Institution: Newcastle University

Unit of Assessment: 14 Civil and Construction Engineering

Title of case study: Energy reduction for sustainable wastewater treatment

1. Summary of the impact

Anaerobic-aerobic sequencing biological wastewater treatment systems (AASB) developed at Newcastle University transformed waste treatment in the personal care product industry by significantly reducing energy use in waste processing. AASB produces high quality effluents, produces biogas, and use up to 68% less energy than traditional approaches. A full-scale AASB treatment plant was built by L'Oreal in 2012 in Suzhou (China), which since start-up has reduced sludge production by 20%, CO_2 emissions by 28%, and chemical use by 30%. The Suzhou AASB system won the Corporate Water Stewardship Award at the 2013 Global Water Summit and further systems are under construction at factories in China, France and Indonesia.

2. Underpinning research

Research at Newcastle University was led by Professor David Graham (Ecosystems Engineering) and Dr Jan Dolfing (Senior Research Associate). AASB research and development was primarily performed by Dr P Mehnet (2008-2010), Dr SZ Ahammad (2010-2013) and Dr B Christgen (2012-2013) in collaboration with colleagues at L'Oreal. Further, Professor Tom Curtis (Environmental Engineering) at Newcastle University is translating AASB and other low-energy technologies to domestic wastewater treatment applications with Northumbrian Water Limited (NWL).

Current biological waste treatment solutions often do not achieve their full potential (**P1**) because they demand too much energy or do not recover potential energy from carbon-rich wastes (**P2**). Most wastewaters are treated using aerobic biological processes where extra oxygen is added to accelerate organic carbon decomposition. However, aerobic systems use large quantities of energy. Recent Newcastle University research showed that 29% of all energy consumed in the water/wastewater nexus in Northern England is used for waste aeration alone (**G4**). Therefore, if organic carbon loadings were reduced on aerobic treatment units, significant energy savings could be achieved. This is especially true for industrial wastes, such as the personal care product industry (PCP), which can contain >100 times more organic carbon than typical domestic wastewater (**G1**, **P3**, **P4**).

Profs Graham and Curtis have explored innovative biological wastewater treatment solutions at a fundamental level since 2001 aimed at reducing energy consumption (**P1**). However, it was not until ENERMIN (**G1**) was awarded to Graham (with L'Oreal) that directed research on low-energy waste treatment technologies was explicitly pursued. The PCP industry traditionally employed physiochemical and aerated treatment processes, which consumed huge quantities of energy; up to 10% of total energy used at an operating factory (**P3**).

Early ENERMIN research focused on anaerobic treatment reactor designs, passive aerobic reactor systems, and pre-treatment options to reduce organic carbon loads to existing aerated reactors (**P3, P4**). Bench trials from 2008-2010 showed anaerobic processes alone could not achieve similar effluent quality as aerobic systems (50-70% versus >90% organic carbon removal; **P4**). However, they showed combustible biogas could be obtained from PCP wastes, which was significantly correlated with acetoclastic methanogen abundances (*Methanosarcinaceae*) in the anaerobic reactors (**P4**). Passive aeration systems, such as sponge reactors, also showed promise in PCP wastewater treatment because have a low energy footprint. However, they could only achieve 80-85% organic carbon removal (**P3**). These results indicated some active aeration was needed, but also showed anaerobic reactors could produce biogas and reduce organic carbon loads. Therefore, the AASB system was conceived, which includes an anaerobic pre-treatment reactor followed by aerated final treatment reactors. AASB was bench and pilot-trialled at Newcastle and L'Oreal, and data showed AASB systems used up to 68% less energy than aerobic systems and achieved >90% carbon removal (**P4**). This lead to the construction of a full-scale AASB treatment system by L'Oreal in Suzhou.

Parallel to ENERMIN research, EPSRC-funded research (**G2-G5**) extended AASB and other low-

energy technologies to domestic wastewater treatment applications (**P2, P5**). Approaches included microbial fuel cells (2009-2012; Dr E Heidrich, Dr B Christgen), low temperature anaerobic digestion (2009-2012; Dr E Bowen) and low-oxygen nitrification (2006-2010; Dr M Bellucci). Newcastle research showed there was 17.7 to 28.7 kJ of potential energy available per gram of wastewater Chemical Oxygen Demand (COD), which is 20% greater than previous believed (**P2**). This work showed the value of domestic wastes as an energy source had been underappreciated, which resulted in the pilot-scale testing of "next generation" bioelectrochemical anaerobic treatment systems for application in the UK (**P5**). Our successful intersection of reduced energy use (e.g., AASB; **P4**) and increased energy potential from wastewater (**P2**) has led to the development of a new NWL-based pilot testing facility (in design) with a £524K contribution from NWL as part of Newcastle's recently awarded EPSRC Frontiers in Engineering grant (**G6**).

3. References to the research

Key outputs: (Key Outputs are P1, P2, P4)

[P1] Curtis TP, Head IM, Graham DW. 2003. Theoretical ecology for engineering biology. *Environ Sci Technol*, **37**:64A-70A. *First explanation of how ecological theory that can be applied to engineering biology.*

[P2] Heidrich ES, TP Curtis, J Dolfing, 2011. Determination of the Internal Chemical Energy of Wastewater. *Environ Sci Technol*, **45**:827-832. *The paper shows that wastes have greater potential as energy resources than previously believed.*

[P3] Ahammad SZ, A Zealand A, J Dolfing, C Mota, DV Armstrong, DW Graham. 2013a. Low-energy treatment of colourant wastes using sponge biofilters for the personal care product industry. *Bioresource Technol*, **129**:634-638.

[P4] Ahammad SZ, JL Bereslawski, J Dolfing, C Mota, DW Graham. 2013b. Anaerobic-aerobic sequencing bioreactors improve energy efficiency for treatment of personal care product industry wastes. *Bioresource Technol.* **139**:73-79. *Description of the AASB system.*

[P5] Heidrich, E. S., Dolfing, J., Scott, K., Edwards, S. R., Jones, C. and Curtis, T. P., 2012. Production of hydrogen from domestic wastewater in a pilot-scale microbial electrolysis cell. Appl Microbiol Biotechnol **97**:6979-6989.

Key research grants:

[G1] EU-FP7: Marie Curie Excellence Project 218305, 2007-2012, Energy-Use Minimization in Residuals Management in the Personal Care Product Industry (ENERMIN). PI: D. Graham; Co-PI: H Bucholtz, L'Oreal; £190K.

[G2] EPSRC Platform Grant (UK): EP/F008473/1, 2008-2013, General and Unifying Concepts for Wastewater Treatment Plant Design. PI: T Curtis; Co-PIs: R Davenport, D Graham, D Werner; £774K.

[G3] EPSRC (UK): EP/G032033/1, 2009-2012, What is the True Temperature Limit for the Anaerobic Treatment of Domestic Wastewater? PI: T Curtis; Co-PI: R Davenport; £654K.

[G4] EPSRC (UK) – SECURE: EP/I002154/1, 2010-2014, Self-Conserving Urban Environments. PI: M Bell; Co-PIs: D. Graham plus four other Co-PIs at Loughborough, Sheffield and Exeter Universities; £2.8M.

[G5] EPSRC (UK) - Mitigation of risks from emerging hazards in India: EP/K50340X/1, 2011-2012, Integration of Field Training, Energy-conserving Waste Treatment and Next-generation, Sequencing Technologies. PI: D. Graham; Co-PIs: J. Amezaga, R Davenport; £29K.

[G6] EPSRC (UK) – Frontiers in Engineering. PIs: N. Wright, T. Curtis; 11 CIs; £5.57M.

4. Details of the impact

Newcastle research into low-energy waste treatment technologies has transformed waste treatment practices in the personal care product industry (PCP), which led to the construction of an AASB treatment plant in China and design/construction of similar new plants at factories in France,

China and Indonesia. The Suzhou (China) plant has reduced sludge production by 20%, CO_2 emissions by 28%, and chemical use by 30% since start-up in 2012. The research has expanded the implementation of novel reduced-energy treatment methodologies into the UK water industry.

a) **Change in policy & practice in wastewater treatment for the global PCP industry**

Newcastle's work has achieved a policy and practice change in biological wastewater treatment within the PCP industry, which resulted from the development of new treatment technologies for the industry and a changed perception of "wastes" to "resources" in the minds of industry decision-makers (**E1, E2**).

L'Oreal, a world-leader in the beauty industry has more than 70,000 employees, 41 plants, 600 patents per year and sales exceeding €22.5 billion in 2012. The company's water consumption is equally large, reaching 3 billion m^3 (an equivalent to a city of 130,000 people), and ~10% of all the energy used in a typical factory goes to waste treatment when traditional treatment processes are used. The scale of these problems prompted L'Oreal to perform joint research with Newcastle University in ENERMIN, which was aimed at reducing energy consumption in PCP wastewater treatment (**E1**). This work was consistent with L'Oreal's commitment to improving environmental systems and reducing their carbon footprint, which is consistent with long-term goals for their industry. The Global Environment, Health & Safety Director of L'Oreal stated that (**E2**):

"*Work with colleagues at Newcastle has helped fuel our own efforts at changing the way wastes are viewed and handled in the PCP industry, hopefully making sustainable energy production from wastes a central tenet in waste management across the company and industry*. *L'Oreal are committed to an eco-responsible approach as regards the impact of its activity and aim for excellence in terms of environmental performance. As part of its 10-year strategy (2005-2015) to reduce its ecological footprint, L'Oreal has set itself an ambitious goal for its plants to halve greenhouse gas emissions. The implementation of novel technologies from joint work with Newcastle will significantly contribute to this goal.*"

Following joint research, the optimal solution was AASB, which combined anaerobic and aerobic processes and had never been used in the PCP industry (**E1**). L'Oreal stated (**E2**):

"...research conducted with Newcastle between 2008 and 2012 developed a variety of innovative waste treatment options, including anaerobic-aerobic sequence reactors. Newcastle laboratory studies showed that it can reduce energy consumption by almost 70% relative to traditional aerobic treatment systems and still meet discharge standards. This basic reactor configuration has now been implemented at full-scale in the factory within L'Oreal Asia at Suzhou, China".

The Suzhou wastewater plant treats approximately 82,000m^3 of wastewater per year and employs 400 people. This new treatment system is designed to ultimately save greater than 20% energy, 80% use of chemicals, reduce sludge by 70% and improve the effluent quality by 50%. Since mid-2012, L'Oreal has thus far reduced sludge by 20%, CO_2 emissions by 28%, and the use of chemicals by 30% (**E3**). Based on this success, AASB plants are under development for other factories elsewhere in China (**E2**), Indonesia and France (**E3, E4**), and are being considered for all 41 L'Oreal factories around the world. The Suzhou AASB plant was awarded the Industrial Water Stewardship Award at the April 2013 Global Water Summit held in Seville, Spain (**E3, E4**), an event attended by 450-500 industrial world leaders and highlighted AASB to 289 different global companies (**E5**).

Looking ahead to meet the company's continued global sustainable development targets, L'Oreal declared (**E2**):

"*It is anticipated that the joint work with Newcastle University will promote the use of novel-energy-efficient technologies across industry and a positive significant impact in sustainable industrial treatment at a global level. This will help us towards our goals of reduced greenhouse gas emission, and responsible and sustainable growth.*"

b) Introduction of novel reduced-energy treatment technologies into the UK water industry

Northumbrian Water Limited (NWL) provides water and sewerage services to 2.7 million people in the northeast of England and water services to 1.8 million people in the southeast of England. NWL's collaboration with Newcastle University is central to their policy of reducing energy

consumption and carbon emissions by developing a new generation of low-energy wastewater treatment processes. The Research & Development Manager at NWL stresses the importance of Newcastle's research [**E7**]:

"*We value the research conducted at Newcastle which is rooted in understanding wastewater treatment systems at a deep and fundamental level, yet in doing so provides solutions and innovations at which are practical to industry. Over the last decade we have collaborated with Newcastle University in a number of research areas....including low temperature anaerobic digestion, microbial fuel cells and low energy nitrification. There has been many successful outcomes to this research including the first example of hydrogen generation in a pilot scale microbial electrolysis cell powered by domestic wastewater operational between 2011-12."*

Their commitment to establish a pilot plant facility at one of their operational sites for use in the Newcastle research is supported by NWL Chief Executive [**E6**]:

"*We propose to make available a waste water pilot plant test-bed facility, which we will design and build according to your requirements, for parameterising and testing your models; we will provide access to operational sites, personnel and information. We estimate the in-kind value of this support to be £524,000 over the life of the project.*"

5. Sources to corroborate the impact

[E1] EU FP7 Webpage for ENERMIN, which includes a history of waste treatment approaches in the PCP industry prior to this research. http://cordis.europa.eu/projects/218305

[E2] Avadavat letter from Global Environment, Health & Safety Director, L'Oreal, which states the significant role of Newcastle University in changing the corporate mind-set in the corporation relative to waste treatment.

[E3] Corporate Water Stewardship Award (July 2013) Newsletter which mentions the collaboration between L'Oreal and Newcastle University.

[E4] Webpage announcement of the 'Corporate Water Stewardship Award' at the 2013 Global Water Summit held in Seville, Spain, which names L'Oreal, Veolia Water and Newcastle University as responsible parties for the awarded treatment system. http://globalwaterawards.com/2013-awards-shortlist-winners

[E5] World Summit webpage that summarises the number of attendees and the number of companies that witnessed the awarding of the award. http://www.watermeetsmoney.com/attendees http://www.watermeetsmoney.com/sites/default/files/GWS2013_%20Feb2013.pdf

[E6] Chief Executive at NWL, a personal avadavat stating importance of Newcastle University research on the EPSRC Frontier project involving the simulation of open engineered biological systems.

[E7] Research & Development Manager at NWL provides a personal avadavat for the influence our research on waste treatment designs within the company, but also for the decision to build the new pilot to support further technical development.