

Editorial: Full-scale investigations in water and wastewater treatment

Through a series of engagements with strategic players in the global water community, the International Water Association identified an innovation gap in the water sector, specifically relating to the scale-up and implementation of newly developed water treatment technologies. The gap exists between laboratory scale research and small-scale piloting of technologies, and the end point of full-scale operation, whereby new technologies are adopted by the market. This creates a situation where, at times, the sector is forced to import market ready solutions from other sectors, such as oil and gas, because of this innovation gap in our own sector. As such, the issue of water technology scale-up, implementation, and commercialisation was identified as a key area of concern.

This concern is expressed in a diversity of ways in international innovation literature. The public literature tends to focus on the issues of commercialisation gaps and challenges. Rice *et al.* (2002) studied the challenges of transitioning discontinuous (as opposed to incremental) innovation projects to commercialisation and suggested several propositions for bridging the innovation gap. They reported that ‘a substantial “readiness gap” exists between the [R&D] project teams and the receiving business units and that bridging this gap was more difficult than anticipated’. They identified seven propositions ‘for improving the effectiveness of transition management’, suggesting the potential usefulness of the following managerial approaches: conducting a transition readiness assessment; assembling a transition team; establishing an oversight board; developing a transition plan; providing transition funding from corporate sources; laying the groundwork for a big market; and engaging senior management champions.

Later, Slater & Mohr (2006) proposed that ‘in order to successfully develop and commercialize...innovations, not only does the firm need to conceptualize and develop the innovation in the first place; it must also be successful in reaching more than just a niche market of innovators – early adopters. In other words, it must overcome the *innovator’s dilemma* as well as cross the chasm. These two problems are faced by all firms – but especially those operating in high-technology markets or driven by technological innovations – and are related in that they both

derive from the underlying skill set the firm brings to its marketing strategy.’ Arundel & Bordoy (2008) concurred that, ‘It is a common perception that European public-funded research fails to commercialize their discoveries, in contrast to the perceived success of their American counterparts. This resulted in policies aimed at improving the commercialization of European publicly-funded research, including the establishment of Technology Transfer Offices (TTOs)...’

All of these previous workers demonstrated that the issue of innovation gaps which exist in subtly different ways in differing contexts are real in many parts of the world. The current mismatch between the end of the road for ‘pure’ research and the first step on the path of full-scale industrial development poses challenges to policy implementation, particularly where environmental authorisations are concerned, and consequently temporary relaxation of effluent discharge standards or the implementation of percentile compliance is one of the many possible positive actions that can be taken to provide enabling regulatory environments to de-risk full-scale experimental work. The current regulatory context does not yet make that provision (Nienaber *et al.* 2015).

In the current context, what will the role of research, and consequently technical journals, be? One possible answer is to increase peer reviewed publication of full-scale science and engineering that can be used to exemplify good science, performed at scale, in an uncontrolled environment.

In this special issue, *Water Science and Technology* addresses this need and offers several presentations of full-scale or pilot-scale (at full-scale conditions) results of mid- or long-term investigations of the application of new developments in wastewater and water supply technologies. In all, 45 papers were submitted out of which 24 were selected for publication after peer review. The papers present case studies using scientific methods for the assessment of the new, so that the results are based on all relevant and comprehensive data, and adequate data quality assessment methods (e.g. mass and energy balances, temperature and parameter variability over time). The selected papers are grouped under four categories and include the following.

CASE STUDIES ON FULL-SCALE NATURAL AND NEAR-NATURAL SYSTEMS

Natural and near-natural systems are increasingly becoming part of the technology mix for wastewater treatment. However, case studies on full-scale natural and near-natural systems are lacking compared to those on conventional systems. There were three selected papers in this category. [Peña *et al.* \(2015\)](#) reported on the start-up and maturation phases of a full-scale, high-rate anaerobic pond bioreactor for municipal wastewater treatment which exhibited adaptation in less than 1.5 months, and yielded an ST/SV ratio 0.46 and specific methanogenic activity of 0.43 g-CH₄-CODg⁻¹SV⁻¹d⁻¹. The robust performance reported for the system was similar to that reported by [Sun *et al.* \(2015\)](#) for a tertiary treatment wetland in a tropical climate, thus demonstrating the effectiveness of these systems, especially in tropical conditions. In their paper, [Sun *et al.* \(2015\)](#) reported on the performance of the tertiary wetland system which achieved removal efficiencies for faecal coliforms (99.9%), TN (70.7%) and TP (68.2%). The system performance was reportedly well predicted using the K-C* model. However, significant disparities between the predictions and testing results were found for BOD and SS and a revised K-C* equation was proposed to account for the internal generation of organics in constructed wetlands with a long-retention time. This is particularly important for full-scale systems which would have longer retention time than most laboratory-scale systems. Another important consideration for natural and near-natural systems is the protection of biomass in the active treatment zone in the systems. This was investigated by [Onodera *et al.* \(2015\)](#) who presented a case study on the protection of biomass from snail overgrazing in a trickling filter using sponge media as a biomass carrier. It was reported that snails (macrofauna) were present on the surface of the sponge media, but could not enter into it, because the sponge media with smaller pores physically protects biomass from snails. As a result, the sponge media maintained a dense biomass, and the reactor required neither chemical treatments nor specific operations such as flooding for snail control. This is an interesting finding giving that the longevity of the systems is an area of critical concern. Furthermore, another area of concern for the systems is their techno-economic feasibility. This was addressed by [Singh *et al.* \(2015\)](#) who presented a techno-economical review of full-scale decentralised wastewater treatment plants with particular emphasis on performance,

land area requirement, capital cost, and operation and maintenance (O & M) costs; all of which are critical areas for natural and near-natural systems.

CASE STUDIES ON RESOURCE RECOVERY AND WASTE RECYCLING

Conventional approaches for wastewater treatment focus on removal of nutrients and carbon and are now becoming increasingly unsustainable, both economically and environmentally. This has driven the case for resource recovery. [Marchi *et al.* \(2015\)](#) and [Geerts *et al.* \(2015\)](#) presented a two-part paper which took a holistic view of resource recovery during the wastewater treatment process, focusing on phosphorus recovery from digested waste sludge. The two-part paper reviewed the technical achievements and challenges related to phosphorus recovery from digested waste sludge; while also examining the economic opportunities and the risks involved. It addressed gaps in our knowledge which relates to the fact that, to date, phosphorus recovery as struvite in wastewater treatment plants has been mainly implemented on water phases resulting from dewatering processes of the sludge line; and it suggested that it is possible to recover struvite directly from sludge phases; thereby minimising the return loads of phosphorus from the sludge line to the water line, and offering additional advantages of higher recovery potential, enhanced dewaterability of the treated sludge, and reduced speed of scaling in pipes and dewatering devices. Results from a full-scale investigation of the process in a waste water treatment plant in Leuven, Belgium was presented, indicating that the process reduced phosphorus load from the sludge line returning to the water line as centrate by 50% and an improved dewaterability of 1.5% of dry solids content was achieved with quality analyses showing that the formed struvite was quite pure. Measurements on the full-scale demonstration plant enabled the profitability of the process to be assessed. It was shown that although possible improvement in sludge dewaterability when recovering struvite from digested sludge has a positive economic amortisation effect, it is at the same time the largest source of financial risk. It was concluded that although struvite recovery from digested sludge is riskier, it is an investment with potentially a higher return than investment in struvite recovery from centrate. The paper provided further information for possible financial incentive schemes to support P-recovery. And in line with the recovery and reuse drive, [Schettters *et al.* \(2015\)](#) presented

a paper aimed at achieving circular economy in drinking water treatment through the reuse of grinded pellets as seeding material in the pellet softening process. In the study, the focus was on calcium carbonate pellets produced as a by-product in the pellet softening process. Two pilot reactors were used to investigate the grinding and sieving of pellets, and the subsequent reuse as seeding material in pellet softening. In one reactor, garnet sand was used as seeding material, and in the other grinded calcite. An economical comparison and a life cycle assessment were made as well. The results show that the reuse of grinded calcite as seeding material in pellet softening is technologically possible, and it reduces the operational costs by €38,000 (1%) and reduces the environmental impact by 5%.

MODELLING

One selected paper by [Sarker *et al.* \(2015\)](#) focused on modelling with the aim of developing an integrated water demand model integrating end uses of water. The model is capable of estimating and forecasting average daily water demand based on the end use pattern and trend of residential water consumption, daily rainfall and temperature, water restrictions and water conservation programmes; and would be particularly useful for water authorities and water resource planners.

CASE STUDIES ON CONVENTIONAL AND ADVANCED PROCESSES AND SYSTEMS

Four papers examined the operational aspects of conventional and advanced processes and systems: [Erdirençelebi & Küçükhemek \(2015\)](#) examined the effect of anaerobic reject water on the operational characteristics of a wastewater treatment plant as a precursor of bulking and foaming. It was found that the anaerobic reject water had a direct effect on bulking in secondary clarifiers and foaming in anaerobic digesters despite its relatively small flowrate. This was quite an important finding as it shows that anaerobic reject water deserves more consideration not only as a pollutant source, but also because of its potential to promote chronic seeding and retention in the system. In a similar vein, [Allerdings *et al.* \(2015\)](#) examined the effect of rapid mixing on the coagulation efficiency in a full-scale drinking-water treatment plant and discusses the mechanisms involved in the floc-formation process. The findings suggest an insignificant role of intense rapid

mixing in sweep flocculation during full-scale water treatment and reveal the potential to reduce the required energy costs for mechanical mixers. [Pruss \(2015a\)](#) reported on a full-scale investigation of the removal of organic matter from surface water during coagulation with sludge flotation and rapid filtration. Their findings indicate that undissolved TOC fraction was effectively removed through coagulation while small doses of ClO_2 added prior to coagulation enhanced the process. However, the process of coagulation using high coagulant doses at $\text{pH} = 6.5$ did not provide reduction in the TOC value below the level of 4 mg C/L required for treated water. [Gumińska & Klos \(2015\)](#) presented a novel approach of using particle counter as a tool to control pre-hydrolysed coagulants dosing and rapid filtration efficiency in a conventional treatment system. Using this approach, it was found that the type of coagulant had a very strong influence on the effectiveness of filtration resulting from the application of an improper coagulant dose; and this is very important in aiding filtration efficiency.

Two papers focused on the technology selection and optimisation: [Pruss \(2015b\)](#) which reported on a full-scale technological investigation to select a surface water treatment technology; and [Sorlini *et al.* \(2015\)](#) which presented a case study on a methodological approach for the optimisation of drinking water treatment plants operation. Both papers give good examples of a technological approach for selection of choice of technology and in defining procedures for performance evaluation and defining optimal solutions for plant upgrading in order to optimize operation.

A further seven papers reported on the performance of various conventional and advanced processes and systems: [Abdel-Shafy *et al.* \(2015\)](#) presented findings from an investigation into the efficiency of a pilot integrated UASB as anaerobic system followed by MBR as aerobic system for the treatment of greywater for unrestricted reuse. The integrated system reportedly achieved final effluent with characteristics of 2.5, 8.5, 6.1, 0.95, 4.6 and 2.3 mg/L for TSS, COD, BOD, phosphates, oil and grease and TKN, respectively; which could enable its unrestricted reuse based on local guidelines. [Rukapan *et al.* \(2015\)](#) investigated reverse osmosis membrane fouling characteristics in full-scale leachate treatment systems with chemical coagulation and microfiltration pre-treatments and showed that the formation of loose-structure cake layer by chemical coagulation pre-treatment could allow effective penetration of chemical cleaning and detachment of foulant layer from the membrane surface. [Sazakli *et al.* \(2015\)](#) reported on Arsenic and antimony removal from drinking water by

adsorption on granular ferric oxide using column tests. It was shown that the loadings until the guideline value was exceeded in the effluent was found to be 0.35–1.63 mg* g^{-1} for arsenic and 0.12–2.11 mg* g^{-1} for antimony and that the adsorption of one element was not substantially affected by the presence of the other. Gardoni *et al.* (2015) reported on a full-scale plug-flow reactor for biological sludge ozonation which aims to address a critical gap in knowledge regarding process optimisation. Reduction of biological excess sludge production using ozone is well-known; however, operational parameters are usually chosen by assuming a direct proportionality between ozone dose and excess sludge reduction. The paper investigated the role of ozone concentration on process efficiency and demonstrates the (non-linear) inverse relationship between ozone dose and specific particulate COD solubilisation in plug-flow contact reactors which makes a useful contribution to the field. Lackner *et al.* (2015) is one of the few papers that reported on the start-up of a full-scale process. The paper reported on the first 650 days of operation a full-scale 550 m³ deammonification SBR-treating effluent from digested sludge dewatering. The SBR was operated with discontinuous aeration and achieved an optimum of around 85% of ammonium removal at a load of 0.17 kg m⁻³ d⁻¹. More significantly, compared to nitrification/denitrification SBR operated in parallel with methanol as carbon source, a significant reduction in costs for energy and chemicals was achieved. Li *et al.* (2015) also reported on practical experience with full-scale structured sheet media integrated fixed-film activated sludge systems for nitrification to address limitations in conventional secondary treatment systems with no or partial nitrification requirement; and which are facing increased flows, loads, and more stringent ammonia discharge limits. The integrated fixed-film-activated sludge systems using both suspended growth and biofilms that grow attached to a fixed plastic-structured sheet media were shown to be a viable solution for solving this challenge and it has proved to be efficient and reliable in achieving not only consistent nitrification, but also enhanced BOD removal and sludge settling characteristics. This paper presents the long-term practical experiences with the system design, operation and maintenance, and performance for three full-scale plants with distinct processes, i.e., a trickling filter/solids contact process, a conventional plug flow activated sludge process and an extended aeration process. Wolska (2015) presented results of studies into water biostability levels in water treatment systems in order to evaluate the potential of microorganism regrowth. It was found that irrespective of the water type and unit treatment process, the limiting

factors for microorganism regrowth in the distribution system were the phosphate ion content and biodegradable dissolved organic carbon.

It is hoped that the wealth of information contained in the selected papers will be of great importance to practitioners in the field of water treatment and water management (consultants, operators, regulators, administration experts, researchers and developers) and it should encourage innovation – innovation in this context being the successful full-scale application of a new development from an idea to full scale.

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