial sensors worldwide. Since their launch in 2018, sales of over **660 sensors** have exceeded **GBP620,000**.

Crown Paints: LU researchers have engaged in applied research to help Crown Paints reduce waste production from its paint manufacturing process at its Darwen and Hull plants, **affecting millions of litres of paint it produces across both sites each week**. Impacts include:

1) **GBP113,000** per annum saved in the cost of reagents used to remove paint particles from the wastewater they produce across its operations at its Darwen and Hull plants (**totalling 30,000 tonnes annually**).
2) **GBP145,000** invested in the construction and commissioning of a new waste paint processing plant at their Darwen and Hull manufacturing sites, following the recommendations of the KTP project between Crown Paints and Lancaster University. This includes investment in the enhancement of water metering throughout the Darwin manufacturing site, which has enabled a full inventory of water usage and the optimisation of wastewater treatment.
3) Analysis by LU of magnolia matt emulsion paint produced using recycled water, rather than clean water, showed no adverse effects in terms of colour and opacity and is being adopted into their manufacturing process.
4) A new robust model that provides extensive analysis of the dewatering filtration process, yielding the vital physico-chemical parameters of yield stress and diffusivity for the solid waste "cake" produced [3.5].
5) Paint surface analysis using the SEM/EDX at LU has led to a new technique to assist future R&D approaches to paint formulation and to the diagnosis of mechanisms of paint failure.

2. Underpinning research

The amelioration and disposal of wastewater streams is one of the most frequently used industrial processes in the world. For the paints industry, it is a significant source of cost, meaning all companies are seeking to optimise existing processes; waste disposal processes are also under intense scrutiny from an environental perspective, making the process of wastewater from the paint industry an essential focal point for applied research at LU.

Fielden has specialised in the development of chemical sensing systems for industrial applications. He has also researched more recently into ultrasonic-based techniques for efficient removal of suspended particles in water [3.1]; and the potential for electrochemical removal of dyestuffs from wastewater [3.2, 3.3]. The applications of the novel light-scattering sensor technology to wastewater monitoring as part of the KTP [G2] programme with Process Instruments Ltd, provided detailed insight into monitoring and control systems for treating particle-laden wastewater, including paint waste.

Martin is an experienced chemical engineer split between industry (15 years in commodity chemicals and water) and academia. During his career, he has worked on solid-liquid separations for systems as diverse as water treatment, mineral "slimes" dumps and antiperspirant specialising in the development of rigorous design methods [3.4], techniques for modelling and optimising systems)

Applications to partner projects
This Impact Case Study concerns three research projects that address the monitoring of suspended solids in treatment of wastewater (Process Instruments); a move towards a circular economy with paint waste (Nimtech); and the elimination of waste in paint manufacture (Crown Paints). The three projects are linked, as the preliminary feasibility study with Nimtech ("Paint Loop" MRes joint funded by Nimtech (GBP30,000) and the Centre for Global Eco-innovation (CGE) at Lancaster University (LU)) was based at Crown Paints (Darwen site) who provided the source of paint waste. This encouraged Crown Paints to engage in a more substantial programme with LU [G1] A parallel programme between LU and Process Instruments [G2] developed a sensing platform for monitoring suspended solids in wastewater. The technical knowledge of PI concerning the dosing of particle-laden waste with aluminium sulfate and polyclay, led to sharing of their understanding and best practice with the Crown Paints project, through the common project principal investigator (Fielden).

This combined expertise of Fielden and Martin, along with an earlier feasibility study on paint waste with Nimtech Ltd (Fielden as Principal Investigator, Wardrop as the RA), where Crown Paints Ltd were the third-party collaborator, catalysed Crown Paints (Darwin, Lancashire) to enter a partnership funded through a KTP grant [G1] (Fielden as Principal Investigator, Martin as Co. Investigator, and Wardrop as RA). **This was the first research grant between Crown Paints and LU, and indeed, the first major grant-funded research partnership between Crown Paints and a UK university in its 250-year history.**

One of the higher volume waste streams is wastewater (effluent) from Crown's two manufacturing sites based at Darwen and Hull, which totals approximately 30,000 tonnes annually. Despite the huge quantities, the effluent is pre-treated in effluent treatment plants at both sites before being piped for secondary water treatment. Crown's effluent treatment plants also produce a by-product from this process themselves, which although currently regarded as waste has potential value which is yet to be utilised. Our research has worked to help reduce the volume of this effluent at source, to understand the underlying chemistry of the waste treatment process leading to its optimisation and associated cost reduction, whilst investigating possible uses for the biproduct [3.5]. The key elements of the research carried out within the KTP project with Crown Paints include:

i) **The compilation of a full inventory of all water used on the Darwen site (including a considerable component of rainwater that also ends up in the waste stream)**: This has informed Laboratory-based experimental investigations by Lancaster University researchers, including: chemical analysis of small-scale paint formulation and recycling of the recovered water into the primary paint production, revealing that recycled water did not adversely affect the properties of the paint: using magnolia matt emulsion paint (the company's highest-volume product), colour and opacity tests **showed an insignificant change to the optical properties of the paint formulated with recycled water.** Findings published in [3.5]

ii) **The investigation of possible alternative dewatering technologies**: Apart from the filter press, which is currently used, centrifugation was considered as a possible alternative. (Initially, ultrasound precipitation [3.1] was also considered, but measurement of the particle size distribution in typical paint waste ruled this out). No other technologies came near to the filter press or centrifugation in a literature and patent review conducted by Lancaster University.

iii) Pilot laboratory studies into the electrochemical removal of paint dyes from wastewater [3.2; 3.3] were carried out on dilute solutions of dyes used in the colouration of Crown's paint products, followed by direct electrochemical processing of dye-laden paint wastewater. Whilst the results demonstrated some reduction in the dye components, the process was not sufficiently efficient to warrant further investigation or scale-up.

iv) **An analysis/optimisation of the chemistry of the coagulation/flocculation process, to reduce waste and improve efficiency**: The optimisation research identified a much 'leaner' combination of aluminium sulfate and polyclay provided the desired coagulation/ flocculation [3.5]. This element of research was underpinned by expertise from Process Instruments, who provided comprehensive technical information of the underlying chemistry of aluminium sulfate-based coagulation, and its control for the removal of particulate matter from wastewater. **This was the major research study of the KTP programme.** It led to the construction of a laboratory-scale "mimic" of the filter press system, with an added automatic and programmable control for the pressure-applied piston, which forces the flocculated waste within a cylindrical chamber through a circle of the same filtration membrane material used in the full-scale filter press. The laboratory instrument also recorded the linear progression of the piston in the cylinder, as the flocculated waste was dewatered at constant, or programmed, applied pressure. The pressure, linear displacement, and time data were then analysed by a new model developed as part of the project. This model demonstrated the efficacy of the scaled down filter press mimic and led to the provision of vital physico-chemical parameters that revealed how different formulations of the reagents would influence the "yield stress" and "diffusivity" of the solid waste "cake" formation. Three principal formulations of low, medium and high polyclay dosing have been described in the associated publication [3.5].

3. References to the research

3.1. Prest, J. E., Treves Brown, B. J., **Fielden**, **P. R.**, Wilkinson, S. J., and Hawkes, J. J., (2015): Scaling-up ultrasound standing wave enhanced sedimentation filters. *Ultrasonics*. *56*, 260-270. https://doi.org/10.1016/j.ultras.2014.08.003 **(4 citations)**

3.2 Yusuf, H. A., Redha, Z. M., Baldock, S. J., **Fielden P. R.**, and Goddard, N. J., (2016): An analytical study of the electrochemical degredation of methyl orange using a novel polymer disk electrode. Microelectronic Engineering, 149, 31-36. https://doi.org/10.1016/j.mee.2015.09.003 **(8 citations)**

3.3 Yusuf, H. A., Redha, Z. M., Ahmed, H. A., **Fielden**, **P. R.,** Goddard N. J., and Baldock, S. J., (2017): A miniaturized injection-moulded flow-cell with integrated conducting polymer electrodes for on-line electrochemical degradation of azo dye solutions. *Microelectronic Engineering*. 169, 16-23. https://doi.org/10.1016/j.mee.2016.11.016 **(7 citations)**

3.4 Zhang, Y., Grassia, P., **Martin, A.**, Usher, S., and Scales, P., (2015): Mathematical modelling of batch sedimentation subject to slow aggregate densification. *Chemical Engineering Science*. 128, p. 54-63. 10 p. https://doi.org/10.1016/j.ces.2015.01.066 **(10 citations)**

3.5 Wardrop, J., Baldock, S. J., Coote, I., Demaine, R., **Fielden, P. R.** and **Martin, A.,** (2020): Rapid Characterisation of Suspensions for Waste Treatment and Resource Recovery. *ChemRxiv*. Preprint. https://doi.org/10.26434/chemrxiv.13385429.v1

[G1] Crown Paints Ltd. (UK) Knowledge Transfer Partnership - Innovate UK and Crown Paints - Code: KTP010134 - 509753 (GBP200,457)

[G2] Process Instruments Ltd. (UK) Knowledge Transfer Partnership - Innovate UK and Process Instruments - Code: KTP9353 (GBP261,914)

4. Details of the impact

4.1 Design and introduction of novel technologies for the measurement of suspended solids in liquids and its commercial uptake – Process Instruments

Process Instruments (PI) Ltd are a SME who specialise in the measurement and control of water disinfection (potable and swimming pools), and the measurement and control of particle removal from potable and wastewater through coagulation and flocculation methodology. The desire to manufacture their own particle sensors, instead of relying on other commercially available devices from third-party suppliers Stemmed from the fact that, prior to the KTP programme with Lancaster

University, there was no single sensor on the market that could span the range of 2NTU to 8% particle concentration; two separate sensors were required to achieve the same effect.

Optimisation of the chemistry of the coagulation and flocculation processes by Lancaster University [3.5] within the KTP programme, led by Fielden, resulted in the successful development of a particle sensor that could monitor the range of 2 NTU to 8% particle concentration, with **significantly superior stability, linearity and dynamic range** compared with any current commercially available particle sensor for deployment in both potable and waste waters. This enabled PI to launch **two new products**: SoliSense® [5.1] and Turbsense® [5.2]. Turbsense® is a further variant of the SoliSense® device, which has given Process Instruments a sensor design that covers extremely low concentrations of particles in water (0 to 10NTU). The sensor designs are very similar but adjusted for very low particle concentrations and combined with a specialised water sampling device (developed internally by Process Instruments as a follow-on to the KTP project) to eliminate the errors associated with micro-bubbles.

SoliSense has the greatest dynamic range of any commercial particle sensor and is a **unique selling point,** since third-party end users only need to purchase a single sensor, which reduces both initial cost and halves maintenance costs thereafter. Furthermore, the linearity of the sensor developed through [G2] has enabled the subsequent development of a **novel patented algorithm** [5.3] that fully compensates for drift, which is a significant problem with conventional suspended solids sensors. Since their launch in 2018, both SoliSense® and Turbsense® are **manufactured by PI at their Burnley factory**, and have sold **over 660 sensors with sales exceeding GBP620,000 to end users in 24 countries** [5.4].

4.2 Improved awareness and understanding of waste generation in paint manufacture resulting in changes in practice and process at Crown Paints

The partnership between Lancaster University researchers and Crown Paints was initially motivated by the company's ambition to reduce the waste it generated as part of the paint manufacturing process, with the goal of becoming a net-zero waste paint manufacturer [5.5i-ii]. **New water metering systems were installed** at critical points in the manufacturing plant to gain the first accurate inventory of clean water usage and wastewater generation. This inventory enabled a **clearer understanding of the origins and volumes of the paint waste streams**, and the frequency of their generation throughout a production cycle and over the calendar year. The findings showed that Crown generated around **30,000 tonnes of wastewater** (effluent), and **120 tonnes of waste paint** per year [5.5i].

Initial research focussed on the chemistry of particle removal from paint waste, through the addition of the key reagents of aluminium sulfate and polyclay, and on the importance of pH control. This research was carried out using a jar test in the Crown Paints analytical development laboratory. **The understanding of how reagent dosing influenced the flocculation of the particulate waste was assisted through technical advice and drew on equipment provided by Process Instruments** [5.4]. This important link between the companies was inaugurated by Fielden, as Principal Investigator to both research programmes, who realised the potential benefits to the Crown Paints project of the more effective particle-sensing technology developed by PI.

This detailed understanding allowed trials and optimisation of a modified dosing chemistry to be carried out (in particular, determination of the minimum amounts required of aluminium sulfate and polyclay to deliver efficient flocculation) within the treatment plants at Darwen and Hull. Consequently, **the dosing chemistry practices were changed at both Darwen and Hull (affecting over a million litres of paint manufactured each week across the two sites) based on the KTP studies, grounded in the technical expertise provided by Process Instruments and the research expertise of Fielden and Martin from Lancaster University, which has given an annual saving in reagent costs of GBP113,000 pa.** [5.6]. This may be broken down into Darwen: (GBP20,000 pa caustic washings; GBP10,000 pa polymer washings; GBP5,000 pa in lower polyclay dosing; GBP18,000 pa in the reduction of plant washing due to increased process efficiency) and Hull: (GBP40,000 pa in reduced polyclay and aluminium sulfate consumption due to optimisation of the reagent formulation in waste filter cake generation).

4.3 Fundamental research into the optimisation of the flocculation chemistry and the improved efficiency of dewatering by filter press.

Novel benchtop apparatus, designed and constructed by Fielden and Martin, allowed for systematic research by Crown and Lancaster University into the interplay between the reagent chemistry and a range of particle-laden paint waste from representative streams at the Darwen and Hull plants). This apparatus provided detailed data of the dewatering process, which led to the development of a mathematical model that could evaluate the compression data to yield the key physicochemical parameters of yield stress and diffusivity of the solid "cake" waste generated by the dewatering process [3.5]. The outcome of this fundamental research was an optimised formulation for the Crown Paints Effluent Treatment Plants.

Thanks to the insights granted by the benchtop test apparatus, alternative dewatering processes were considered as part of the KTP programme, including ultrasonic sedimentation and centrifugation. Centrifugation was considered the closest competitor to the filter press, which resulted in a 6-month evaluation of a pilot centrifuge system by Crown at their Darwen site. This study showed that the filter press was the most efficient dewatering technology for the removal of particulates from paint waste. Subsequently, **the wastewater treatment plant at the Darwen site was renewed at a cost of GBP55,000, and at the Hull site for GBP70,000 to reflect the outcome of the main element of the KTP programme** [5.6].

4.4 Applied research into the recycling of solid paint waste leading to a reduction is waste production

Another project investigated both the recycling of the paint waste "cake" generated by the filter press and the water filtrate. The cake waste is currently sent to landfill but has been shown through the KTP programme to have applications as a "bulking" agent in the manufacture of external masonry paint, which is being acted on by the company to *"to realise the economic and environmental benefits"* [5.5i-ii]. Laboratory-scale research showed that recycled water from the filter press process could be used in the manufacture of magnolia paint (the major paint type manufactured by the company) without detrimental effects on the paint colour and opacity. This finding has already shaped Crown's knowledge of the process, has helped to reduce waste production in the paint manufacturing of particular products, and is being rolled out across Crown's large-scale, complex manufacturing process which includes over a million litres of paint produced weekly [5.5i-ii] and [5.6].

Unplanned in the original KTP programme, it became apparent that the partnership between Crown and Lancaster University could also benefit the company through access to specialist equipment at the Chemistry Department at LU. Specifically, the polymer development scientists benefitted from access to our Field-Emission Scanning Electron Microscope (Jeol JSM-7800F plus Oxford Instruments Xmax-50 EDS) with which they were able to evaluate novel emulsion paint formulations for the structure of the emulsion and the distribution of fillers, such as TiO_2 [5.6]. Whilst it is difficult to quantify this element of impact, **the findings have been presented to the parent Hempel Group** by Craig Wood, and represent a **new approach to the evaluation of future paint formulations, referenced in recent company reports as having, and the diagnosis of the failure of paint formulations** [5.5ii and 5.6].

5. Sources to corroborate the impact

5.1 Link to website and brochure for SoliSense® product and development (accessed January 2021): https://www.processinstruments.co.uk/products/suspended-solids-monitor/.
5.2 Link to website for TurbSense® product and development (accessed January 2021): https://www.processinstruments.co.uk/products/turbidity-meter/.
5.3 US Patent Application: 20190234873 16/315131: https://portal.uspto.gov/pair/PublicPair (01/08/2019).
5.4 Process Instruments letter of corroboration by Managing Director (2021).
5.5: i) Crown Sustainability Report (2015/2016) p.8 showing the impact of Lancaster University research on the company's proposed sustainability strategy. ii) Crown Social Responsibility Report showing the impact of the KTP on Crown's waste management processes (2018/2019), p.11.
5.6 Testimonial letter provided by Crown Paints (2021).